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Sunday, June 18

12:30	Industry Sessions Registration
13:00 - 13:10	Industry Session Opening Remarks Terry Tsao, President <i>SEMI, TAIWAN</i>

Industry Session - Start-Up (Room 301A)

13:10-13:40	MEMS & SENSORS INDUSTRY TRENDS Claire Troadec, RF Activity Leader <i>Yole Développement, FRANCE</i>
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Since 2000, we have entered the age of sensing and interacting with the wide diffusion of sensors that give us a better, safer perception of our environment. From the automotive to the medical, consumer, industrial, defense markets, to name a few, all application domains have benefited from the MEMS & Sensors innovative technologies. With IoT gaining momentum, sensors are definitely key technologies to enable tomorrow's dreams like smart cities, smart buildings, smart transportation... In our talk, we will review the MEMS & Sensors market and emphasize on the upcoming challenges in the sensor industry. We will address the Market as well as the Technology trends of major sensors (imaging, environmental, inertial,...). We will demonstrate that the golden age of one market driving innovation is behind us. Today and tomorrow is all about multiple fragmented markets!

13:40 - 14:10	HOW MEMS AND ENTREPRENEURS ARE DRIVING IoT Kurt Petersen, Co-Founder <i>NovaSensor, Cepheid, SiTime, etc., Silicon Valley Band of Angels, USA</i>
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IoT will not be a sudden, revolutionary "event" which abruptly catapults us into the brave new world of smart, interconnected everything. Instead, IoT will gradually creep up on us. In fact, IoT is gradually creeping up on us today. Many new technical advances are required to achieve the full capabilities and advantages of IoT. Energy harvesting, pico-power circuits and wireless communication, low power sensors, new classes of sensors, new approaches to security, new data storage infrastructure, new packaging modalities. MEMS is one of the leading technologies to drive many of these capabilities for IoT, especially in the areas of energy harvesting and sensors. We will discuss recent new trends and new devices in the MEMS space, as well as potential upcoming areas for MEMS devices which, today, have very little ongoing R&D. In addition, however, in order to further the proliferation of IoT, we need more than new technologies and new MEMS devices; we need new IoT IDEAS. This is where entrepreneurs and the new, world-wide entrepreneurial culture is significantly accelerating the development and commercialization of new IoT invention and adoption. The proliferation of new start-up companies and new IoT inventions is transforming how we think about IoT and what our smart, IoT-connected world will look like over the new decades.

14:10 - 14:40	MEMS STARTUPS – WEST AND EAST, THEN AND NOW Wan-Thai Hsu, Co-Founder, Discera, USA <i>CTO and Vice President, TXC Corp., TAIWAN</i>
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Micro-Electro-Mechanical Systems (MEMS) is a technology that miniaturize mechanical or electro-mechanical devices through microfabrication. Before late 1990's, although there were few startups commercializing pressure sensors, most of the commercial activities of MEMS mainly reside in large corporations. From late 90's to early 2000, with more maturity of key MEMS processes, more fabless or fab-light MEMS startups came into play. Many of them created new application categories that did not exist before. After TSMC, the largest semiconductor manufacturer in the world, announced its interests in MEMS in 2005, MEMS processes are more fixed and standardized. Standardized processes enable faster commercialization process. Moreover, with more MEMS manufacturing capacities in Asia, many Asian MEMS startups have shown great commercial success with the advantages of having manufacturing, packaging, and testing infrastructure in the region. This talk compares the environment for MEMS startups now versus 20 years back in different regions with some case studies. More importantly, it concludes with a summary of possible suggested strategies for next waves of innovation and commercialization in MEMS technologies.



Source: Kaohsiung City Government Photographer: Chung-Hui Pao

Industry Session - IoT (Room 301A)**14:40 - 15:10 HIGH PERFORMANCE PIEZO MEMS AF TECHNOLOGY READY FOR MP**

Pierre Craen, Chief Technology Officer
poLight A.S., NORWAY

The first product, the TLens Silver, is not just a replacement of traditional VCM technology for Auto Focus, it enables a range of totally new experiences, use cases and ways to build innovation and hence strengthen the differentiation for mobile phone makers. Indeed, thanks to the extreme focus speed, the poLight technology enables instant focus that will dramatically enhance the user experience, enabling image capture of events always in focus in almost any conditions for any cameras. poLight will present its innovative way of implementing the technology that will enable always sharp image without the need of running traditional autofocus algorithm or using specific distance measurement system. Beside the unique capabilities of the TLens (the Tunable Lens) like, extremely quick autofocus, constant field of view (improve image stitching/bracketing computation process), High optical axis stability, extremely low power consumption, the TLens is a key enabler for Multicamera solution, due to its small footprint, the cameras can be placed close together (good for high resolution, extended dynamic range, optical zoom etc) but also key enabler for implementation of larger screen, especially for face camera. Moreover, TLens technology will benefit to the ecosystem, indeed the constant field of view, high optical axis stability, low hysteresis, non-gravity sensitive and non-electromagnetic sensitive, compare to VCM, will enable solutions that will easily avoid cross talk between cameras and surrounding electronics like loudspeakers, antennas etc, will reduce implementation & calibration cost and opening for new design degree of freedom for mobile phone design.

15:10 - 15:30 Break**15:30 - 16:00 THE IoT SYSTEM CHALLENGE**

Leopold Beer, Asia President
BOSCH Sensortec, CHINA

While there is lots of ongoing analysis on the business potential and the disruptive power of the IoT, there is more silence related to potential technical implementation options. Of course there are various communication standards in place to cover all paths from the data generation up to the cloud connectivity but there is less public analysis on the data hierarchy and the way data is generated. During his speech, Leopold will focus on a feasible data generation model that starts at the sensor level but also addresses the functional link up to the cloud data analysis system. While doing this, Leopold will analyze what's already available technology today and where there are gaps that still need to be closed. Within this technically dynamic environment Leopold will present Bosch Sensortec's approach and already available solutions.

16:00 - 16:30 ENVIRONMENTAL MONITORING WITH LOW COST SENSOR NETWORKS

Frank Pasveer, Program Manager IoT
imec, BELGIUM

Air quality has a strong influence on human health and wellbeing. Monitoring the air quality and making the data available to end-users is the first step towards awareness for a healthier society. To achieve this goal, measuring sufficient spatial and temporal data is critical and hence dense sensor networks are needed, both indoor and outdoor. The gas sensors in these networks need to be relatively low cost, preferable small and low power. The talk will outline the state-of-the-art in gas sensors for air quality monitoring networks and considers emerging and potential future developments. The need for good calibration, especially over expected long-lifetimes, to ensure good data quality from these sensor networks, will be discussed. Next to sensor technology, we will also address some of the general challenges in the IoT space, like monitoring and maintenance, smarter data use.

16:30 - 17:00 CITY OF TOMORROW: SMART MOBILITY FOR A SUSTAINABLE FUTURE

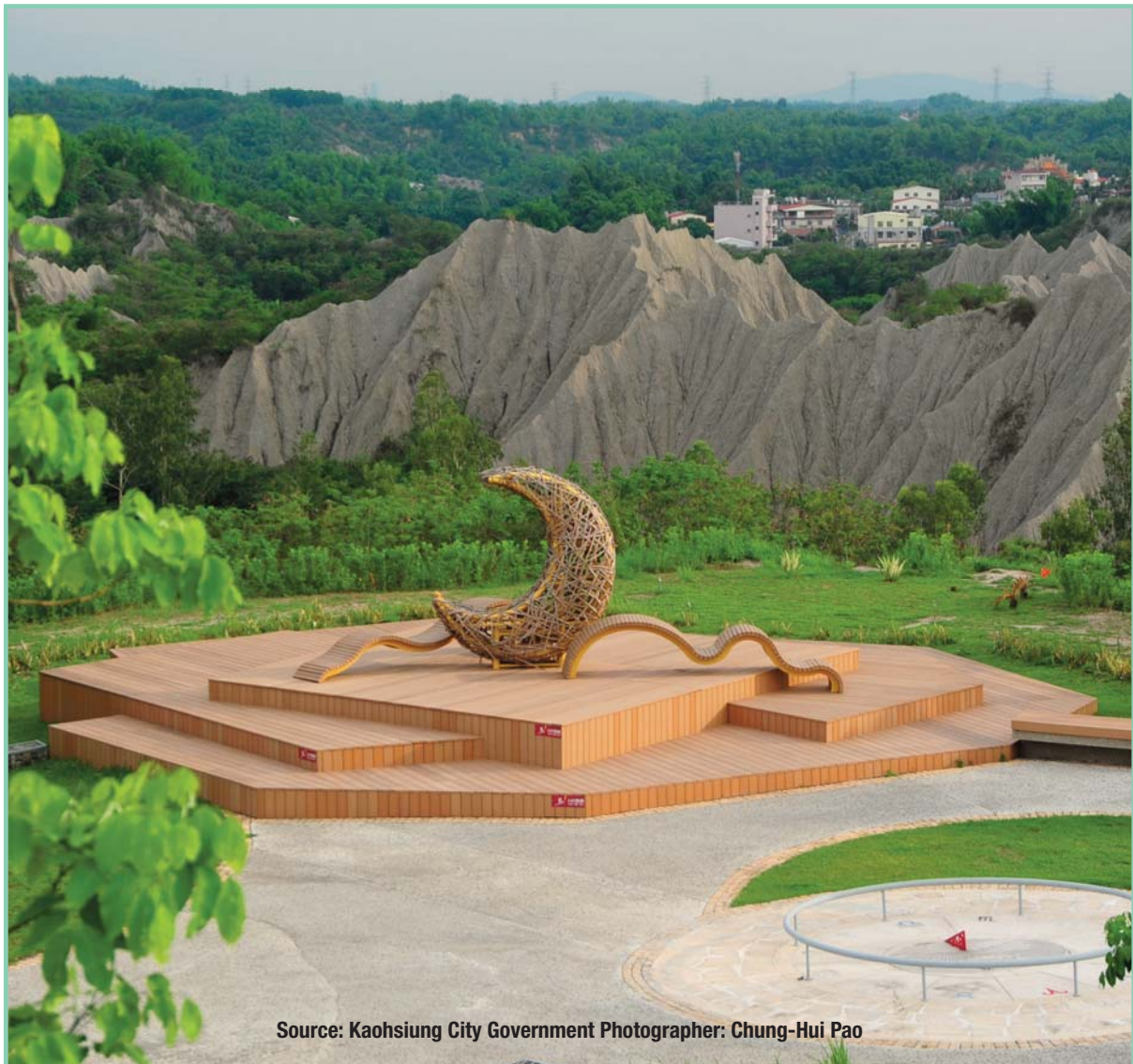
John Lin, Vice President
Ford (Lio Ho) Motor Company, TAIWAN

We're on the cusp of a mobility revolution. And we at Ford are excited about that because we've literally spent more than 100 years getting ready for this moment. Ford Smart Mobility is the plan to take connectivity, mobility, autonomous vehicles, the customer experience along with data and analytics to the next level. Ford also presents a vision for the "City of Tomorrow" to inspire innovation and assist cities in solving mobility challenges to help people move more easily today and in the future. Ford's City of Tomorrow looks at how near-term mobility advancements – including autonomous and electric vehicles, ride-sharing and ride-hailing and connected vehicles – interact with urban infrastructure and create a transportation ecosystem. Further out, Ford sees the City of Tomorrow with significant concentrations of autonomous vehicles, most of which will be electrified. The presentation will discuss about the mobility challenges, opportunities and emerging solutions that will shape the City of Tomorrow.

Industry Session - IoT (continued)**17:00 - 17:30 ENHANCING FAB PRODUCTIVITY AND CAPITAL EFFICIENCY FOR MEMS/IOT MARKET**

Michelle Bourke, Strategic and Technical Marketing Director
Lam Research Corporation, USA

The Industrial Internet of Things (IIoT) is a platform that supports the deployment of a wide range of smart manufacturing solutions. MEMS sensors are critical components in the infrastructure that forms this Industrial IIoT. As this infrastructure proliferates, it will continue to drive demand for increasingly advanced yet cost-effective sensor technologies. To satisfy this demand, the requirement for semiconductor processing equipment that enhances the customers' fab productivity and capital efficiency is also growing. Lam Research has been working to extend our product lifecycle through technology enhancements and productivity upgrades to our etch, deposition, and clean technologies to ensure we meet the needs of the MEMS and sensor manufacturing community. These developments not only focus on our deep silicon etch technology, which is already an established process used in the fabrication of MEMS devices, but also on the processing of new materials that are key to the next generation of MEMS and NEMS. In parallel, through a process of continuing innovation, we are consistently introducing our own suite of smart manufacturing tools that allow these process solutions to be deployed with improved operational efficiency and productivity. In this presentation, we will review both these technical and productivity solutions and provide examples of how their parallel implementation can provide the most effective platform for the fabrication of advanced MEMS and sensor technologies.

17:40 - 20:00 Conference Registration/Check-In Opens**17:40 - 20:00 Welcome Reception**

Source: Kaohsiung City Government Photographer: Chung-Hui Pao

Monday, June 19

07:00	Registration/Check-In Continues
08:30 - 09:10	<p>Welcome Address General Chair: Weileun Fang, <i>National Tsing Hua University, TAIWAN</i> General Co-Chair: CP Hung, <i>ASE Group, TAIWAN</i></p> <p>Technical Program Introduction Technical Program Chair: Shuichi Shoji, <i>Waseda University, JAPAN</i></p>
09:10 - 09:50	<p>PLENARY PRESENTATION I Session Chair: S. Konishi, <i>Ritsumeikan University, JAPAN</i></p> <p>M1G.001 FROM SENSORS TO INTELLIGENCE 1 B.J. Woo, G. Liu, E. Cheng, I. Wu, S.-F. Huang, D.N. Yaung, and Alexander Kalnitsky <i>Taiwan Semiconductor Manufacturing Company, Ltd. (TSMC), TAIWAN</i></p> <p>Sensor related development activities at TSMC are presented. Our CMOS-MEMS processes with the “Si pillar” WLCSP capability enable inertial and pressure sensors design with the smallest footprint and volume. Recently added piezo-electric materials processing capabilities will allow us to adapt the CMOS-MEMS integration to a wider range of applications. While current developments are carried out in the 8” line using CMOS processes with low power and precision analog capabilities, we have also demonstrated feasibility of building CMOS-MEMS devices using 12” wafers since we feel future applications may require very low power CMOS enabled by deep sub-micron devices. TSMC invented, made and characterized a novel BioMOSFET device for electrical detection of very low ion concentrations in a solution. This technology allows users to integrated large sensor arrays with the addressing and sensing electronics, built-in heaters and reference electrodes, essentially providing a single chip solution suitable for personal health care applications. Our development activities in optical sensing cover a wide range of applications from visible light detection (CMOS Image Sensors) to near infrared for “machine vision”, 3D imaging and very low light detection.</p>
09:50 - 10:30	<p>PLENARY PRESENTATION II Session Chair: J. Brugger, <i>École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND</i></p> <p>M1G.002 LABS, CELLS AND ORGANS ON CHIP: TECHNOLOGIES AND BIOMEDICAL APPLICATIONS 6 Albert van den Berg <i>University of Twente, NETHERLANDS</i></p> <p>Over the past few decades both micro/ nanofabrication and microfluidics technologies have been crucial for the rapid development of Lab on a Chip systems. Here we present a few examples of this. Firstly, a capillary electrophoresis system on chip for blood analysis will be presented. Secondly, we show how nanostructures enable new chemical sensors and how they can be exploited to obtain highly sensitive and uniform SERS surfaces, enabling sensitive biomolecule detection and allowing simultaneous electrochemical experimentation. Then we present a microfluidic device in which we can trap and electroporate individual cells to study gene transfection. Finally, we show how Lab on a Chip systems can be used to realize so-called “Organs on Chip” that mimic functional organ behavior. In particular a Blood Brain Barrier (“BBB chip”) is presented to study behavior of tight junctions, while we also demonstrate a microfluidic chip mimicking atherosclerosis, and show how thrombus formation around narrowing in the artificial blood vessel takes place. These examples clearly demonstrate the power and future potential of such microsystems for biomedical applications.</p>
10:30 - 11:00	Break and Exhibit Inspection
11:00 - 11:40	<p>PLENARY PRESENTATION III Session Chair: Y. Gianchandani, <i>University of Michigan, USA</i></p> <p>M1G.003 DEVELOPING CHEMICAL SENSORS TO OBSERVE THE HEALTH OF THE GLOBAL OCEAN 10 Kenneth S. Johnson <i>Monterey Bay Aquarium Research Institute, USA</i></p> <p>Robotic networks of platforms carrying physical, chemical, and biological sensors that can monitor basic metabolic processes are required to observe ocean health. The sensors must operate for the 5 to 10 year period between research vessel visits with no direct human intervention and little or no chance for sensor recalibration. The sensors and the platforms that carry them must operate from the surface to depths of several kilometers. Here I describe work done by marine scientists to develop integrated networks of chemical sensors with these properties. Much of the focus will be on chemical sensors that can operate for years at a time without laboratory recalibration.</p>

11:40 - 11:50	Transducers 2019 Conference Presentation
11:50 - 12:00	Announcements
12:00 - 14:00	Lunch and Exhibit Inspection

Industry Session - IDM (Room 301A)

12:30 - 13:00 **READY-TO-GO IoT ECO-SYSTEM**

Collins Wu, Marketing and Application Director of Analog & MEMS Group
STMicroelectronics, CHINA

IoT has become popular topic because it brings human a more convenient and easier life. ST has created a ready-to-go for IoT eco-system, including hardware building blocks, pre-integrated software, solutions and development & prototyping tools (SensorTile). You can find us in smart driving, smart industry, smart home & city, also smart things. ST would like to make driving safer, greener and more connected; to enable the evolution of industry towards smarter, safer and more efficient factories and workplaces; to make home more intelligent for better living, higher security, and less waste; to enable cities more available resources; to make everyday things smarter, connected and more aware of their surroundings. ST believes IoT devices should comply to a challenging mix requirements to match the targeted applications. Thus, it requires a set of powerful, compact, secure and low power components. The turnkey solution are key to ease developers' life, including Pre-integrated hardware and software solutions and easy-to-use tools.

13:00 - 13:30 **MEMS TECHNOLOGIES EVOLVE AUTOMOBILES!?**

Nobuaki Kawahara, Senior Director, Head of Research Laboratories
DENSO Corporation, JAPAN

Automotive electronics have been evolving and creating new control systems to realize safer and more eco-friendly vehicles. Many automotive functions are changing from mechanical to electronic control. By changing the control systems, the number of electronic parts such as sensors, electronic circuits, and actuators has been drastically increasing. And this trend will continue in the future to evolve automobiles. MEMS technologies, along with the packaging, electronic circuit, and software technologies, will become more important in the future vehicle equipped with many advanced sensors. These interrelated technologies are all essential for product development. Undoubtedly, the control system becomes more advanced with each improvement in the sensing speed or sensor accuracy. In the presentation, the future trend of automobiles and MEMS will be discussed, and the research activities of DENSO will be explained.

13:30 - 14:00 **FBAR IMPACT ON MOBILE PHONES**

Richard Ruby, Director of Technology
Broadcom, USA

FBAR and BAW now generate Billions of revenue dollars per year in the mobile space. FBAR has been and continues to be a premium filter technology for those high end phones serving the world. FBAR filter/duplexer technology enables better signal integrity (Quality of Service), compliance with Carrier Aggregation, power handling and integration of multiple filters with Power Amplifiers, LNAs and switches (the 'Front End'). This talk will go over the metrics of FBAR technology (coupling coefficient, and Q) and highlight how these key metrics enables the Flag Ship phones today. Beyond the acoustic properties of FBAR, there is also the benefit of the MEMs style microcap – an all-silicon wafer scale package. An overview of the mobile market and the forces driving that market will be discussed.

14:00 - 16:00 **Poster/Oral Session M3P (Refreshments Available)**

Poster/Oral presentations are listed by topic category with their assigned number starting on page 58.



Source: Kaohsiung City Government

Session M4A Bio Probes	Session M4B <i>In Vivo</i>	Session M4C Microphones & Other Physical Sensors	Session M4D RF MEMS I
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: E. Meng, <i>University of Southern California, USA</i> P. Ruther, <i>University of Freiburg, GERMANY</i>	Session Co-Chairs: Y. Sun <i>University of Toronto, CANADA</i> Y. Yamanishi <i>Kyushu University, JAPAN</i>	Session Co-Chairs: J. Arcamone <i>Leti, FRANCE</i> X. Zhang <i>Boston University, USA</i>	Session Co-Chairs: S. Bhav <i>Purdue University, USA</i> D. Chang <i>HRL Laboratories, USA</i>
16:00 - 16:15			
M4A.001 MODELING, FABRICATION, AND TESTING OF A MEMS MULTICHANNEL ALN TRANSDUCER FOR A COMPLETELY IMPLANTABLE COCHLEAR IMPLANT	M4B.001 PTA BALLOON CATHETER INTEGRATED ELECTROACTIVE POLYMER TRANSDUCER FOR SENSING VASCULAR BLOCKAGE AND DISTURBING VESSEL PLAQUES	M4C.001 AN ULTRA-SENSITIVE SPINTRONIC STRAIN-GAUGE SENSOR WITH GAUGE FACTOR OF 5000 AND DEMONSTRATION OF A SPIN-MEMS MICROPHONE	M4D.001 CMOS-MEMS RESONANT DEMODULATOR FOR NEAR-ZERO-POWER RF WAKE-UP RECEIVER
16:15 - 16:30			
M4A.002 HIGH-DENSITY CMOS NEURAL PROBE IMPLEMENTING A HIERARCHICAL ADDRESSING SCHEME FOR 1600 RECORDING SITES AND 32 OUTPUT CHANNELS	M4B.002 DEVELOPMENT OF NOVEL PH IMAGE SENSOR FOR <i>IN-VIVO</i> APPLICATION	M4C.002 A NOVEL SILICON "STAR-COMB" MICROPHONE CONCEPT FOR ENHANCED SIGNAL-TO-NOISE-RATIO: MODELING DESIGN, AND FIRST PROTOTYPE	M4D.002 AN INNOVATIVE 3-D MECHANICALLY-COUPLED ARRAY DESIGN FOR MEMS RESONATOR AND OSCILLATORS
16:30 - 16:45			
M4A.003 MICROSCALE TRANSPORT PHYSICS DURING ATOMIC FORCE MICROSCOPY MASS SPECTROMETRY AND IMPROVED SAMPLING EFFICIENCY	M4B.003 3D-PRINTED BIODEGRADABLE POLYMERIC STENT INTEGRATED WITH A BATTERY-LESS PRESSURE SENSOR FOR BIOMEDICAL APPLICATIONS	M4C.003 FREQUENCY SELECTIVE MEMS MICROPHONE BASED ON A BIOINSPIRED SPIRAL-SHAPED ACOUSTIC RESONATOR	M4D.003 d_{15} -ENHANCED SHEAR-EXTENSIONAL ALUMINUM NITRIDE RESONATORS WITH $k_2 > 4.4\%$ FOR WIDE-BAND FILTERS
16:45 - 17:00			
M4A.004 A 64-CHANNEL WIRELESS NEURAL SENSING MICROSYSTEM WITH TSV-EMBEDDED MICRO-PROBE ARRAY FOR NEURAL SIGNAL ACQUISITION	M4B.004 A NEW 3D SELF-ADAPTIVE NERVE ELECTRODE FOR HIGH DENSITY PERIPHERAL NERVE STIMULATION AND RECORDING	M4C.004 A MEMS SLIP SENSOR: ESTIMATIONS OF TRIAXIAL FORCE AND COEFFICIENT OF STATIC FRICTION FOR PREDICTION OF A SLIP	M4D.004 EFFECT OF CURVATURE AND ELECTRODE COVERAGE ON THE QUALITY FACTOR OF BICONVEX ALN-ON-SI MEMS RESONATORS
17:00 - 17:15			
M4A.005 FABRICATION AND INDUCTIVE POWER TRANSFER IN WIRELESS SPHERICAL PILL MICROPROBES	M4B.005 SLAVE FLEXIBLE MICRO-FINGER INTEGRATED WITH SENSOR FOR MASTER-SLAVE SENSE PRESENTATION SYSTEM	M4C.005 PHOTOCURABLE PUA (POLY URETHANEACRYLAT) CANTILEVER INTEGRATED WITH ULTRA-HIGH SENSITIVE CRACK-BASED SENSOR	M4D.005 DESIGN AND CHARACTERIZATION OF MICRORESONATORS SIMULTANEOUSLY EXHIBITING 1/2 SUBHARMONIC AND 2:1 INTERNAL RESONANCES
17:15 - 17:30			
M4A.006 MEMS FORCE SENSOR ARRAY FOR EVALUATING THE CONTRACTILITY OF IPS CELL-DERIVED CARDIOMYOCYTES	M4B.006 REMOTE RADIO CONTROLLED INSECT-COMPUTER HYBRID LEGGED ROBOT	M4C.006 A HIGH-QUALITY RESONANT PRESSURE MICRO SENSOR WITH THROUGH-SILICON-VIA ELECTRICAL INTERCONNECTIONS	M4D.006 AIN GHZ ULTRASONIC PULSE DIFFRACTION BASED TRANSMIT-RECEIVE OSCILLATOR WITH 1 PPM STABILITY

**Session M4A
Bio Probes**
ROOM 301A
16:00 - 17:30

- M4A.001 MODELING, FABRICATION, AND TESTING OF A MEMS MULTICHANNEL ALN TRANSDUCER FOR A COMPLETELY IMPLANTABLE COCHLEAR IMPLANT 16**
C. Zhao, K.E. Knisely, and K. Grosh
University of Michigan, USA

We develop a miniaturized multichannel aluminum nitride acoustic transducer. The transducer is designed to be implantable in a guinea pig's cochlea and work as a front end of a completely implantable cochlear implant. We build a finite element analysis model to design and analyze the transducer. We fabricate the transducer using micro-electrical-mechanical systems technique. The functionality of the transducer is tested, and the measured results match the modeled results.

- M4A.002 HIGH-DENSITY CMOS NEURAL PROBE IMPLEMENTING A HIERARCHICAL ADDRESSING SCHEME FOR 1600 RECORDING SITES AND 32 OUTPUT CHANNELS 20**
A. Sayed Herbawi, L. Kiessner, O. Paul, and P. Ruther
University of Freiburg, GERMANY

This paper presents the design, fabrication, and testing of CMOS-based intracortical neural probes with an unprecedented high electrode count. A hierarchical decoding scheme is implemented in the system which allowed to integrate 1600 recording sites arranged as 50 blocks of 32 electrodes on a 100- μ m-wide and 10-mm-long probe shaft. Single electrodes as well as tetrode combinations can be read out on 32 parallel analog output channels.

- M4A.003 MICROSCALE TRANSPORT PHYSICS DURING ATOMIC FORCE MICROSCOPY MASS SPECTROMETRY AND IMPROVED SAMPLING EFFICIENCY 24**
H. Moon, T.J. Comi, S.J.B. Dunham, B. Kwon, J.V. Sweedler, and W.P. King
University of Illinois, Urbana Champaign, USA

This paper reports improvements of atomic force microscopy mass spectrometry (AFM-MS), in which ~ 1 attoliter of analyte is desorbed by a heated AFM cantilever tip and analyzed offline with a mass spectrometer. Decoupling the AFM sampling apparatus from the MS system enabled optimization of microscale transport physics independent of ionization efficiency, and thereby improved the system efficiency by 2.5X over the state of the art.

- M4A.004 A 64-CHANNEL WIRELESS NEURAL SENSING MICROSYSTEM WITH TSV-EMBEDDED MICRO-PROBE ARRAY FOR NEURAL SIGNAL ACQUISITION 28**
Y.-C. Huang¹, P.-T. Huang¹, Y.-C. Hu¹, S.-L. Wu¹, Y.-H. You¹, Y.-K. Wang¹, J.-R. Duann², T.-W. Chiu¹,
W. Hwang¹, K.-N. Chen¹, C.T. Chuang¹, and J.-C. Chiou¹
¹National Chiao Tung University, TAIWAN and ²National Central University, TAIWAN

This paper presents an implantable high spatial resolution μ -probe array with TSV 2.5D integration technology that realizes a miniaturized implantable device on flexible printed circuit (FPC). Moreover, an antenna is also implemented on the backside of FPC for wireless data transmission. The μ -probe array can achieve better SNR with neural signal processing circuit composed of a pseudo-resistor-based analog front-end amplifier.

- M4A.005 FABRICATION AND INDUCTIVE POWER TRANSFER IN WIRELESS SPHERICAL PILL MICROPROBES 32**
R. Likhite, W. Luo, D.J. Young, and C.H. Mastrangelo
University of Utah, USA

We report the fabrication and wireless power coupling of a neural probe, not based on the needle geometry but a much less intrusive minimum-radius spherical pill. The pills 1-1.5 mm in diameter are formed by bonding of parylene hemispherical shells containing feedthrough electrodes and coils patterned along the shell surface.

- M4A.006 MEMS FORCE SENSOR ARRAY FOR EVALUATING THE CONTRACTILITY OF IPS CELL-DERIVED CARDIOMYOCYTES 36**
K. Matsudaira, T.-V. Nguyen, K.H. Shoji, T. Tsukagoshi, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

We report a force sensor array to measure iPS cell-derived cardiomyocytes (iPS-CMs) contractility at multiple locations simultaneously with high sensitivity. The fabricated device has six piezoresistive cantilevers whose sensing resolution was less than 0.1 nN. Using the device, we measured the contractile force of an iPS-CMs layer. The results show that though the onsets of the contractions of the cells were synchronized, the contractile waveform differed for iPS-CMs at different locations.

Session M4B
In Vivo
ROOM 301B
16:00 - 17:30

- M4B.001 PTA BALLOON CATHETER INTEGRATED ELECTROACTIVE POLYMER TRANSDUCER FOR SENSING VASCULAR BLOCKAGE AND DISTURBING VESSEL PLAQUES 39**
 G.-H. Feng, L.-C. Wang, and I.-H. Yeh
National Chung Cheng University, TAIWAN

We develop a novel ellipsoid-shaped soft and biocompatible device which can be integrated with balloon catheter. The device contains a 3-dimensional electroactive polymer core element and is packaged by PDMS. The core element with a unique hollow design allows the catheter passing through and can be anchored at an arbitrary position of the catheter. The electroactive core possesses radial directional displacement and force sensing functions without using external electricity.

- M4B.002 DEVELOPMENT OF NOVEL PH IMAGE SENSOR FOR *IN-VIVO* APPLICATION 43**
 S. Nanasaki¹, H. Horiuchi², H. Inada², Y. Nakamura¹, F. Dasai¹, T. Iwata¹, K. Takahashi¹, J. Nabekura², and K. Sawada¹
¹Toyohashi University of Technology, JAPAN and ²National Institute for Physiological Sciences, JAPAN

We developed a living body insertion type 32×128 CCD ion image sensor. After fabricating the ion image sensor, the Si substrate was polished to the thickness of 100µm for the insertion construction. In order to prevent a leak current, the parylene C with a thickness of 4 µm was deposited. The two-dimensional pH measurement in the brain was successfully. Furthermore, the simultaneous detection of pH and spike signal similar to nerve activity was demonstrated with the stimulation.

- M4B.003 3D-PRINTED BIODEGRADABLE POLYMERIC STENT INTEGRATED WITH A BATTERY-LESS PRESSURE SENSOR FOR BIOMEDICAL APPLICATIONS 47**
 J. Park¹, J.-K. Kim², S.A. Park³, D.S. Sim¹, M.H. Jeong¹, and D.-W. Lee¹
¹Chonnam National University, KOREA, ²Gwangju University, KOREA, and ³Korea Institute of Machinery and Materials, KOREA

This paper describes the fabrication and evaluation of a 3D printed polymer stent integrated with a wireless pressure sensor. We employed a polymer material based on a polycaprolactone-biodegradable material. The 3D printing-based manufacturing process for the biodegradable polymer stent was relatively simple. The pressure sensor with multilayers was fabricated using an SU-8 thermal-pressure bonding process. Finally, animal test was conducted using the wireless pressure sensor.

- M4B.004 A NEW 3D SELF-ADAPTIVE NERVE ELECTRODE FOR HIGH DENSITY PERIPHERAL NERVE STIMULATION AND RECORDING 51**
 C. Li¹, H.S. Sohal¹, F. Li², T. Zanos¹, L. Goldman¹, R.K. Narayan¹, and C.E. Bouton¹
¹Feinstein Institute for Medical Research, USA and ²New York Institute of Technology, USA

This paper reports a novel 3D self-adaptive nerve electrode for site-specific stimulation and high density nerve signal recording. Specifically, a new pre-shaping method is developed to achieve tight contact to small nerves (diameter < 200µm) with high signal-to-noise (SNR) but not to compress them.

- M4B.005 SLAVE FLEXIBLE MICRO-FINGER INTEGRATED WITH SENSOR FOR MASTER-SLAVE SENSE PRESENTATION SYSTEM 55**
 R. Kawashima, S. Hagimori, H. Sato, and S. Konishi
Ritsumeikan University, JAPAN

This paper presents a flexible micro-finger as slave machine of a master-slave sense presentation system. A sensor integrated into the micro-finger acquires information about contact object, such as temperature. Human interface of the master-slave system is also implemented to present temperature acquired by the slave micro-finger. The effective contribution of micro-finger to temperature measurement on unstable biological surface and master-slave temperature presentation system is demonstrated.

- M4B.006 REMOTE RADIO CONTROLLED INSECT-COMPUTER HYBRID LEGGED ROBOT 59**
 F. Cao and H. Sato
Nanyang Technological University, SINGAPORE

A remotely controllable insect-computer hybrid legged robot was demonstrated by electrically stimulating individual leg muscles to regulate the leg motions. The walking speed is controllable by proportionally adjusting the step frequency.

Session M4C

Microphones & Other Physical Sensors

ROOM 304A

16:00 - 17:30

- M4C.001 AN ULTRA-SENSITIVE SPINTRONIC STRAIN-GAUGE SENSOR WITH GAUGE FACTOR OF 5000 AND DEMONSTRATION OF A SPIN-MEMS MICROPHONE** 63
 Y. Fuji, M. Hara, Y. Higashi, S. Kaji, K. Masunishi, T. Nagata, A. Yuzawa, K. Otsu, K. Okamoto, S. Baba, T. Ono, A. Hori, and H. Fukuzawa
Toshiba Corporation, JAPAN

We report on the first spintronic strain-gauge sensor (Spin-SGS) based on a magnetic tunnel junction with a high gauge factor exceeding 5000. We also demonstrate a novel "Spin-MEMS microphone," in which Spin-SGSs are integrated on a diaphragm. The Spin-MEMS microphone exhibits a signal-to-noise ratio (SNR) of 57 dB(A) due to high strain sensitivity of the Spin-SGSs. Furthermore a Spin-MEMS microphone with a first resonance frequency of 74 kHz is also fabricated and exhibits an SNR of 45 dB(A).

- M4C.002 A NOVEL SILICON "STAR-COMB" MICROPHONE CONCEPT FOR ENHANCED SIGNAL-TO-NOISE-RATIO: MODELING DESIGN, AND FIRST PROTOTYPE** 67
 J. Manz¹, G. Bosetti¹, A. Dehé², and G. Schrag¹
¹Technical University of Munich, GERMANY and ²Infineon Technologies AG, GERMANY

A novel comb-structure-based, capacitive MEMS microphone concept is proposed, which is supposed to significantly reduce viscous damping losses and, hence, offers the potential to enhance the signal-to-noise-ratio beyond those of up-to-date silicon condenser microphones. The concept is verified by virtual prototyping methods applying a fully energy-coupled and properly calibrated system-level model. Measurements of first prototypes show promising results and agree very well with simulations.

- M4C.003 FREQUENCY SELECTIVE MEMS MICROPHONE BASED ON A BIOINSPIRED SPIRAL-SHAPED ACOUSTIC RESONATOR** 71
 Y. Kusano, J. Segovia-Fernandez, S. Sonmezoglu, R. Amirtharajah, and D.A. Horsley
University of California, Davis, USA

We present a frequency-selective MEMS microphone achieved by utilizing spiral-shaped acoustic resonators inspired by the spiral-shaped structures found in the human ear. The resonators were fabricated by 3D-printing and easily integrated with our test circuit board. Here, we demonstrate simulation and experimental results investigating the effect of aperture locations, and achieving a 2.7x increase in linear sensitivity response at the resonance frequency of 430 Hz.

- M4C.004 A MEMS SLIP SENSOR: ESTIMATIONS OF TRIAXIAL FORCE AND COEFFICIENT OF STATIC FRICTION FOR PREDICTION OF A SLIP** 75
 T. Okatani, A. Nakai, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

We report on a MEMS slip sensor that estimates triaxial force as well as coefficient of static friction for prediction of a slip. The sensor was composed of the outer and inner elastomers separated by a hard substrate, which enable to measure triaxial force independently of coefficient of static friction. We fabricated a prototype of the sensor and evaluated it by pressing and sliding it on various conditions of coefficient of static friction.

- M4C.005 PHOTOCURABLE PUA (POLY URETHANEACRYLAT) CANTILEVER INTEGRATED WITH ULTRA-HIGH SENSITIVE CRACK-BASED SENSOR** 78
 D.-S. Kim¹, Y.W. Choi², T. Lee², G. Lee², D. Kang³, M. Choi², and D.-W. Lee¹
¹Chonnam National University, KOREA, ²Seoul National University, KOREA, and ³Ajou University, KOREA

We describes the fabrication and characterization of ultra-sensitive polymeric cantilever sensor to precisely measure the change in contraction force of cardiomyocytes. In spite of all these interesting characteristics, the mechanical crack-based sensor inspired from the spider sensor has not yet been used for biological applications i.e. for detecting cardiomyocyte movements. Herein, we have successfully developed a novel sensing technique for measuring the contraction force of cardiomyocytes.

- M4C.006 A HIGH-QUALITY RESONANT PRESSURE MICRO SENSOR WITH THROUGH-SILICON-VIA ELECTRICAL INTERCONNECTIONS** 82
 L. Zhu^{1,2}, Y.H. Xing^{1,2}, B. Xie^{1,2}, C. Xiang^{1,2}, Y.L. Lu^{1,2}, D.Y. Chen¹, J.B. Wang¹, and J. Chen¹
¹Chinese Academy of Sciences, CHINA and ²University of Chinese Academy of Sciences, CHINA

This paper reports a high-Q resonant pressure micro sensor with through-silicon-via electrical interconnections. In order to avoid the failure of vacuum packaging, a through-silicon-via technology was developed to achieve the wire interconnections. Experimental results showed that the Q-factor of the resonator was higher than 27000, and the differential sensitivity was quantified as 84.36 Hz/kPa.

**Session M4D
RF MEMS I**
ROOM 304B
16:00 - 17:30

- M4D.001** **CMOS-MEMS RESONANT DEMODULATOR FOR NEAR-ZERO-POWER RF WAKE-UP RECEIVER** 86
M.E. Galanko, A. Kochhar, G. Piazza, T. Mukherjee, and G.K. Fedder
Carnegie Mellon University, USA

We demonstrate a CMOS-MEMS resonant demodulator for use in a nanoWatt-power RF wake-up sensor. "Near-zero" power operation is enabled through voltage step-up and frequency keying in passive MEMS elements. Additionally, the integrated MEMS demodulator minimizes parasitics and performs high-Q filtering to prevent false triggering due to interference signal feedthrough. A demodulator with minimum transduction gap size 400 nm shows agreement with device models during high-frequency testing.

- M4D.002** **AN INNOVATIVE 3-D MECHANICALLY-COUPLED ARRAY DESIGN FOR MEMS
RESONATOR AND OSCILLATORS** 90
C.-Y. Chou, M.-H. Li, C.-Y. Chen, C.-Y. Liu, and S.-S. Li
National Tsing Hua University, TAIWAN

A 3-D mechanically-coupled resonator array has been demonstrated for the first time using CMOS-MEMS technology. A high-performance vertically-coupled (VC) CMOS-MEMS resonator pair is utilized to extend the array topology into 3-D configuration with on-chip interfaced circuit through a TSMC 0.35 μm 2P4M CMOS-MEMS platform. An array design of 9 VC pairs was fabricated and characterized with resonance frequency of 5.64 MHz and Q-factor of 1,092.

- M4D.003** **d_{15} -ENHANCED SHEAR-EXTENSIONAL ALUMINUM NITRIDE RESONATORS WITH $k^2 > 4.4\%$ FOR
WIDE-BAND FILTERS** 94
B. Jo, M. Ghatge, and R. Tabrizian
University of Florida, USA

This paper introduces a novel AlN resonator that fuses transverse-extensional (d_{31}) and thickness-shear (d_{15}) piezoelectric constants to realize a large k^2 , with a laterally defined f0. A shear-extensional Lamb wave, benefiting from simultaneous d_{31} and d_{15} couplings, is efficiently trapped to realize a high Q resonator. A 733MHz prototype is presented, with a Q of 1400 and a k^2 of 4.4% when transduced with a single-sided electrode pattern. Also, a ladder filter is implemented with a 2.5% BW.

- M4D.004** **EFFECT OF CURVATURE AND ELECTRODE COVERAGE ON THE QUALITY FACTOR OF BICONVEX
ALN-ON-SI MEMS RESONATORS** 98
M.W.U. Siddiqi¹, C. Tu², and J.E.-Y. Lee¹
¹City University of Hong Kong, HONG KONG and ²University of Illinois, Urbana-Champaign, USA

This paper analyzes the effect of varying the curvature of a MEMS resonator on its Q in terms of the width change of the acoustic cavity. Experimental results show that the width change of the acoustic cavity should be at least $\lambda/2$ of the resonant cavity to achieve optimal Q. Curving beyond λ reduces coupling with little increase in Q. We also examine the impact of electrode coverage on Q: Narrowing electrode width increases Q but shortening the length reduces Q.

- M4D.005** **DESIGN AND CHARACTERIZATION OF MICRORESONATORS SIMULTANEOUSLY EXHIBITING
1/2 SUBHARMONIC AND 2:1 INTERNAL RESONANCES** 102
A. Sarrafan, B. Bahreyni, and F. Golnaraghi
Simon Fraser University, CANADA

We report the design and experimental results for a microresonator simultaneously exhibiting nonlinear interactions due to 1/2 subharmonic and 2:1 internal resonances. Finite element models of the structure were built and used to layout the device with two desired vibrational modes with a ~2:1 frequency ratio. The device design methodologies can be employed to fabricate various sensors, including nonlinear gyroscopes incorporating 2:1 internal resonance.

- M4D.006** **AIN GHZ ULTRASONIC PULSE DIFFRACTION BASED TRANSMIT-RECEIVE OSCILLATOR
WITH 1 PPM STABILITY** 106
M. Abdelmejeed, J.C. Kuo, and A. Lal
Cornell University, USA

We present a CMOS compatible ultrasonic pulse delay-based oscillator with 0.71 ppm stability and a designable temperature coefficient profile. The frequency deviation for a center frequency of 1.09 MHz is 53 ppm. The oscillator utilizes the delay due to the travel time of GHz wave packets through the silicon bulk, generated and received by AlN transducers. The piezoelectric transducer oscillator architecture is compatible with post-CMOS processing, and has potential to consume minimal CMOS area.

18:20 - 21:00
Sunset Beach Reception

8:00	Registration		
Session T1A Droplets	Session T1B Bio Imaging	Session T1C Piezoelectric Transducers	Session T1D RF MEMS II
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: J. Ducrée, <i>Dublin City University, IRELAND</i> J. Kim, <i>Pohang University of Science and Technology (POSTECH), KOREA</i>	Session Co-Chairs: H. Onoe <i>Keio University, JAPAN</i>	Session Co-Chairs: A. Duwel <i>Draper, USA</i> P. French, <i>Delft University of Technology, NETHERLANDS</i>	Session Co-Chairs: T. Akin, <i>Middle East Technical University, TURKEY</i> H. Xie <i>University of Florida, USA</i>
8:30 - 9:00			
T1A.001 INVITED SPEAKER BALLISTIC ENERGY CONVERSION	T1B.001 INVITED SPEAKER CMOS BASED ION IMAGE SENSOR - FUSION OF BIO SENSOR TECHNOLOGY AND IMAGE SENSOR TECHNOLOGY	T1C.001 INVITED SPEAKER PIEZOELECTRIC NANO-ELECTROMECHANICAL SYSTEMS	T1D.001 INVITED SPEAKER EFFORTS TOWARD IDEAL MICRO-ELECTROMECHANICAL SWITCHES
9:00 - 9:10			
T1A.002 CONTACT FUSION OF DROPLETS PATTERNED ON OPPOSING PLATES FOR CELLULAR TRANSPORTATION AND MEDIUM EXCHANGE FOR HANGING DROPLET CELL CULTURE	T1B.002 HIGH-DENSITY MAPPING OF BRAIN SLICES USING A LARGE MULTI-FUNCTIONAL HIGH-DENSITY CMOS MICROELECTRODE ARRAY SYSTEM	T1C.002 PASSIVE SIGNAL AMPLIFICATION VIA SERIES-PIEZOELECTRIC READ-OUT	T1D.002 THIN FILM PACKAGED REDUNDANCY RF MEMS SWITCHES FOR SPACE APPLICATIONS
9:15 - 9:30			
T1A.003 A PORTABLE DROPLET MAGNETOFLUIDIC PLATFORM FOR AUTOMATED RNA QUANTIFICATION AND ANALYSIS	T1B.003 A LENS-FREE SINGLE-SHOT FLUORESCENT IMAGING SYSTEM USING CMOS IMAGE SENSORS WITH DIELECTRIC MULTI-LAYER FILTER	T1C.003 RESIDUAL-STRESS-BALANCED PIEZOELECTRIC FILM BASED DIRECTION SENSITIVE FLOW SHEAR-STRESS SENSOR FOR QUADCOPTER NAVIGATION	T1D.003 SWITCHABLE LAMB WAVE DELAY LINES USING AlGaIn/GaN HETEROSTRUCTURE
9:30 - 9:45			
T1A.004 CENTRIFUGE-BASED MEMBRANE EMULSIFICATION TOWARD HIGH-THROUGHPUT GENERATION OF MONODISPERSE LIPOSOMES	T1B.004 FULLY PACKAGED VIDEO-RATE CONFOCAL LASER SCANNING ENDOMICROSCOPE USING LISSAJOUS FIBER SCANNER	T1C.004 A SILICON VECTOR LIGHT SENSOR FOR PROXIMITY SENSING APPLICATIONS	T1D.004 A MEMS INERTIAL SWITCH WITH ELECTROSTATIC FORCE ASSISTANCE AND MULTI-STEP PULL-IN FOR ELIMINATING BOUNCE AND PROLONGING CONTACT TIME
9:45 - 10:00			
T1A.005 A MICROCAPSULE ARRAY FOR QUANTITATIVE FLUORESCENCE DETECTION OF COPPER IONS BASED ON FUNCTIONAL NUCLEIC ACID	T1B.005 DEVELOPING BIOMETRIC PASSIVE RECOGNITION SENSOR APPLICABLE TO WEARABLE DEVICES: PART II - PRELIMINARY VERIFICATION WITH A SHUTTLE ROLLER COASTER STRUCTURE	T1C.005 MONOCRYSTALLINE PMNN-PZT THIN FILM ULTRASONIC RANGEFINDER WITH 2 METER RANGE AT 1 VOLT DRIVE	T1D.005 ULTRA-MINIATURE FUNDAMENTAL-MODE UHF QUARTZ MEMS OSCILLATOR

**Session T1A
Droplets**
ROOM 301A
8:30 - 10:00

- T1A.001** **INVITED SPEAKER**
BALLISTIC ENERGY CONVERSION **110**
J.C.T. Eijkel¹, A. van den Berg¹, and Y. Xie²
¹*Twente University, NETHERLANDS* and ²*Northwestern Polytechnical University, CHINA*

Ballistic energy conversion is the direct conversion of kinetic energy into electrical energy. Aqueous droplet-based platforms are eminently suitable for this method, as droplets can be conveniently supplied with both kinetic energy and electrical charge. Starting with the 19th century gravity-driven Kelvin thunderstorm and the electrostatic generators of Melcher and Zahn from the 1960s, we describe the recent development of ballistic energy conversion both in experiment and theory. With this method experimental efficiencies of 48% have been reached at 20 kV operating voltage with an extremely simple setup. Theory predicts maximal efficiencies of more than 90%, operation at <100 Volt. Downscaling also promises to remove one of the largest disadvantages of electrostatic generators, namely the low power density: power densities of 1-1000 kW/m² are predicted.

- T1A.002** **CONTACT FUSION OF DROPLETS PATTERNED ON OPPOSING PLATES FOR CELLULAR TRANSPORTATION AND MEDIUM EXCHANGE FOR HANGING DROPLET CELL CULTURE** **115**
H. Maeda, C. Ohya, T. Matsuyoshi, T. Kobayashi, and S. Konishi
Ritsumeikan University, JAPAN

This paper presents cellular transportation from a droplet on an originator plate to a droplet on an opposite receiver plate by using contact fusion of two droplets. This technique can be applied to medium exchange, drug delivery, and *in-situ* characterization for hanging droplet cell culture. Our study enables patterning of droplet arrays on the receiver plate so that contact fusion of droplets can occur where droplets exist on the receiver plate.

- T1A.003** **A PORTABLE DROPLET MAGNETOFLUIDIC PLATFORM FOR AUTOMATED RNA QUANTIFICATION AND ANALYSIS** **119**
A.Y. Trick, D.J. Shin, and T.-H. Wang
Johns Hopkins University, USA

We present a miniaturized droplet magnetofluidic assay system on a cartridge smaller than 1 cubic inch for automated purification, amplification and melt analysis of RNA targets. This platform demonstrates quantification and confirmation of nucleic acid targets through post-amplification analysis with comparable performance to benchtop RT-PCR assays.

- T1A.004** **CENTRIFUGE-BASED MEMBRANE EMULSIFICATION TOWARD HIGH-THROUGHPUT GENERATION OF MONODISPERSE LIPOSOMES** **123**
D.C. Shin, S. Yoshida, Y. Morimoto, and S. Takeuchi
University of Tokyo, JAPAN

We developed a centrifugal emulsification device toward high-throughput generation of monodisperse liposomes. The device generated liposomes in two steps, membrane emulsification by asymmetric through-hole on a plate and transfer of the emulsion to oil/water interface. Since a number of asymmetric through-holes can be fabricated on the plate by standard photolithographic process, the proposed device will be a powerful tool for massive generation of liposomes.

- T1A.005** **A MICROCAPSULE ARRAY FOR QUANTITATIVE FLUORESCENCE DETECTION OF COPPER IONS BASED ON FUNCTIONAL NUCLEIC ACID** **127**
E. He¹, L. Cai², D. Guo¹, Y. Zhou², X. Zhang², and Z. Li²
¹*Tsinghua University, CHINA* and ²*Peking University, CHINA*

We develop a portable, low-cost, user-friendly and ultrasensitive microcapsule array for quantitative fluorescence detection of copper ion based on functional nucleic acid strategy. Since the reagents are pre-sealed through ice-printing technique and stored in frozen microcapsules before application, long-term stability of this device is guaranteed. This assay shows great sensitivity with the minimum detection limit of 100 nM (100 fmol) and specificity.

**Session T1B
Bio Imaging**
ROOM 301B
8:30 - 10:00

- T1B.001** **INVITED SPEAKER**
CMOS BASED ION IMAGE SENSOR - FUSION OF BIO SENSOR TECHNOLOGY AND
IMAGE SENSOR TECHNOLOGY **131**
K. Sawada, K. Takahashi, T. Iwata, and T. Hattori
Toyohashi University of Technology, JAPAN

Non Labeled Image Sensing technology is strategic research area in bio-medical field. By combining imaging sensors with chemical sensors has developed novel ion image sensor that can visualize specific ions from cells in real time. Ions are crucial for sustaining the activities of living things, and understanding their behavior is critical for developing innovative drugs and devices based on chemical reactions. If we could make photographing ion movement as simple as releasing the shutter on a digital camera, we could visualize unseen phenomena and contribute to creating a new industry. We has invented a simpler, more precise system that converts the quantity of ions into the quantity of electrons and allows changes in the ion distribution to be visualized in real time. We have recently reported on the use of the sensor for real time imaging of acetylcholine (ACh), which was not able to be observed yet. Insights in the variation of the concentration of ACh may lead to new methods for the treatment of Alzheimer's disease. In this presentation, I will present some application results of the ion image sensors and discuss possibilities of the new tool for biomedical fields.

- T1B.002** **HIGH-DENSITY MAPPING OF BRAIN SLICES USING A LARGE MULTI-FUNCTIONAL HIGH-DENSITY**
CMOS MICROELECTRODE ARRAY SYSTEM **135**
V. Viswam¹, R. Bounik¹, A. Shadmani¹, J. Dragas¹, M. Obien^{1,2}, J. Müller^{1,2}, Y. Chen^{1,3}, and A. Hierlemann¹
¹ETH Zürich, SWITZERLAND, ²MaxWell Biosystems AG, SWITZERLAND, and ³Analog Devices, CHINA

We developed a CMOS-based microelectrode array system that enables high-resolution mapping of neuronal signals *in-vitro* with multiple readout modalities. The overall system features 59,760 micro-electrodes, 2048 action-potential, 32 local-field-potential and 32 current recording, 32 impedance-measurement and 28 neurotransmitter-detection channels and 16 stimulation channels. The system includes the largest number of electrodes and different sensing modalities to date.

- T1B.003** **A LENS-FREE SINGLE-SHOT FLUORESCENT IMAGING SYSTEM USING CMOS IMAGE SENSORS**
WITH DIELECTRIC MULTI-LAYER FILTER **139**
K. Imai¹, M. Nishigaki¹, Y. Onozuka¹, Y. Akimoto¹, M. Nagai¹, S. Matsumoto², and S. Kousai¹
¹Toshiba Corporation, JAPAN and ²Takeda Pharmaceutical Company Limited, JAPAN

This paper reports a lens-free single-shot fluorescent imaging system based on CMOS image sensors with the dielectric multi-layer filter to reduce excitation light. The achieved spatial resolution was <10 µm, which was improved to one-third of that of state-of-the-art single-shot fluorescent imaging. As a result, the individual nuclei of rat primary neurons stained with Hoechst 33342 were distinguished in the fluorescent image with as short as 0.2 sec exposure time.

- T1B.004** **FULLY PACKAGED VIDEO-RATE CONFOCAL LASER SCANNING ENDOMICROSCOPE**
USING LISSAJOUS FIBER SCANNER **143**
K. Hwang, J.-B. Kim, Y.-H. Seo, J. Ahn, P. Kim, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We developed a fully packaged confocal endomicroscope high resolution and high frame-rate (HRHF) Lissajous fiber scanning. The confocal endomicroscope features a resonant scanning fiber with ~1kHz actuated by a piezoelectric tube (PZT). Our main results clearly demonstrate exceptional fill factor of 85% at 10 Hz in frame rate. The endomicroscope was further combined with a portable confocal microscopic system to obtain video-rate 2D reflectance as well as *in-vivo* mouse vascular imaging.

- T1B.005** **DEVELOPING BIOMETRIC PASSIVE RECOGNITION SENSOR APPLICABLE TO WEARABLE DEVICES:**
PART II - PRELIMINARY VERIFICATION WITH A SHUTTLE ROLLER COASTER STRUCTURE **147**
W. Yuan¹, Z. Gu¹, Y. Xu¹, H. Liu¹, and D.F. Wang^{1,2}
¹Jilin University, JAPAN and ²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

This paper reports a new wrist vein biometric recognition method based on a shuttle roller coaster structure. The 3D wrist vein identification, for the first time, is constructed to achieve high spatial resolution and is demonstrated to obtain vein images in 360 degrees especially for mobile applications.

Session T1C Piezoelectric Transducers

ROOM 304A

8:30 - 10:00

- T1C.001 INVITED SPEAKER**
PIEZOELECTRIC NANOELECTROMECHANICAL SYSTEMS 151
 K.M. Howell, A. De Pastina, A. Lozzi, T. Larsen, M. Faizan, and **L.G. Villanueva**
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

For almost a century piezoelectric materials have been widely used in actuators, clocks, frequency sources, filters and other components in communication systems. Ultra-thin piezoelectric films (below 100 nm in thickness) are particularly interesting for the fabrication of resonant Nanoelectromechanical Systems (NEMS), which have huge potential in sensing but also offer a great platform for fundamental studies. In my talk I will analyze the effect of geometries and material properties of the system so that we can minimize the effect of parasitic reactances; in particular using ferroelectric materials. In addition, I will introduce our efforts on identifying surface piezoelectricity, a property that when moving to very thin layers might become dominant in some cases.

- T1C.002 PASSIVE SIGNAL AMPLIFICATION VIA SERIES-PIEZOELECTRIC READ-OUT** 155
 S. Sonmezoglu¹, J. Segovia-Fernandez¹, S.T. Block¹, Y. Kusano¹, J.M. Tsai², R. Amirtharajah¹, and D.A. Horsley¹
¹University of California, Davis, USA and ²Invensense Inc., USA

We present an innovative method to passively amplify the output voltage in MEMS piezoelectric accelerometers through a series read-out scheme. In a conventional piezoelectric MEMS sensor, output charge is collected by a single capacitor. Here, we present a monolithic accelerometer employing 15-element array of smaller piezo capacitors formed between patterned top-bottom electrodes. By connecting these capacitors in series, the output voltages are added in series, increasing the output voltage.

- T1C.003 RESIDUAL-STRESS-BALANCED PIEZOELECTRIC FILM BASED DIRECTION SENSITIVE FLOW**
SHEAR-STRESS SENSOR FOR QUADCOPTER NAVIGATION 159
 G.-H. Feng, S.-R. Ye, and M.-E. Wei
National Chung Cheng University, TAIWAN

An innovative piezoelectric thin-film based flow shear stress sensor fabricated by micromachining and stereolithography is presented. Three novelties are included: (1) Hydrothermally growing lead zirconate titanate films on both sides of micromachined titanium cantilever beams. (2) Fabricating 3-dimensional structure array on the micromachined planar structure by stereolithography. (3) Using the 3-dimensional photopolymer structure array to couple airflow for sensing.

- T1C.004 A SILICON VECTOR LIGHT SENSOR FOR PROXIMITY SENSING APPLICATIONS** 163
 I. El-chami, D.H. Zhuo, S. Vosoogh-Grayli, and B. Bahreyni
Simon Fraser University, CANADA

We present the operating principle, fabrication details, and experimental verification of a 3D vector light sensor design for angular proximity detection applications. The structure is based on creating photodiodes on side walls of micro-sized mesa pyramids in silicon. Unlike planar pixel designs, the 3D design allows for direction estimation of light sources. The sensor's unique design and simple fabrication process give the 3D design the potential to replace current planar array designs.

- T1C.005 MONOCRYSTALLINE PMNN-PZT THIN FILM ULTRASONIC RANGEFINDER**
WITH 2 METER RANGE AT 1 VOLT DRIVE 167
 Z. Zhou^{1,2}, S. Yoshida¹, and S. Tanaka¹
¹Tohoku University, JAPAN and ²Tsinghua University, CHINA

We develop and demonstrate a MEMS-based ultrasonic rangefinder using a single pMUT based on monocrystalline PMnN-PZT thin film sputter-deposited on Si substrate with long distance detection (>2m) in air as well as low voltage actuating (1V^{p-p}) and low power consumption (8.3μJ/pulse). Basic properties and pulse-echo performance are characterized with various measurements.

Session T1D RF MEMS II

ROOM 304B

8:30 - 10:00

- T1D.001** **INVITED SPEAKER**
EFFORTS TOWARD IDEAL MICROELECTROMECHANICAL SWITCHES 171
J.-B. Yoon, Y.-H. Yoon, M.-H. Seo, S.-D. Ko, Y.-H. Song, M.-W. Kim, H.-H. Yang, J.O. Lee, and W.-W. Jang
Korea Advanced Institute of Science and Technology (KAIST), KOREA

Since a microelectromechanical (MEM) switch with an electrostatically actuated cantilever was first demonstrated by Petersen in 1978 [1], MEM switches have actively been researched by many research groups. However, comparing with the conventional metal-oxide-semiconductor field-effect transistor (MOSFET), MEM switches are still suffering from their high actuation voltage and insufficient operational reliability, which still remain as a difficult challenge to many MEMS researchers and hinder commercialization of the MEM switches. In this work, we look at what lies behind these difficulties in MEM switches and illustrate bright ideas that have been sought to enhance the actuation voltage and switch endurance (lifetime) problems.

- T1D.002** **THIN FILM PACKAGED REDUNDANCY RF MEMS SWITCHES FOR SPACE APPLICATIONS** 175
F. Souchon, D. Saint-Patrice, J.L. Pornin, D. Bouchu, C. Baret, and B. Reig
CEA, LETI, FRANCE

A low cost packaging solution has been successfully implemented on RF MEMS switches. The encapsulation is made at wafer level by thin film packaging, it allows keeping very small footprint for the device and is fully compatible with wire bonding and flip chip assembly. The packaged switches despite their highly shrinked size reveal excellent microwave performances and promising behaviors in terms of reliability, especially for redundancy schemes required by space applications.

- T1D.003** **SWITCHABLE LAMB WAVE DELAY LINES USING AlGaIn/GaN HETEROSTRUCTURE** 179
H. Zhu¹ and M. Rais-Zadeh^{1,2}
¹University of Michigan, USA and ²California Institute of Technology, USA

We report the first demonstration of GaN-based switchable Lamb wave delay lines with >40 dB ON/OFF ratio at GHz range. The high-density two-dimensional electron gas in AlGaIn/GaN heterostructure is used to screen out the lateral electric field and switch off the piezoelectric transducer. With a proper pitch-to-thickness ratio, the proposed Lamb wave delay line only exhibits zero-order symmetric and anti-symmetric Lamb wave mode responses while providing spurious mode reduction up to 26.5 GHz.

- T1D.004** **A MEMS INERTIAL SWITCH WITH ELECTROSTATIC FORCE ASSISTANCE AND MULTI-STEP PULL-IN FOR ELIMINATING BOUNCE AND PROLONGING CONTACT TIME** 183
J. Li, Y. Sun, Y. Wang, Z. Yang, G. Ding, H. Wang, and X. Zhao
Shanghai Jiao Tong University, CHINA

We design, simulate, fabricate, and test a MEMS inertial switch with electrostatic force assistance and multi-step pull-in behavior to weaken the bounce and keep a long contact in the inertial switch before the leakage of electricity ends. In our design, the several small planes are flexibly connected each other to form the movable electrode and the air layer is directly used as the insulator in the electrostatic pull-in.

- T1D.005** **ULTRA-MINIATURE FUNDAMENTAL-MODE UHF QUARTZ MEMS OSCILLATOR** 187
D.T. Chang, Y. Yoon, H.P. Moyer, P.D. Brewer, and H.D. Nguyen
HRL Laboratories, LLC, USA

We present an ultra-miniature, oscillator (1 cubic mm total volume) built with a thickness shear mode quartz resonating element integrated with a SiGe BiCMOS sustaining ASIC to achieve a fundamental-mode UHF operation of > 800 MHz. This low-power (< 25mW) oscillator achieves excellent acceleration sensitivity (< 1E-9/g) without active vibration compensation and is suitable for high performance hand-held/portable applications.

10:00 - 10:30 **Break and Exhibit Inspection**

Session T2A Cell Analysis	Session T2B Chemical Sensors	Session T2C Graphene	Session T2D Optical Transducers I
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: B. Pruitt <i>Stanford University, USA</i>	Session Co-Chairs: T. Cui <i>University of Minnesota, USA</i> A. Llobera <i>ZEISS Group, GERMANY</i>	Session Co-Chairs: J. Miao, <i>Nanyang Technological University, SINGAPORE</i> G. Villanueva, <i>École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND</i>	Session Co-Chairs: A. Basu <i>Wayne State University, USA</i> C. Lee, <i>National University of Singapore, SINGAPORE</i>
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T2A.001 CANTILEVER ARRAY FOR MEASURING TRACTION FORCES OF CELLS IN A CONFINED SPACE	T2B.001 A HUMIDITY SENSOR WITH HIGH SENSITIVITY AND LOW TEMPERATURE COEFFICIENT OF FREQUENCY BASED ON ALN SURFACE ACOUSTIC WAVE AND GRAPHENE OXIDE SENSING LAYER	T2C.001 AN AC SENSING SCHEME FOR MINIMAL BASELINE DRIFT AND FAST RECOVERY ON GRAPHENE FET GAS SENSOR	T2D.001 OPTICAL MEMS INDEX FINGER MICROGESTURE INPUT DEVICE FOR MOBILE AND WEARABLE DEVICES
10:45 - 11:00			
T2A.002 A MICROFLUIDIC SENSOR FOR SINGLE CELL DETECTION IN A CONTINUOUS FLOW	T2B.002 A PEDOT:PSS-BASED ORGANIC ELECTROCHEMICAL TRANSISTOR WITH A NOVEL DOUBLE-IN-PLANE GATE ELECTRODE FOR PH SENSING APPLICATION	T2C.002 AN ULTRASENSITIVE MERCURY SENSOR BASED ON SELF-ASSEMBLED GRAPHENE AND GOLD NANOPARTICLES ON SHRINK POLYMER	T2D.002 REAL-TIME VERTICAL/HORIZONTAL SECTION IMAGING AND 3D IMAGE CONSTRUCTION USING A 3-AXIS ELECTROMAGNETIC CONFOCAL MICROSCANNER
11:00 - 11:15			
T2A.003 CELL ANALYSIS SYSTEM USING A FILTER-FREE FLUORESCENCE SENSOR	T2B.003 MULTIPLE STRUCTURAL COLOR HYDROGEL ARRAY INTEGRATED WITH MICROFLUIDIC CHIP FOR BIOCHEMICAL SENSOR	T2C.003 ELECTROCHEMICAL DETECTION OF NITRATE IONS IN SOIL WATER USING GRAPHENE FOAM MODIFIED BY TiO ₂ NANOFIBERS AND ENZYME MOLECULES	T2D.003 TUNABLE DIELECTROPHORETIC MICROLENS WITH LOWERED DRIVING VOLTAGE
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T2A.004 MEMS ENABLED LIVE CELL MECHANICS AND DYNAMICS IN SHEAR LOADING	T2B.004 ALL-SOLID-STATE MULTIMODAL PROBE BASED ON ISFET ELECTROCHEMICAL MICROSENSORS FOR <i>IN-SITU</i> SOIL NUTRIENTS MONITORING IN AGRICULTURE	T2C.004 SUPERIOR GAS DETECTION BY NANOPOROUS GRAPHENE STRUCTURES	T2D.004 A PHYSICALLY TRANSIENT FORM OF FUNCTIONAL PROTEIN OPTICS
11:30 - 11:45			
T2A.005 EXTRACELLULAR NEURAL STIMULATION AND RECORDING WITH A THIN-FILM-TRANSISTOR (TFT) ARRAY DEVICE	T2B.005 A HIGH SENSITIVITY MEMS CAPACITIVE HYDROGEN SENSOR WITH INVERTED T-SHAPED ELECTRODE AND RING-SHAPED PALLADIUM	T2C.005 LOW-FREQUENCY ELECTRONIC NOISES IN CVD GRAPHENE GAS SENSORS	T2D.005 PORTABLE FOURIER TRANSFORM INFRARED SPECTROMETER BASED ON AN ELECTROTHERMAL MEMS MIRROR

**Session T2A
Cell Analysis**
ROOM 301A
10:30 - 11:45

- T2A.001 CANTILEVER ARRAY FOR MEASURING TRACTION FORCES OF CELLS IN A CONFINED SPACE 191**
 K.H. Shoji, K. Matsudaira, T. Tsukagoshi, T.-V. Nguyen, K. Noda, and I. Shimoyama
University of Tokyo, JAPAN

We reports a sensor to directly measure the traction forces generated by cells in a confined space. The sensor consists of an array of miniaturized piezoresistive cantilevers which are surrounded by a pluronic-F127 pattern. The pattern allows the self-alignment and directional movement of the cells on the cantilever array. Thus, this method enables the quantitative evaluation of the traction forces of cells with controlled migrating direction.

- T2A.002 A MICROFLUIDIC SENSOR FOR SINGLE CELL DETECTION IN A CONTINUOUS FLOW 194**
 F. Liu, P. Kc, G. Zhang, and J. Zhe
University of Akron, USA

We invented a microfluidic magnetic bead assay for SINGLE cell detection, which can 1) accurately detect individual single cells *in situ* in a continuous flow, and 2) measure sizes and counts of each cell type from a heterogeneous cell suspension environment. This device enables single cell detection in a continuous flow and could be applied to facilitate general cell detection applications such as stem cell identification and enumeration.

- T2A.003 CELL ANALYSIS SYSTEM USING A FILTER-FREE FLUORESCENCE SENSOR 198**
 Y.-J. Choi¹, Y. Shinozaki², K. Takahashi¹, T. Iwata¹, S. Koizumi², and K. Sawada¹
¹Toyohashi University of Technology, JAPAN and ²University of Yamanashi, JAPAN

We proposed a cell analysis system without fluorescence filters using a filter-free fluorescence sensor which used wavelength dependent absorption depth in a Si substrate. A filter-free fluorescence sensor can be used to detect cell labeled with various fluorescence reagents. The measured fluorescence of cell(astrocytes labeled with Calcein-AM) was good agreement with fluorescence intensity observed by conventional fluorescence microscopy.

- T2A.004 MEMS ENABLED LIVE CELL MECHANICS AND DYNAMICS IN SHEAR LOADING 202**
 E. Sadeghipour, M.A. Garcia, W.J. Nelson, and B.L. Pruitt
Stanford University, USA

We designed, fabricated, and deployed a silicon MEMS device to strain a sheet of epithelial (2D and skin-like) cells in tension and/or shear simultaneously. We deployed the device with upright bright-field and fluorescence microscopy in live-cell experiments spanning 42 hours. For the first time, our MEMS-based assay enabled quantification of the mechanics and dynamics of epithelial monolayers under shear deformation. In-plane shear forces are important in many biological processes and diseases.

- T2A.005 EXTRACELLULAR NEURAL STIMULATION AND RECORDING WITH A THIN-FILM-TRANSISTOR (TFT) ARRAY DEVICE 206**
 F.A. Shaik, Y. Ikeuchi, G. Cathcart, S. Ihida, H. Toshiyoshi, and A. Tixier-Mita
University of Tokyo, JAPAN

Success has been achieved for the first time in stimulating and recording primary cortical neurons culture using a transparent Thin-Film-Transistor (TFT) array substrate. Unlike Multi-Electrode-Arrays substrates, used for neurons activity recording, we develop a platform using TFT substrate, allowing larger scale neurons activity recording using electrical and optical interface. *In-situ* voltage and external current pulses were used to stimulate. The spikes of neurons were observed in both cases.

Session T2B
Chemical Sensors
ROOM 301B
10:30 - 11:45

- T2B.001 A HUMIDITY SENSOR WITH HIGH SENSITIVITY AND LOW TEMPERATURE COEFFICIENT OF FREQUENCY BASED ON ALN SURFACE ACOUSTIC WAVE AND GRAPHENE OXIDE SENSING LAYER 210**
X. Le, H. Ding, J. Pang, Y. Wang, and J. Xie
Zhejiang University, CHINA

We propose a humidity sensor based on SAW device and graphene oxide sensing layer. Utilizing a thin AlN layer and a highly-doped Si substrate layer, the TCF of the sensor is found to be around -22.1 ppm/°C, much smaller than conventional SAW humidity sensors. Moreover, the sensor has a broad detection range from 5% to 95%RH and shows high sensitivity up to 420.8 kHz/10%RH at 90%RH. Little hysteresis, excellent stability, fast response and short recovery time of the sensor are obtained.

- T2B.002 A PEDOT:PSS-BASED ORGANIC ELECTROCHEMICAL TRANSISTOR WITH A NOVEL DOUBLE-IN-PLANE GATE ELECTRODE FOR PH SENSING APPLICATION 214**
A.E. Kirchan, K.T. Kim, M.K. Steward, and S. Choi
University of Washington, USA

We developed a miniaturized PEDOT:PSS based organic electrochemical transistors (OECTs) with a high transconductance of 35 mS for a pH sensing application. In order to achieve this, we designed, fabricated, and characterized a novel double-in-plane gate electrode. All electrodes (gate, source, and drain) were placed in the same plane. Such a high transconductance with in-plane architecture will allow the development of portable OECT arrays for various chemical/biological sensing applications.

- T2B.003 MULTIPLE STRUCTURAL COLOR HYDROGEL ARRAY INTEGRATED WITH MICROFLUIDIC CHIP FOR BIOCHEMICAL SENSOR 218**
K. Niibe and H. Onoe
Keio University, JAPAN

This paper describes a multiple structural color hydrogel array integrated with a two-layered microfluidic chip. The microfluidic chip can sense multiple targets at the same time by visible color changes of the arrayed stimuli-responsive hydrogels in the top chambers. Sample solution was injected in the bottom chamber and reacted to hydrogel via porous membrane. We evaluated our device by measuring reflection spectra, and confirmed the visible color changes of our sensor.

- T2B.004 ALL-SOLID-STATE MULTIMODAL PROBE BASED ON ISFET ELECTROCHEMICAL MICROSENSORS FOR *IN-SITU* SOIL NUTRIENTS MONITORING IN AGRICULTURE 222**
M. Joly^{1,2}, L. Mazenq¹, M. Marlet², P. Temple-Boyer¹, C. Durieu², and J. Launay¹
¹LAAS-CNRS, FRANCE and ²Agronutrition, FRANCE

We designed a silicon chip dedicated to the monitoring of soil nitrogen cycle in agriculture. Our study shows that ion-sensitive field effect transistors (ISFET) are suitable for analysis of nutrients measured directly in soil as opposed to soil extracts analysis. Our pH-ISFET recorded soil pH for six months in good accordance with the standard method. pNO₃ and pNH₄-ISFET allowed the *in-situ* measurements of natural variations of soil nitrogen contents caused by microorganisms' activity.

- T2B.005 A HIGH SENSITIVITY MEMS CAPACITIVE HYDROGEN SENSOR WITH INVERTED T-SHAPED ELECTRODE AND RING-SHAPED PALLADIUM 226**
H. Yamazaki, Y. Hayashi, K. Masunishi, D. Ono, and T. Ikehashi
Toshiba Corporation, JAPAN

We report on a novel Pd-based MEMS capacitive hydrogen gas sensor which has an "inverted T-shaped" electrode and a "ring-shaped palladium" layer that enable high sensitivity. Thanks to these structures, deformation of the membrane caused by hydrogen can be efficiently transduced to the capacitance change. The capacitance change is found to be 3 times larger than that of the conventional structure. We also show that the proposed sensor has a broad design window that maximizes the sensitivity.

Session T2C
Graphene
ROOM 304A
10:30 - 11:45

- T2C.001 AN AC SENSING SCHEME FOR MINIMAL BASELINE DRIFT AND FAST RECOVERY ON GRAPHENE FET GAS SENSOR** 230
 Y. Liu¹, J. Yu¹, Y. Cui¹, T. Hayasaka¹, H. Liu^{1,2}, X. Li¹, and L. Lin^{1,2}
¹University of California, Berkeley, USA and ²Tsinghua-Berkeley Shenzhen Institute, USA

This work reveals a new AC sensing scheme for boosted recovery and minimal baseline drift on graphene FET gas sensor, achieving an ultrafast baseline recovery speed (within ~10s) in various vapors such as water, methanol and ethanol respectively, around 10X faster than the conventional DC sensing scheme. As such, the proposed sensing scheme and results could open up a new frontier for gas sensing with accelerated sensing speed in practical uses and fundamental research.

- T2C.002 AN ULTRASENSITIVE MERCURY SENSOR BASED ON SELF-ASSEMBLED GRAPHENE AND GOLD NANOPARTICLES ON SHRINK POLYMER** 234
 Z. Wu¹, G. Jing¹, and T. Cui²
¹Tsinghua University, CHINA and ²University of Minnesota, USA

Ultrasensitive trace mercury micro sensor fabricated by gold nanoparticle mixed with graphene suspension solution and layer-by-layer self-assembly on a shrink polymer based a micro gold electrode is reported for the first time.

- T2C.003 ELECTROCHEMICAL DETECTION OF NITRATE IONS IN SOIL WATER USING GRAPHENE FOAM MODIFIED BY TiO₂ NANOFIBERS AND ENZYME MOLECULES** 238
 M.A. Ali, Y. Jiao, S. Tabassum, Y. Wang, H. Jiang, and L. Dong
 Iowa State University, USA

This paper reports a microfluidic nitrate sensor using a graphene foam (GF) based porous electrode modified by titanium dioxide nanofibers (nTiO₂) and nitrate reductase enzyme molecules. The porous GF allows an easy access of nTiO₂ and enzyme into the GF for surface biofunctionalization. This provides high loading capability of enzymes for catalytic reaction with nitrate. The sensor offers superior sensitivity and selectivity to nitrate even in presence of many interfering ions in soil solution.

- T2C.004 SUPERIOR GAS DETECTION BY NANOPOROUS GRAPHENE STRUCTURES** 242
 J. Wu¹, K. Tao², J. Miao¹, and L.K. Norford³
¹Nanyang Technological University, SINGAPORE, ²Northwestern Polytechnical University, CHINA, and
³Massachusetts Institute of Technology, USA

A new method combining microwave plasma enhanced chemical vapor deposition (MPCVD) with ultrasonic fragmentation is exploited to prepare nanoporous graphene (Gr) thin film for detection of CO₂ and NH₃ with high performance, including high sensitivity, linearity, low limit of detection and reversibility. For instance, NH₃ with the low concentration of 2 ppm is detected with a good response of 19.2%. Furthermore, CO₂ with the concentration as low as 20 ppm can also be detected.

- T2C.005 LOW-FREQUENCY ELECTRONIC NOISES IN CVD GRAPHENE GAS SENSORS** 246
 Y. Cui, Y. Liu, J. Yu, T. Hayasaka, X. Li, W. Cai, H. Liu, and L. Lin
 University of California, Berkeley, USA

We report the investigation of low-frequency noise in the PEI doped graphene gas sensor using CVD to make a field effect transistor. Compare to the state-of-art, three advancements have been achieved: (1) first demonstration of 1/f noise characterization in PEI doped CVD graphene gas sensor; (2) the simulated random charge transfer events by the gas adsorption-desorption processes on the graphene surface; and (3) rejection of the complex background noise by digital signal processing method.

**Session T2D
Optical Transducers I**
ROOM 304B
10:30 - 11:45

- T2D.001 OPTICAL MEMS INDEX FINGER MICROGESTURE INPUT DEVICE FOR MOBILE AND WEARABLE DEVICES 250**
 N. Sarkar^{1,2}, B. O'Hanlon^{1,2}, G. Lee^{1,2}, D. Strathearn^{1,2}, M. Olfat^{1,2}, A. Rohani^{1,2}, and R.R. Mansour^{1,2}
¹University of Waterloo, CANADA and ²AdHawk Microsystems, CANADA

We report the first optical microsystem that captures index finger microgestures with the precision, bandwidth, power consumption and form-factor required for handwriting and gesture keyboarding on smart watches and mobile handsets. Finger position is measured with 30µm resolution at 550Hz while consuming ~15mW. A VCSEL, scanning Fresnel element, and photodiode are packaged to fit unobtrusively in a wearable device. This component enables high-resolution touch-less 3D gesture input to wearables.

- T2D.002 REAL-TIME VERTICAL/HORIZONTAL SECTION IMAGING AND 3D IMAGE CONSTRUCTION USING
A 3-AXIS ELECTROMAGNETIC CONFOCAL MICROSCANNER 254**
 G. Cao¹, H. Mansoor², H. Zeng^{1,3}, I.T. Tai^{1,3}, and M. Chiao¹
¹University of British Columbia, CANADA, ²AR Medical Technologies, Inc. CANADA, and
³BC Cancer Agency Research Center, CANADA

We develop a 3-axis electromagnetic confocal microscanner for real-time imaging of vertical/horizontal cross section (relative to tissue) of onion peel samples. The horizontal and vertical section image have a field -of-view of 200 × 200 µm² at frame rate of 5 fps and 1fps. We also demonstrate 3D imaging of PDMS micropillar arrays.

- T2D.003 TUNABLE DIELECTROPHORETIC MICROLENS WITH LOWERED DRIVING VOLTAGE 258**
 Y.D. Almoallem and H. Jiang
 University of Wisconsin, USA

We report a new double-sided design (DSD) of an electrode structure driving a tunable liquid microlens based on a dielectric force. The clear advantage of our DSD over previously reported conventional single-sided design of electrodes for electro-driven lenses is the much lower driving voltage, given similar device scale about 1mm of lens diameter. The contact angle changed from 4° to 18°, when the voltage increased to 25 VRMS, which is lower than previous work by at least a factor of four.

- T2D.004 A PHYSICALLY TRANSIENT FORM OF FUNCTIONAL PROTEIN OPTICS 262**
 Z. Zhou^{1,2}, Z. Shi³, X. Cai^{1,2}, and H. Tao^{1,2,4}
¹Chinese Academy of Sciences, Shanghai, CHINA, ²University of Chinese Academy of Sciences, CHINA,
³Huashan Hospital of Fudan University, CHINA and ⁴University of Texas, USA

We report a set of biofunctionalizable and biodegradable diffractive optical elements (DOEs) using silk proteins as the building materials for a proof-of-principle demonstration of transient optics. The diffraction pattern of a DOE is highly sensitive to its surrounding environments and its structural integrity, which offers numerous opportunities for sensing applications based on its transient behavior.

- T2D.005 PORTABLE FOURIER TRANSFORM INFRARED SPECTROMETER BASED
ON AN ELECTROTHERMAL MEMS MIRROR 265**
 D. Wang¹, X. Han¹, H. Liu¹, Q. Chen¹, W. Wang^{1,2}, and H. Xie^{1,2}
¹WiO Technology, CHINA and ²University of Florida, USA

This paper reports a MEMS-based Fourier transform infrared spectrometer (µFTIR), enabled by an innovative H-shaped electrothermal MEMS mirror. The H-shaped MEMS mirror consists of 32 symmetrically-distributed three-level ladder bimorph actuators, leading to large linear displacement with negligible tilting. The new µFTIR was applied in the composition prediction of soybeans, and the experiment results showed it can accurately measure the protein content.

11:45 - 14:00 Lunch and Exhibit Inspection

Industry Session - Fab (Room 301A)**12:30 - 12:55 PROCESS MODULE & BIG DATA ASSISTED MANUFACTURING: FAST TIME-TO-PRODUCTION**

Jerwei Hsieh, Vice President for RD
Asia Pacific Microsystems (APM), Inc., TAIWAN

Entering into the Era of IoT nowadays, demand for MEMS sensors is on the rise. To realize larger variety sensors with relatively smaller volume, developers and manufactures have to work out better ways to expedite faster time-to-production, so as to seize the market from a tinny window of opportunity. From MEMS foundry point of view, to reduce the time spent at process transfer between labs and fabs, and to prevent likely product failure mechanisms in process integration, are effective ways to significantly reduce development time. This presentation will base on the themes, to describe how APM, a MEMS pure play foundry, does to enable fast time-to-production. Adopting tailored process modules and carefully integrating processes are the keys to crank out reliable MEMS products in a short time. Applying big data can further enable reliable manufacturing. APM is aiming to leverage the accumulated experiences to pave the way for Clients' faster and high quality MEMS production.

12:55 - 13:20 DEDICATED FAB IT SUPPORT SYSTEMS AND NPI PROTOCOLS ENABLE FAST PROCESS TRANSFER AND TIME TO MARKET FOR MEMS

Tomas Bauer, Senior Vice President
Silex Microsystems AB, SWEDEN

MEMS foundry processing compared to IC foundry processing holds fundamental differences that are necessary to understand and manage in order to achieve efficient and competitive time to market for customized MEMS products. Where IC process development often rests on decades of process legacy, applying only minor tweaks to a well-known fundamental baseline, MEMS process development is usually done from a far less established starting point. One way the industry has tried to solve this issue is to make custom MEMS more "IC like" by offering standard process platforms. This works well in the IC space where the foundry owns the process platform capable of providing fundamental design parameters (feature size, voltage, parasitics etc), and the foundry customer will create and compete against its peers by developing a product design and stack of 2D masks within the limitations and design rules of the process. The challenge such approach puts on MEMS is that MEMS is very often competing not only in the 2D top view of the design but actually much more in the integrated 3D stack comprising also the vertical axis of the mechanical design with a far wider range of process parameter dependency than any process simulation software can properly manage today. Building a standard process platform in MEMS worthy of the definition very often ends up being a very poor compromise of all challenges the approach is facing. The most competitive product design needs to play at the limitation of what is physically possible, leaving very few options to compromise. Silex is a leading Pure Play MEMS foundry provider with decades of experience developing customized MEMS processes for innovation leaders in the MEMS industry. This presentation will share some of the fundamental support systems and protocols developed by Silex to help MEMS foundry customers get to market with a competitive product in the fastest possible time.

13:20 - 13:45 THE CHALLENGE AND OPPORTUNITY OF 200MM/300MM MORE-THAN-MOORE (MTM) TECHNOLOGY TRANSITIONS

Mike Rosa, Head of Marketing, Equipment Products Group (EPG)
Applied Materials, Inc., USA

In recent years, the 200mm wafer fab equipment market has enjoyed somewhat of a renaissance. With the meteoric rise of emerging technologies or the so called More-than-Moore (MTM) class of device technologies, the 200mm and below wafer fabs are seeing increased wafer volume demand and tool utilization rates that are driving the demand for both capacity add and new technology tools alike. While this has proven to be a boon in many respects for equipment OEMs, there are new and existing challenges to be overcome in supporting a growing 200mm market and with that, the increased potential for transition of MTM technologies to 300mm. From technology segment trends, to supply chain inventory, impact of new vs. used on price and delivery times, device technology transitions, to presenting the value of wafer size migration. This presentation outlines and discusses some of the challenges faced by Applied Materials' 200mm EPG as it navigates the pitfalls and opportunities in rapidly changing legacy semiconductor equipment market place.

13:45 - 14:10 INTEGRATION AND DEVELOPMENT OF DISRUPTIVE MATERIALS IN MANUFACTURING FAB

Wilbur Catabay, Senior Vice President
TSI Semiconductors, USA

Over the past few years, there has been declining capability of domestic fabrication in North America. Most of the manufacturing has taken place in Asia with large foundries that only want to work with large integrated design manufacturers with large wafer volumes. This leaves a void for small to mid size IDM's, Mil-Aero, and more importantly incubation start-up companies with innovative technologies targeting today's "Smart Markets". IDM's and Entrepreneurs with new, smart architectures and novel disruptive materials are usually not accepted by more mainstream fabs, leaving them with precious few places to fabricate their technologies with secure IP retention. TSI Semiconductors will give an overview of how to close the gap that enables these disruptive technologies by way of novel materials and integration using CMOS platforms in a high volume manufacturing fab. TSI's business model provides a flexible development lab environment that co-exist in a high volume manufacturing foundry fab.

14:00 - 16:00 Poster/Oral Session T3P (Refreshments Available)

Poster/Oral presentations are listed by topic category with their assigned number starting on page 58.

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16:00 - 16:15			
T4A.001 MICROFLUIDIC HYDROGEL HANGING-DROP NETWORK FOR HIGH-RESOLUTION MICROSCOPY OF 3D MICROTISSUES	T4B.001 LIQUID-ON-BEAM STRUCTURE FOR GAS SENSING	T4C.001 FLEXIBLE HAPTIC DISPLAY WITH 768 INDEPENDENTLY CONTROLLABLE SHAPE MEMORY POLYMERS TAXELS	T4D.001 MAGNETICALLY DRIVEN ENERGY-HARVESTER WITH MONOLITHICALLY INTEGRATED HIGH-ENERGY-DENSITY MAGNETS
16:15 - 16:30			
T4A.002 A NOVEL ROUND BOTTOM μ -WELL ARRAY CHIP WITH BIOMIMETIC NANO-CILIA PROMOTES 3D TUMOR CULTURES AND METASTATIC BIOASSAYS	T4B.002 STATIC AND DYNAMIC OPERATION OF METAL-COATED HYDROGEL CANTILEVER HUMIDITY SENSORS BASED ON HYGROSCOPIC MISMATCH	T4C.002 DYNAMIC STRAIN DISTRIBUTION SENSOR SHEET BASED ON ULTRA-THIN PZT/SI ARRAY ON FLEXIBLE SUBSTRATE FOR BRIDGE MONITORING WIRELESS SENSOR NETWORK	T4D.002 ELECTRET BASED MICRO ENERGY HARVESTING DEVICE WITH BOTH BROAD BANDWIDTH AND HIGH POWER DENSITY FROM OPTIMAL AIR DAMPING
16:30 - 16:45			
T4A.003 INDEPENDENTLY CONTROLLABLE MICROWELL ARRAY WITH FLUIDIC MULTIPLEXER FOR MASS PRODUCTION OF EMBRYONIC BODIES	T4B.003 $\text{Ni}_2(\text{dobdc})$ MOF (METAL-ORGANIC FRAMEWORK) NANOCRYSTALS FOR ULTRA-SENSITIVE DETECTION OF ppb-LEVEL CO WITH RESONANT-CANTILEVER	T4C.003 WITHDRAWN	T4D.003 OPTICALLY-DRIVEN GAS GENERATOR BY PHOTOVOLTAIC ASSISTED PHOTOELECTROLYSIS USING Se/TiO_2 HETEROJUNCTION STRUCTURE
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T4A.004 3D MICROFLUIDIC PERFUSION CELL CULTURE SYSTEM WITH LINEAR CONCENTRATION GRADIENT AND AIR BUBBLE TRAPPING	T4B.004 FABRICATION AND CHARACTERIZATION OF VOC SENSORS BASED ON SUSPENDED ZINC OXIDE NANORODS FUNCTIONALIZED BY COBALT PORPHYRIN	T4C.004 FOLDABLE PAPER ELECTRONICS BY DIRECT-WRITE LASER PATTERNING	T4D.004 ELECTRET MATERIALS FOR ENHANCED PERFORMANCE OF TRIBOELECTRIC ENERGY SCAVENGING FROM WIND FLOW
17:00 - 17:15			
T4A.005 DIFFERENTIATION OF NEURAL STEM CELLS REGULATED BY THREE-DIMENSIONAL TISSUE SHAPE	T4B.005 INVESTIGATION OF PD-CU-SI METALLIC GLASS FILM FOR HYSTERESIS-FREE AND FAST RESPONSE CAPACITIVE MEMS HYDROGEN SENSORS	T4C.005 STRETCHABLE SMART PATCH: SERPENTINE NETWORK CONNECTED FUNCTIONAL NODE ARRAY WITH ENHANCED ACOUSTIC EMISSION DETECTABILITY AND THERMO-ACTIVATED DRUG DELIVERY FUNCTIONS	T4D.005 A SELF-POWERED WIRELESS SENSING NODE FOR AMBIENT VIBRATION PATTERN IDENTIFICATION BY USING A HYBRID ENERGY-HARVESTING MODE
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T4A.006 IN-SITU, REAL-TIME MONITORING OF NUTRIENT UPTAKE ON PLANT CHIP INTEGRATED WITH NUTRIENT SENSOR	T4B.006 A SINGLE-WIRE LARGE-AREA FILAMENT EMITTER FOR SPECTROSCOPIC ETHANOL GAS SENSING FABRICATED USING A WIRE BONDING TOOL	T4C.006 TEXTURE MEASUREMENT FOR FABRICS INCLUDING WARM/COOL AND FLUFFINESS SENSATION BY MULTIMODAL MEMS SENSOR	T4D.006 WITHDRAWN
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T4A.007 TOWARD FABRICATION OF VASCULARIZED TISSUES USING A BILAYER CO-CULTURE APPROACH ACHIEVED BY A MESH CULTURE TECHNIQUE	T4B.007 NANOSCALE EASY TEAR PROCESS FOR ULTRA-FAST RESPONSIVE COLLOIDAL CRYSTAL-PDMS COMPOSITE VOC SENSORS	T4C.007 EPIDERMAL WIRELESS SENSORS ON RELEASABLE FILMS FOR BIOPHYSICAL SIGNAL MEASUREMENT ON FACIAL AREAS	T4D.007 A WRIST-WORN ROTATIONAL ENERGY HARVESTER UTILIZING MAGNETICALLY PLUCKED {001} ORIENTED BIMORPH PZT THIN-FILM BEAMS

Session T4A
Cell Culture
ROOM 301A
16:00 - 17:45

- T4A.001 MICROFLUIDIC HYDROGEL HANGING-DROP NETWORK FOR HIGH-RESOLUTION MICROSCOPY OF 3D MICROTISSUES** 269
 E.A. Aeby, P.M. Misun, M. Müller, K. Renggli, A. Hierlemann, and O. Frey
 ETH Zürich, SWITZERLAND

We present an array-based microfluidic chip for parallelized culturing of 3D microtissues under varying perfusion conditions. The 3D microtissues are immobilized at the bottom of hanging hydrogel microdrops. Precision in positioning and stability of the microtissues over time renders the platform suitable for use with multi-position, high-resolution imaging techniques. Fabrication and operation of the chip is simple and robust, as it does not require unconventional equipment.

- T4A.002 A NOVEL ROUND BOTTOM μ -WELL ARRAY CHIP WITH BIOMIMETIC NANO-CILIA PROMOTES 3D TUMOR CULTURES AND METASTATIC BIOASSAYS** 273
 C.-T. Kuo^{1,2}, J.-Y. Wang², A.M. Wo², B.P.C. Chen¹, and H. Lee²
¹University of Texas Southwestern Medical Center, USA and ²National Taiwan University, TAIWAN

We present a microarray chip integrated with novel round bottom μ -well arrays and biomimetic nano-cilia, which can, for the first time, not only recapitulate *in vivo*-like tumor microenvironment but also be achieved *in situ* for hallmarks of tumor-based bioassays.

- T4A.003 INDEPENDENTLY CONTROLLABLE MICROWELL ARRAY WITH FLUIDIC MULTIPLEXER FOR MASS PRODUCTION OF EMBRYONIC BODIES** 277
 M. Ikeuchi, M. Shibata, and K. Ikuta
 University of Tokyo, JAPAN

A palm-sized cell culture system "PASMA" has been developed for automatic mass production of embryonic bodies. The key problem in increasing the number of microwells is the costly and large solenoid valves. Here, we have introduced fluidic multiplexer circuits composed of pneumatically actuated normally-open valves and normally-closed valves. As a result, we have succeeded in increasing the number of microwells from 100 to 256 despite decreasing the number of solenoid valves from 20 to 16.

- T4A.004 3D MICROFLUIDIC PERFUSION CELL CULTURE SYSTEM WITH LINEAR CONCENTRATION GRADIENT AND AIR BUBBLE TRAPPING** 281
 D.H. Park¹, H.J. Jeon¹, M.J. Kim¹, X.D. Nguyen¹, K. Morten², and J.S. Go¹
¹Pusan National University, KOREA and ²University of Oxford, UK

This paper presents a 3D perfusion cell culture system. The perfusion system is integrated with linear concentration generator, meandered microchannel mixer and bubble trapping reservoir. We evaluate the performance of key components numerically and experimentally. Finally, the 3D perfusion system with linear gradient of concentration of H₂O₂ examines cytotoxicity of muscle cells with Ewing's sarcoma

- T4A.005 DIFFERENTIATION OF NEURAL STEM CELLS REGULATED BY THREE-DIMENSIONAL TISSUE SHAPE** 285
 Y. Matsushiro¹, M. Kato-Negishi², and H. Onoe¹
¹Keio University, JAPAN and ²University of Tokyo, JAPAN

We propose the effect of three-dimensional (3D) tissue shape on the differentiation ratio of neurons. We cultured mouse neural stem cells (mNSCs) in the agarose microchamber sealed with an agarose sheet. Various lane-shaped mNSC tissues were fabricated and differentiated to neurons and glial cells. We confirmed that tissues of thin width and thickness have higher differentiation ratio of neurons than that of spherical-shaped tissue.

- T4A.006 *IN-SITU*, REAL-TIME MONITORING OF NUTRIENT UPTAKE ON PLANT CHIP INTEGRATED WITH NUTRIENT SENSOR** 289
 H. Jiang, M.A. Ali, Y. Jiao, B. Yang, and L. Dong
 Iowa State University, USA

There is an urgent requirement to maximize nutrient use efficiency (NUE) of crops for sustainable agriculture and ecosystems. We report *in-situ* monitoring of nutrient uptake of rice plants grown in a microfluidic plant chip with embedded nutrient sensors. We have demonstrated real-time detection of nitrate and phosphate availability in growth medium over a 15-day plant growth time. This approach can be adopted to realize real-time quantification of NUE for many important plants.

- T4A.007 TOWARD FABRICATION OF VASCULARIZED TISSUES USING A BILAYER CO-CULTURE APPROACH ACHIEVED BY A MESH CULTURE TECHNIQUE** 293
 K. Yamada¹, K.O. Okeyo², O. Kurosawa³, H. Oana¹, and M. Washizu¹
¹University of Tokyo, JAPAN, ²Kyoto University, JAPAN, and ³RIKEN, JAPAN

We present a technique for a bilayer tissue fabrication using a mesh culture approach which permits direct cross-layer cell-cell interaction and communication. To fabricate the bilayer, HUVECs were seeded directly atop a preformed fibroblast layer on a suspended mesh and allowed to spread and form a monolayer. Micro-vessel formation by HUVECs and a gradual thickening of fibroblast layer occurred after continued culture, demonstrating fibrosis-like reaction resulting from cross-layer interaction.

Session T4B
Gas Sensors I
ROOM 301B
16:00 - 17:45

- T4B.001 LIQUID-ON-BEAM STRUCTURE FOR GAS SENSING** 297
M.-D. Nguyen¹, K. Matsumoto², and I. Shimoyama¹
¹University of Tokyo, JAPAN and ²Toyo University, JAPAN

This paper reports an approach for gas sensing, using liquid-on-beam structure. The key here is the beam was designed at the interface of liquid and air. Consider gas molecules adhere to the upper surface of liquid, the liquid's surface tension changes, resulting in the deformation of the beam. Since a small amount of gas molecule adhesion to the liquid surface can change the surface tension, this sensing method is supposed to be fast and sensitive.

- T4B.002 STATIC AND DYNAMIC OPERATION OF METAL-COATED HYDROGEL CANTILEVER HUMIDITY SENSORS BASED ON HYGROSCOPIC MISMATCH** 300
S. Kim¹, B. Lee¹, Y. Yoon¹, T. Thundat², and J. Lee¹
¹Sogang University, KOREA and ²University of Alberta, CANADA

We fabricate metal-hydrogel composite cantilevers, thin metal layer (150-nm copper) on two orders of magnitude thicker hydrogel (10- μ m polyethyleneglycol diacrylate; PEGDA), to explore static and dynamic operation of metal-coated hydrogel cantilever humidity sensors based on hygroscopic mismatch up to the relative humidity of 40% for the first time.

- T4B.003 Ni₂(dobdc) MOF (METAL-ORGANIC FRAMEWORK) NANOCRYSTALS FOR ULTRA-SENSITIVE DETECTION OF ppb-LEVEL CO WITH RESONANT-CANTILEVER** 303
Y. Lv, T. Xu, P. Xu, H. Yu, and X. Li
Chinese Academy of Sciences, CHINA

MOF (metal-organic framework) material of Ni₂(dobdc) nanocrystals is explored as resonant-gravimetric sensing material for CO detection. Due to the ultra-high surface-area and the active metal center-sites, the MOF of Ni₂(dobdc) exhibits adsorbing induced high-performance sensing to CO gas. By loading the MOF material onto resonant microcantilever, the gravimetric sensor has experimentally exhibited response to 80ppb CO, which indicates an extremely-high sensitivity.

- T4B.004 FABRICATION AND CHARACTERIZATION OF VOC SENSORS BASED ON SUSPENDED ZINC OXIDE NANORODS FUNCTIONALIZED BY COBALT PORPHYRIN** 307
K. Lee, D.-H. Baek, and J. Kim
Yonsei University, KOREA

We report volatile organic compound (VOC) sensors based on suspended zinc oxide nanorods (ZnONRs) functionalized by cobalt porphyrin (CoPP) as sensing material. The ZnONRs are synthesized between two facing micro-bridges to form a two-terminal device. The ZnONRs are designed to be suspended well above the substrate for better exposure to and adsorption of VOC molecules to enhance sensitivity. Both of the two bridges serve as micro-heaters to increase the temperature of ZnONRs.

- T4B.005 INVESTIGATION OF PD-CU-SI METALLIC GLASS FILM FOR HYSTERESIS-FREE AND FAST RESPONSE CAPACITIVE MEMS HYDROGEN SENSORS** 311
Y. Hayashi, H. Yamazaki, D. Ono, K. Masunishi, and T. Ikehashi
Toshiba Corporation, JAPAN

We show that PdCuSi metallic glass (MG) is a promising material for Pd-based capacitive MEMS hydrogen sensors, reducing both hysteresis and response time of the sensing operation. Firstly, we show that the fabricated PdCuSi MG film exhibits no hysteresis during hydrogen absorption and desorption. Drastic reduction of the response time is also shown. Secondly, based on the measured strain property, we show that the capacitive sensing scheme has advantage in sensing low concentration hydrogen.

- T4B.006 A SINGLE-WIRE LARGE-AREA FILAMENT EMITTER FOR SPECTROSCOPIC ETHANOL GAS SENSING FABRICATED USING A WIRE BONDING TOOL** 315
S. Schröder^{1,2}, H. Rödjegård², G. Stemme¹, and F. Niklaus¹
¹KTH Royal Institute of Technology, SWEDEN and ²SenseAir AB, SWEDEN

We present the first filament-based single-wire infrared (IR) emitter for non-dispersive infrared gas sensors using advanced wire bonding technology. Our approach offers the prospect for fully automated assembly of a single emitter filament on a silicon substrate. The fabricated IR emitter utilizes a filament made of Kanthal with high thermal stability and superior emitting properties under atmospheric conditions. Our approach enables the realization of low-cost and high performance IR emitters.

- T4B.007 NANOSCALE EASY TEAR PROCESS FOR ULTRA-FAST RESPONSIVE COLLOIDAL CRYSTAL-PDMS COMPOSITE VOCs SENSORS** 319
H.K. Chang¹, A.K. Thokchom², T. Kim², and J. Park¹
¹Sogang University, KOREA and ²Ulsan National Institute of Science & Technology (UNIST), KOREA

In this paper, the ultra-fast responsive colorimetric Volatile organic compounds (VOCs) sensor was developed through nanoscale easy tear process upon colloidal crystal (CC), allowing direct contact with analytes. The proposed device shows the superior performance compared to previous work, and is expected to have a great potential for easy, intuitional, real-time and on-site monitoring for environments.

Session T4C Stretchables & Wearables

ROOM 304A

16:00 - 17:45

T4C.001 FLEXIBLE HAPTIC DISPLAY WITH 768 INDEPENDENTLY CONTROLLABLE SHAPE MEMORY POLYMERS TAXELS 323

N. Besse, J.J. Zárate, S. Rosset, and H.R. Shea
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We report a high-resolution flexible haptic display with 768 (32×24) individually addressable taxels designed for wearable and VR applications. The device integrates a thin Shape Memory Polymer membrane with one compliant heaters per taxel, a flexible PCB, and a stretchable pneumatic chamber. The actuator yield is 99 % with an average displacement of 275 μm and with 225 mN holding force. One line can be reconfigured and latched in 2.5 s; the entire array can be refreshed in under 1 min.

T4C.002 DYNAMIC STRAIN DISTRIBUTION SENSOR SHEET BASED ON ULTRA-THIN PZT/SI ARRAY ON FLEXIBLE SUBSTRATE FOR BRIDGE MONITORING WIRELESS SENSOR NETWORK 327

T. Kobayashi¹, T. Yamashita¹, K. Togashi², R. Oohigashi², H. Okada¹, T. Takeshita¹, S. Takamatsu³, and T. Itoh³
¹National Institute of Advanced Industrial Science and Technology (AIST), JAPAN, ²Dai Nippon Printing Co. Ltd, JAPAN, and ³University of Tokyo, JAPAN

We have developed dynamic strain distribution sensor sheet using FPC with 5×5 MEMS-based ultra-thin PZT/Si array. The sensor sheets equipped with signal processing and wireless communication module were attached on stainless plate and partly cracked concrete of actual bridge. In both case, the output voltage from the PZT/Si on the crack is 3-5 times larger than that on the smooth surface. The resultant mapping images of dynamic strain distribution have shown anomaly at the cracked site.

T4C.003 WITHDRAWN

T4C.004 FOLDABLE PAPER ELECTRONICS BY DIRECT-WRITE LASER PATTERNING 335

B. Li¹, Y. Chu^{1,2}, X. Zang¹, M. Wei¹, H. Liu^{1,2}, Y. Liu^{1,2}, Y. Ma¹, C. Li¹, X. Wang², and L. Lin^{1,2}
¹University of California, Berkeley, USA and ²Tsinghua-Berkeley Shenzhen Institute, CHINA

Foldable paper electronics are fabricated with direct write laser patterning. As fabricated paper electronics inherit the microfiber network from paper and also have nanoscale pores and 2D metal carbide flakes generated due to laser ablation. This hierarchy structure guarantees the intrinsic advantages of this material as sensors and capacitors which need large specific area. As a preliminary demonstration, we show a wireless paper-based moisture sensor and supercapacitor in this paper.

T4C.005 STRETCHABLE SMART PATCH: SERPENTINE NETWORK CONNECTED FUNCTIONAL NODE ARRAY WITH ENHANCED ACOUSTIC EMISSION DETECTABILITY AND THERMO-ACTIVATED DRUG DELIVERY FUNCTIONS 339

G.-H. Feng and W.-M. Tseng
National Chung Cheng University, TAIWAN

We develop a multifunctional and stretchable smart patch. This patch contains the piezoelectric node array for sensing acoustic emission (AE) wave and thermally activated PNIPAM nodes for delivering drug. The PZT sensing node array is realized with an electrically-connected serpentine network which allows the node array to stretch in an arbitrary planar direction. The normal force of AE detection head coupling to the sensing object can be enhanced while the patch is stretched.

T4C.006 TEXTURE MEASUREMENT FOR FABRICS INCLUDING WARM/COOL AND FLUFFINESS SENSATION BY MULTIMODAL MEMS SENSOR 343

F. Sato¹, T. Shiwa¹, K. Takahashi¹, T. Abe¹, M. Okuyama², H. Noma³, and M. Sohagawa¹
¹Niigata University, JAPAN, ²Osaka University, JAPAN, and ³Ritsumeikan University, JAPAN

The developed multimodal MEMS sensor can detect force as resistance change of the strain gauge on the micro-cantilever of the sensor, light as impedance change of the Si layer by the photoconductive effect and temperature drop by heat transfer from the sensor to the contact object as resistance and impedance change of the sensor. It is demonstrated that the texture features of fabrics including tactile and visual, in addition, warm/cool sensation can be characterized by a single MEMS sensor.

T4C.007 EPIDERMAL WIRELESS SENSORS ON RELEASABLE FILMS FOR BIOPHYSICAL SIGNAL MEASUREMENT ON FACIAL AREAS 347

W. Dai¹, A. Kankipati², X. Yu², B. Mahajan², H. Pan², and X. Huang¹
¹Tianjin University, CHINA and ²Missouri University of Science and Technology, USA

We develop an ultrathin, stretchable device capable of soft lamination onto skin by a releasable film for wireless determination of biophysiological signals such as skin biopotential, strain, and acceleration. The entire system allows comprehensive sleep evaluation to enable highly individualized treatment plans for patients with sleep disorders.

Session T4D Energy Harvesters

ROOM 304B

16:00 - 17:45

- T4D.001 MAGNETICALLY DRIVEN ENERGY-HARVESTER WITH MONOLITHICALLY INTEGRATED HIGH-ENERGY-DENSITY MAGNETS 351**
 F. Lofink¹, V. Tolstrup¹, T. Lisec¹, T. Reimer¹, A. Piorra², D. Meyners², E. Quandt², and B. Wagner¹
¹Fraunhofer Institute for Silicon Technology (ISIT), GERMANY and ²Christian-Albrechts-University of Kiel, GERMANY

This paper presents the first piezoelectric MEMS energy-harvester with monolithically integrated fully back-end-of-line compatible high-energy-density magnets. At resonance a power output of several ten μW is reported which is by orders of magnitude higher than state-of-the-art magnetic MEMS harvesters. In addition, by the combination of high energy density and large volume in our micromagnets our devices have a high surface-normalized power output of about $40 \mu\text{W}/\text{mm}^2$.

- T4D.002 ELECTRET BASED MICRO ENERGY HARVESTING DEVICE WITH BOTH BROAD BANDWIDTH AND HIGH POWER DENSITY FROM OPTIMAL AIR DAMPING 355**
 Y. Zhang¹, Y. Hu¹, S. Chen¹, Z. Peng¹, X. Li², and F. Wang¹
¹Southern University of Science and Technology, CHINA and ²Shanghai Institute of Microsystem and Information Technology, CHINA

We have demonstrated an electret based energy harvester with both broad bandwidth and high normalized power density. MEMS fabrication process is proposed with detailed study on the packaging pressure and air damping effect. Bandwidth of 12Hz and NPD of 14.1 mWcm⁻³g⁻² are achieved, which outperforms most of the previous harvesters. The excellent overall performance gives promising application for random sources and multi-devices stack for wireless sensing.

- T4D.003 OPTICALLY-DRIVEN GAS GENERATOR BY PHOTOVOLTAIC ASSISTED PHOTOELECTROLYSIS USING SE/TiO₂ HETEROJUNCTION STRUCTURE 359**
 T. Kobayashi and S. Konishi
 Ritsumeikan University, JAPAN

We propose an optically-driven gas generator by integration of thin-film photoelectrochemical cell (PEC) and heterojunction photovoltaic cell (PV). A Se/TiO₂ PV can supply its open circuit voltage to a TiO₂-Pt PEC for accelerating photoelectrolysis. Since TiO₂/ITO layers can be used as common materials for both PEC and PV devices, our gas generator is applicable to on-chip integration. Configuration by only thin-film materials allows material-restriction-free integration in terms of substrate.

- T4D.004 ELECTRET MATERIALS FOR ENHANCED PERFORMANCE OF TRIBOELECTRIC ENERGY SCAVENGING FROM WIND FLOW 363**
 Y. Wu¹, Z. Huang¹, Y. Hu¹, Z. Peng¹, X. Li², and F. Wang¹
¹Southern University of Science and Technology, CHINA and ²Shanghai Institute of Microsystem and Information Technology, CHINA

This paper reports the application of electret materials on triboelectric generator for enhanced performance comparing to the traditional nanogenerator simply based on contact electrification. Various electrets like PTFE film, CYTOP and TOPAS, COC were prepared and charged under different conditions to explore the optimal choice.

- T4D.005 A SELF-POWERED WIRELESS SENSING NODE FOR AMBIENT VIBRATION PATTERN IDENTIFICATION BY USING A HYBRID ENERGY-HARVESTING MODE 367**
 Q.S. He^{1,2}, C. Dong³, K.L. Li^{1,4}, J.C. Wang^{1,2}, D.C. Xu³, and X.X. Li^{1,2}
¹Chinese Academy of Sciences, CHINA, ²University of Chinese Academy of Sciences, CHINA, ³Soochow University, CHINA, and ⁴Shanghai Normal University, CHINA

We propose a novel self-powered wireless-sensing-node for vibration-type distinguishable environment monitoring by using a hybrid energy-harvesting mode. The smart energy harvester has vibration-threshold triggered electricity-generating function. Two such harvesters with different vibration-thresholds are used to distinguish the vibration caused by weak shake or strong knock. Moreover, electromagnetic harvesters are also used to generate more electric-power for transmitting the alarm-signal.

- T4D.006 WITHDRAWN**

- T4D.007 A WRIST-WORN ROTATIONAL ENERGY HARVESTER UTILIZING MAGNETICALLY PLUCKED {001} ORIENTED BIMORPH PZT THIN-FILM BEAMS 375**
 T. Xue¹, H.G. Yeo², S. Trolrier-McKinstry², and S. Roundy¹
¹University of Utah, USA and ²Pennsylvania State University, USA

We design, fabricate and characterize a wrist-worn eccentric rotor-based energy harvester utilizing multiple magnetically plucked flower petal-shape bimorph PZT thin-film beams. The bimorph beam is formed by depositing {001} oriented PZT films on both sides of a 50 μm thick Nickel foil. The films were grown up to 5.5 μm per layer by high temperature sputtering. The prototype achieves approximately 40 μW power output from a benchtop pseudo walking motion input.

8:00

Registration

Session W1A
Eye

Session W1B
CMOS

Session W1C
Fabrication I

Session W1D
Resonant MEMS I

ROOM 301A

ROOM 301B

ROOM 304A

ROOM 304B

Session Co-Chairs:

S. Wahl
Universitz of Tübingen, GERMANY

Session Co-Chairs:

N. Barnio, *Universitat Autònoma de Barcelona, SPAIN*

M. Wong, *Hong Kong University of Science and Technology, HONG KONG*

Session Co-Chairs:

V.J. Cadarso, *Monash University, AUSTRALIA*

F. Niklaus, *KTH Royal Institute of Technology, SWEDEN*

Session Co-Chairs:

V. Kaajakari
Murata Electronics, USA

A. Lal
Cornell University, USA

8:30 - 9:00

W1A.001
INVITED SPEAKER
MEMS ENABLED
TECHNOLOGIES FOR OCULAR
MONITORING AND THERAPY

W1B.001
INVITED SPEAKER
MICROSCALE SYSTEMS
BASED ON ULTRASONIC
MEMS - CMOS INTEGRATION

W1C.001
INVITED SPEAKER
HIGH THROUGHPUT
LITHOGRAPHY USING
THERMAL SCANNING
PROBES

W1D.001
INVITED SPEAKER
ENGINEERING HIGH Q-FACTOR
MEMS RESONATORS AND
PROBING LOSSES

9:00 - 9:15

W1A.002
IN SITU ACOUSTOMAGNETIC
INTERROGATION OF A
GLAUCOMA VALVE WITH
INTEGRATED WIRELESS
MICROACTUATOR

W1B.002
12 INCH MEMS PROCESS FOR
SENSORS IMPLEMENTATION
AND INTEGRATION

W1C.002
NARROW FOOTPRINT
COPPER SEALING RINGS FOR
LOW-TEMPERATURE HERMETIC
WAFER-LEVEL PACKAGING

W1D.002
P-TYPE SILICON NANOGAUGE
BASED SELF-SUSTAINED
OSCILLATOR

9:15 - 9:30

W1A.003
BLACK-SILICON AS A
MULTIFUNCTIONAL MATERIAL
FOR MEDICAL IMPLANTS:
FIRST DEMONSTRATED USE
IN *IN-VIVO* INTRAOCULAR
PRESSURE SENSING

W1B.003
A LOW-COST MICRO BTU
SENSOR SYSTEM FABRICATED
BY CMOS MEMS TECHNOLOGY

W1C.003
A NOVEL TECHNOLOGY
FOR MEMS BASED ON THE
AGGLOMERATION OF POWDER
BY ATOMIC LAYER DEPOSITION

W1D.003
MAGNETO-ACOUSTIC
OSCILLATOR

9:30 - 9:45

W1A.004
FABRICATION OF RETINA
MODEL HAVING PHOTOELASTIC
PRESSURE SENSOR FOR
VITREORETINAL SURGERY
SIMULATOR

W1B.004
THREE-AXIS CMOS MEMS
INDUCTIVE ACCELEROMETER
WITH NOVEL Z-AXIS SENSING
SCHEME

W1C.004
LOW TEMPERATURE,
WAFER-LEVEL PROCESS OF
ALKALI-METAL VAPOR CELLS
FOR MICRO-FABRICATED
ATOMIC CLOCKS

W1D.004
CMOS-MEMS
THERMAL-PIEZORESISTIVE
OSCILLATORS WITH HIGH
TRANSDUCTION EFFICIENCY
FOR MASS SENSING
APPLICATIONS

9:45 - 10:00

W1A.005
IMPLANTABLE PHOTOTHERAPY
DEVICE TO TREAT DIABETIC
RETINOPATHY

W1B.005
MONOLITHIC PIEZOELECTRIC
ALUMINUM NITRIDE
MEMS-CMOS MICROPHONE

W1C.005
20 MILLIWATT CLASS
ULTRALOW POWER INTEGRATED
OCXO USING POLYIMIDE AND
THIN FILM METAL CONNECTION
SUSPENDED IN VACUUM
PACKAGING

W1D.005
CAPACITIVE SILICON
RESONATORS WITH
PIEZORESISTIVE
HEAT ENGINES

Session W1A
Eye
ROOM 301A
8:30 - 10:00

- W1A.001** **INVITED SPEAKER**
MEMS ENABLED TECHNOLOGIES FOR OCULAR MONITORING AND THERAPY **379**
E. Meng¹, E. Yoon¹, and C. Gutierrez²
¹University of Southern California, USA and ²Verily Life Sciences, USA

The healthy human eye is an exquisite collection of different cell types that collectively form an intricate optoelectro-mechanical system that shapes the final input to the visual processing areas of the brain to achieve vision. A number of different diseases affecting the eye are amenable to engineering solutions enabled by MEMS technologies. The purpose of this paper is to examine different opportunities for MEMS technologies to impact ocular health and review examples of past and current research in this field. Commercial progress is also discussed.

- W1A.002** **IN SITU ACOUSTOMAGNETIC INTERROGATION OF A GLAUCOMA VALVE WITH INTEGRATED WIRELESS MICROACTUATOR** **383**
R.M. Nambisan, S.R. Green, J.D. Stein, and Y.B. Gianchandani
University of Michigan, USA

We report the *in situ* interrogation of a magnetoelastic microactuator integrated on an Ahmed glaucoma valve. These actuators are intended for fibrosis mitigation. Acoustic detection is demonstrated, which can be applied clinically in a manner similar to ophthalmic ultrasonography. Electromagnetic excitation is used. Actuator-integrated valves are implanted *ex vivo* in porcine eyes, and the recorded acoustic signatures indicate that the magnetoelastic actuator is able to vibrate while implanted.

- W1A.003** **BLACK-SILICON AS A MULTIFUNCTIONAL MATERIAL FOR MEDICAL IMPLANTS: FIRST DEMONSTRATED USE IN *IN-VIVO* INTRAOCULAR PRESSURE SENSING** **387**
V. Narasimhan¹, J.O. Lee¹, J. Du², B. Ndjamien¹, D. Sretavan², and H. Choo¹
¹California Institute of Technology, USA and ²University of California, San Francisco, USA

We demonstrate the utilization of black-silicon as a multifunctional material integrated onto the surface of a sub-mm implantable intraocular pressure sensor through successful six-month *in-vivo* studies. Optically, the anti-reflective black-silicon boosts sensor signal-to-noise ratio and enables significant increase in readout distance to clinically viable standards. Biophysically, it acts to suppress any undesirable device fouling and inflammatory response on the sensor.

- W1A.004** **FABRICATION OF RETINA MODEL HAVING PHOTOELASTIC PRESSURE SENSOR FOR VITREORETINAL SURGERY SIMULATOR** **391**
H. Maruyama¹, M. Tsubaki¹, S. Omata¹, T. Masuda¹, K. Harada², M. Mitsuishi²,
K. Totsuka³, F. Araki³, M. Takao³, M. Aihara³, and F. Arai¹
¹Nagoya University, JAPAN, ²Tokyo University, JAPAN, and ³University of Tokyo School of Medicine, JAPAN

We proposed sensor-integrated retina model with similar Young's modulus to human retina. First, we fabricate eye ball model having retina and sclera with similar Young's modulus to human by adjusting the concentration of catalyst. Then, photoelastic coefficient of retinal model is increased by adding the carbon nanomaterial. As a demonstration, pressure distribution on retinal model was measured using the assembled retina and sclera model in skull model having polarization optical system.

- W1A.005** **IMPLANTABLE PHOTOTHERAPY DEVICE TO TREAT DIABETIC RETINOPATHY** **393**
C.A. Cook¹, J.C. Martinez-Camarillo², M.S. Humayun², and Y.-C. Tai¹
¹California Institute of Technology, USA and ²University of Southern California, USA

We report on an implantable phototherapy device to treat diabetic retinopathy by modulating rod cell metabolism. Utilizing a radioluminescent light source, the device achieves a 12-year service lifetime and <30mm³ size. The unique anchoring system facilitates simple, rapid, and robust implantation into the eye.

**Session W1B
CMOS**
ROOM 301B
8:30 - 10:00

- W1B.001** **INVITED SPEAKER**
MICROSCALE SYSTEMS BASED ON ULTRASONIC MEMS - CMOS INTEGRATION 397
F.L. Degertekin
Georgia Institute of Technology, USA

Integration of electronics with micromachined ultrasound transducers is a key promise of capacitive and piezoelectric micromachined ultrasonic transducer technologies. Recent advances leading to successful monolithic ultrasonic MEMS-CMOS integration is reviewed with a brief historical perspective. The significance of these integrated systems in terms of required performance and system complexity is emphasized using a medical ultrasound imaging application as an example. A low voltage CMUT-on-CMOS based single chip intravascular imaging system, which achieves these goals is described and initial imaging experiments are presented. A brief critical review of the current state of CMUT and PMUT technologies is presented with future research directions.

- W1B.002** **12 INCH MEMS PROCESS FOR SENSORS IMPLEMENTATION AND INTEGRATION** 402
C.-W. Cheng^{1,2}, C.-H. Chu¹, L.-M. Hung¹, and W.-L. Fang²
¹Taiwan Semiconductor Manufacturing Company, Ltd. (TSMC), TAIWAN and ²National Tsing Hua University, TAIWAN

This study presents the development of a foundry available process scheme to implement and integrate MEMS devices on 12 inch wafer for the first time. After overcome various process challenges such as etching uniformity and bonding quality, this study has successfully accomplished the bulk Si process scheme on 12-in wafer. In applications, various MEMS devices including resonators, accelerometer, and pirani gauge are implemented and integrated.

- W1B.003** **A LOW-COST MICRO BTU SENSOR SYSTEM FABRICATED BY CMOS MEMS TECHNOLOGY** 406
W. Xu¹, M. Duan¹, M. Ahmed¹, S. Mohamad¹, A. Bermak^{1,2}, and Y.-K. Lee¹
¹Hong Kong University of Science and Technology, HONG KONG and ²Hamad Bin Khalifa University, QATAR

An integrated low-cost micro BTU (μ BTU) sensor system, including a thermoresistive micro calorimetric flow (TMCF) sensor and a resistance temperature detector (RTD), is reported for the first time using a proprietary InvenSense CMOS MEMS technology integrated with a digital signal processing (DSP) unit. This μ BTU system achieves a range of 1.5~15milli-BTU/h and an accuracy <6% for potential for energy monitoring in smart buildings.

- W1B.004** **THREE-AXIS CMOS MEMS INDUCTIVE ACCELEROMETER WITH NOVEL Z-AXIS SENSING SCHEME** 410
Y. Chiu, H.-C. Hong, and C.-M. Chang
National Chiao Tung University, TAIWAN

We report a 3-axis CMOS MEMS inductive accelerometer fabricated by a 0.18 μ m CMOS process. The folded suspension beams around the single shuttle mass function as springs and inductor windings simultaneously. The shuttle mass displacement causes spring deformation and winding inductance variation which is sensed by LC-tank oscillators. A novel z-axis inductive sensing scheme is proposed. Experiments showed sensitivities of 12.9, 21.6, and 1.2 kHz/g in the x, y, and z axes, respectively.

- W1B.005** **MONOLITHIC PIEZOELECTRIC ALUMINUM NITRIDE MEMS-CMOS MICROPHONE** 414
J. Segovia-Fernandez¹, S. Sonmezoglu¹, S.T. Block¹, Y. Kusano¹, J.M. Tsai², R. Amirtharajah¹, and D.A. Horsley¹
¹University of California, Davis, USA and ²InvenSense Inc., USA

A monolithic AlN MEMS-CMOS microphone is developed in this work to target high-sensitivity, low-power applications. The MEMS microphone, which is attached to a 0.18 μ m CMOS buffer by wafer-scale eutectic bonding, consists of a circular-shaped AlN-SiO₂ unimorph membrane of 800 μ m radius and an optimized 15% electrode coverage layout. In this work, the piezo-microphone provides with an off-resonance sensitivity of 0.75mV/Pa, a resonance frequency of 11kHz and a floor noise of 0.03 μ V/Hz.

Session W1C
Fabrication I
ROOM 304A
8:30 - 10:00

- W1C.001 INVITED SPEAKER**
HIGH THROUGHPUT LITHOGRAPHY USING THERMAL SCANNING PROBES 418
C. Rawlings¹, M. Spieser², C. Schwemmer¹, T.S. Kulmala², Y.K.R. Cho¹,
 S. Bonanni², U. Duerig¹, P. Paul², and A.W. Knoll¹
¹IBM Research, SWITZERLAND and ²SwissLitho AG, SWITZERLAND

Thermal scanning probe lithography (t-SPL) has demonstrated unique capabilities for maskless lithography. A heated atomic force microscope tip is used to locally remove a thermally sensitive resist. This process is able to fabricate precise 3D patterns and high resolution structures without the use of charged particles, such as electrons, which have been implicated in substrate damage. Here we outline our work to improve the automation of the tool using model based control, so-called "closed loop lithography". We will also describe our integration of a laser writer into the tool to enable high throughput mix and match lithography. Finally we will outline our work on the implementation of fully integrated cantilever arrays, which can operate in parallel and on insulating substrates.

- W1C.002 NARROW FOOTPRINT COPPER SEALING RINGS FOR LOW-TEMPERATURE**
HERMETIC WAFER-LEVEL PACKAGING 423
 X. Wang¹, S.J. Bleiker¹, M. Antelius², G. Stemme¹, and F. Niklaus¹
¹KTH Royal Institute of Technology, SWEDEN and ²APR Technologies AB, SWEDEN

We report a narrow footprint sealing ring design for low-temperature and mechanically stable wafer-level hermetic packaging. Copper sealing rings that are as narrow as 8 μm successfully seal the enclosed cavities during wafer bonding at 250 °C. Different sealing ring structures are evaluated and demonstrate excellent hermeticity after 3 months of storage in ambient atmosphere. A leak rate of lower than 3.6E-16 mbarL/s is deduced based on results from residual gas analysis.

- W1C.003 A NOVEL TECHNOLOGY FOR MEMS BASED ON THE AGGLOMERATION OF POWDER**
BY ATOMIC LAYER DEPOSITION 427
 T. Lisec¹, S. Chemnitz², F. Lofink¹, T. Reimer², A. Kulkarni¹, G. Piechotta¹, and B. Wagner¹
¹Fraunhofer Institute for Silicon Technology (ISIT), GERMANY and ²Christian Albrechts University of Kiel, GERMANY

A novel fabrication technique for MEMS, based on the agglomeration of micron-sized powder into rigid, three-dimensional, porous structures by means of atomic layer deposition, is described. The structures are thermally and mechanically robust and allow further processing of such substrates in a cleanroom environment. The new technique not only extends the variety of materials suitable for MEMS dramatically. Certain porosity and a large inner surface can be obtained in a simple manner.

- W1C.004 LOW TEMPERATURE, WAFER-LEVEL PROCESS OF ALKALI-METAL VAPOR CELLS**
FOR MICRO-FABRICATED ATOMIC CLOCKS 431
 Y. Hirai, K. Terashima, K. Nakamura, T. Tsuchiya, and O. Tabata
 Kyoto University, JAPAN

We propose a low-temperature process of alkali-metal vapor cells for MEMS atomic clocks using alkali-metal source tablet (AMST) as Cs-dispensers. The AMSTs consisting of CsN₃ deposited on porous alumina allow control over the production of Cs by low-temperature process, which is suitable for improving frequency stability of atomic clocks. The cell fabricated via a combination of optimum AMST parameters and sequential plasma activated Si/glass bonding achieve the highest short-term stability.

- W1C.005 20 MILLIWATT CLASS ULTRALOW POWER INTEGRATED OCXO USING POLYIMIDE**
AND THIN FILM METAL CONNECTION SUSPENDED IN VACUUM PACKAGING 435
 T. Suzuki¹, M. Muroyama¹, T. Taira², N. Kimura², T. Tsukamoto¹, and S. Tanaka¹
¹Tohoku University, JAPAN and ²Nihon Dempa Kogyo Co., Ltd., JAPAN

This paper proposes a 20mW class low-power and miniaturized oven controlled crystal oscillator (OCXO) by combination of the following two methods. 1) A crystal resonator and a CMOS-LSI for oscillation and oven control circuits are integrated for realizing an integrated OCXO chip. 2) The integrated chip is connected with thin film metal interconnection on a thin polyimide film and is suspended by an ultrasonic bonding technique in vacuum packaging for thermal isolation.

Session W1D Resonant MEMS I

ROOM 304B

8:30 - 10:00

- W1D.001 INVITED SPEAKER**
ENGINEERING HIGH Q-FACTOR MEMS RESONATORS AND PROBING LOSSES 439
J.E.-Y. Lee
City University of Hong Kong, HONG KONG

The quality factor (Q) a resonator is critical to its performance be it in the context of an oscillator, filter or sensor. While well-designed monocrystalline silicon resonators can have Qs on par with quartz, they compare much less favorably on electromechanical coupling efficiency. Piezoelectric on silicon resonators combine the merits of piezoelectric transduction with the excellent mechanical properties of monocrystalline silicon, yet their quality factors fall well short of material limits. The exact nature and mechanisms of losses is not entire clearly. This talk will describe research findings on underlying losses and efforts to enhance quality factors in piezoelectric on silicon resonators.

- W1D.002 P-TYPE SILICON NANOGAUGE BASED SELF-SUSTAINED OSCILLATOR** 444
 G. Lehee¹, R. Anciant^{2,3}, F. Souchon^{2,3}, A. Berthelot^{2,3}, P. Rey^{2,3}, and G. Jourdan^{2,3}
¹Safran Tech, FRANCE, ²University Grenoble, FRANCE, and ³CEA-LETI, FRANCE

We demonstrate the first system using P-doped silicon nanogauges as Thermal Piezoresistive actuators under DC-voltage bias. It allows to increase a resonator quality factor to millions for small DC-voltages, and even achieve self-sustained behavior with low power consumption. Thanks to experimental results fitting to theoretical model, major contribution to this effect is attributed to the nanogauges thermal time constant, thus allowing to envision improvement levers.

- W1D.003 MAGNETO-ACOUSTIC OSCILLATOR** 448
 T.A. Gosavi¹ and S.A. Bhawe²
¹Cornell University, USA and ²Purdue University, USA

We demonstrate a hybrid oscillator system that combines the tunability of spin torque oscillators (STOs) with the high quality factor (Q) of a high overtone bulk acoustic resonator (HBAR) in 2-chip system. The demonstrated that the Magneto-Acoustic oscillator (MAO) has tuning range of 6% at 4GHz with 175 kHz linewidth. When compared to STOs we get a 200X reduction in linewidth, while retaining the original frequency tuning range of the STO.

- W1D.004 CMOS-MEMS THERMAL-PIEZORESISTIVE OSCILLATORS WITH HIGH TRANSDUCTION EFFICIENCY FOR MASS SENSING APPLICATIONS** 452
 T.-Y. Liu, C.-C. Chu, M.-H. Li, C.-Y. Liu, C.-Y. Lo, and S.-S. Li
National Tsing Hua University, TAIWAN

The butterfly shaped design utilizing CMOS-MEMS thermal-piezoresistive resonator (TPR) was demonstrated in this work. The motional transconductance reaches record-high values both in vacuum (118.4 $\mu\text{A/V}$) and air (16.96 $\mu\text{A/V}$) among all reported CMOS-MEMS and SOI TPRs. To verify its mass sensing capability, a pico-liter ink jet printing setup was used to demonstrate not only the real time response but also stable frequency shifts with sensitivity of 1.946 Hz/pg.

- W1D.005 CAPACITIVE SILICON RESONATORS WITH PIEZORESISTIVE HEAT ENGINES** 456
 N.V. Toan, N.V. Nha, and T. Ono
Tohoku University, JAPAN

This work reports the design, fabrication, and evaluation of capacitive silicon resonators with piezoresistive heat engines. A combination of capacitive transduction and piezoresistive actuation based on a piezoresistive heat engine in the single micromechanical resonator is proposed to achieve a low insertion loss and small motional resistance. Capacitive silicon resonators with single and multiple piezoresistive beams have been demonstrated.

10:00 - 10:30 Break and Exhibit Inspection

Session W2A Physical Bio-Sensing	Session W2B Microfluidics I	Session W2C Tactile	Session W2D Resonant MEMS II
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: C.-H. Liu, <i>National Tsing Hua University, TAIWAN</i> H. Takao <i>Kagawa University, JAPAN</i>	Session Co-Chairs: Y.-K. Lee, <i>Hong Kong University of Science and Technology, HONG KONG</i> N. Tas <i>University of Twente, NETHERLANDS</i>	Session Co-Chairs: A. Dietzel, <i>Technische Universität Braunschweig, GERMANY</i> C. Rawlings <i>IBM Research, SWITZERLAND</i>	Session Co-Chairs: S. Gong, <i>University of Illinois, Urbana Champaign, USA</i> P. Feng, <i>Case Western Reserve University, USA</i>
10:30 - 10:45			
W2A.001 LOCAL MAGNETIZATION AND SENSING OF FLEXIBLE MAGNETIC TAG FOR LONG-TERM MONITORING UNDER WET ENVIRONMENT	W2B.001 A MICROFLUIDIC DEVICE FOR ELECTRONIC CELL SURFACE EXPRESSION PROFILING USING MAGNETOPHORESIS	W2C.001 FULLY-INTEGRATED, FULLY-DIFFERENTIAL 3-AXIS TACTILE SENSOR ON PLATFORM LSI WITH TSV-BASED SURFACE-MOUNTABLE STRUCTURE	W2D.001 MEMS RELIABILITY STUDY IN SHOCK ENVIRONMENTS THROUGH NUMERICAL AND EXPERIMENTAL INVESTIGATIONS
10:45 - 11:00			
W2A.002 WITHDRAWN	W2B.002 DIELECTROPHORESIS ENRICHMENT WITH BUILT-IN CAPACITIVE SENSOR MICROFLUIDIC PLATFORM FOR TUMOR RARE CELL DETECTION	W2C.002 CAPACITIVE TACTILE SENSOR FOR QUADRUPLD SPATIAL RESOLUTION	W2D.002 MICROMACHINED INTEGRATED SHOCK PROTECTION VIA A SELF-ADAPTIVE NONLINEAR SYSTEM
11:00 - 11:15			
W2A.003 SERS DETECTION AND ANALYSIS OF A SINGLE DNA OLIGOMER USING A SINGLE GOLD NANOPARTICLE DIMER	W2B.003 THE CAPILLARY NUMBER EFFECT ON CELL VIABILITY IN MICROFLUIDIC ELASTO-FILTRATION DEVICES FOR VIABLE CIRCULATING TUMOR CELL ISOLATION	W2C.003 HIGH PERFORMANCE FLEXIBLE TACTILE SENSOR ARRAY USING A LARGE AREA PLASTIC NANO-GRATING SUBSTRATE	W2D.003 A QUALITATIVE TECHNIQUE TO STUDY STABILITY AND DYNAMICS OF MICRO-MACHINED INDUCTIVE CONTACTLESS SUSPENSIONS
11:15 - 11:30			
W2A.004 A MULTI-FUNCTIONALLY OPTOELECTRIC PLATFORM FOR MICRO/NANO PARTICLE MANIPULATION AND APPLICATIONS	W2B.004 A MICROFLUIDIC SENSOR FOR EVALUATION OF SOLUTE AND SOLVENT MEMBRANE PERMEABILITY IN INDIVIDUAL CELLS	W2C.004 ULTRASONIC TACTILE SENSOR INTEGRATED WITH TFT ARRAY FOR CONTACT FORCE MEASUREMENTS	W2D.004 A NOVEL HONEYCOMB-LIKE DISK RESONANT GYROSCOPE
11:30 - 11:45			
W2A.005 FABRY-PEROT INTERFEROMETRIC SURFACE-STRESS SENSOR WITH HIGH WAVELENGTH SELECTIVITY FOR LABEL-FREE BIOSENSING	W2B.005 MICROFLUIDIC DELIVERY OF GENOME-EDITING MATERIALS INTO iPS-CARDIOMYOCYTES USING SYNERGISTIC ELECTROPORATION AND SHEAR STRESS	W2C.005 CMOS-ON-LTCC INTEGRATED FINGERTIP SENSOR WITH 3-AXIS TACTILE AND THERMAL SENSATION FOR ROBOTS	W2D.005 A 0.5MHZ MODE-MATCHED PITCH OR ROLL ANNULUS GYROSCOPE WITH NANO-GAP SLANTED ELECTRODES FOR QUADRATURE CANCELLATION

Session W2A
Physical Bio-Sensing
ROOM 301A
10:30 - 11:45

- W2A.001 LOCAL MAGNETIZATION AND SENSING OF FLEXIBLE MAGNETIC TAG FOR LONG-TERM MONITORING UNDER WET ENVIRONMENT** 460
 Y. Yamanishi¹, D. Matsumura¹, Y. Fujiwara², T. Ohgawara³, and Y. Haramoto⁴
¹Kyushu University, JAPAN, ²Shibaura Institute of Technology, JAPAN, ³BOYLE Co. Ltd., JAPAN, and
⁴National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

We have successfully fabricated and installed flexible magnetic tag which has about 9 bits information to biological material in limited space under wet environment. The magnetizing of tag use focusing of magnetic field based on the magnetic circuit using high magnetic permeability material. Fundamental test show the signal can be discriminated even 30 days after injection of magnetic tag. This study contribute to the long-term monitoring of biomaterials under wet environment.

W2A.002 WITHDRAWN

- W2A.003 SERS DETECTION AND ANALYSIS OF A SINGLE DNA OLIGOMER USING A SINGLE GOLD NANOPARTICLE DIMER** 468
 K. Maruoka, K. Sugano, and Y. Isono
 Kobe University, JAPAN

This paper reports surface enhanced Raman spectroscopy (SERS) detection and analysis of a single DNA oligomer toward SERS-based reliable DNA sequencing using a single gold nanoparticle dimer. Thanks to the Raman enhancing hotspot with 1-nm nanogap between particles in a single dimer, we achieved identification of DNA bases with single-molecule sensitivity, and motion analysis of a single-DNA oligomer according to the transition of Raman intensity from each component.

- W2A.004 A MULTI-FUNCTIONALLY OPTOELECTRIC PLATFORM FOR MICRO/NANO PARTICLE MANIPULATION AND APPLICATIONS** 472
 H.S. Chuang, H.N. Lin, and D.B. Shieh
 National Cheng Kung University, TAIWAN

This paper presents a simple optoelectrokinetic method for manipulating particles by simultaneously inducing electrohydrodynamic flow and electrokinetic motion. Multiple manipulation capabilities including aggregation, translation, sorting, and patterning were achieved. In combination with bead-based immunoassays, we successfully performed signal enhancement and achieved simultaneous detection of dual biomarkers.

- W2A.005 FABRY-PEROT INTERFEROMETRIC SURFACE-STRESS SENSOR WITH HIGH WAVELENGTH SELECTIVITY FOR LABEL-FREE BIOSENSING** 476
 T. Takahashi¹, T. Hizawa¹, N. Misawa², M. Taki¹, K. Sawada¹, and K. Takahashi^{1,3}
¹Toyohashi University of Technology, JAPAN, ²Kanagawa Academy of Science and Technology, JAPAN, and
³Japan Science and Technology Agency (JST), JAPAN

We developed a MEMS Fabry-Perot interferometer with high wavelength selectivity by using Au half-mirrors for a highly sensitive label-free biosensor. By integrating 50-nm-thick Au half-mirrors, wavelength selectivity improved to be 5.2 times. Besides we successfully demonstrated spectral shift of 40 nm caused by membrane deflection due to the immobilization of BSA antibody on the sensor.

Session W2B
Microfluidics I
ROOM 301B
10:30 - 11:45

- W2B.001 A MICROFLUIDIC DEVICE FOR ELECTRONIC CELL SURFACE EXPRESSION PROFILING USING MAGNETOPHORESIS 480**
O. Civelekoglu, R. Liu, M. Boya, C.-H. Chu, N. Wang, and A.F. Sarioglu
Georgia Institute of Technology, USA

We introduce a microfluidic device that utilizes free-flow magnetophoresis to electronically profile the target surface antigen density in a cell population, offering a low-cost alternative to fluorescence activated cell sorter. The device couples magnetophoretic cell sorting with code multiplexed electronic sensors to quantify the spatial mapping of cells. As magnetic load is correlated with the cell's surface expression, we can use our sensor data to determine surface antigen expression.

- W2B.002 DIELECTROPHORESIS ENRICHMENT WITH BUILT-IN CAPACITIVE SENSOR MICROFLUIDIC PLATFORM FOR TUMOR RARE CELL DETECTION 484**
L.D. Quang¹, T.T. Bui², T.V. Quoc³, L.P. Thanh¹, H.T.T. Thuy⁴, V.T. Dau⁵, C.-P. Jen⁶, and T.C. Duc²
¹*Vietnam National University of Science, VIETNAM*, ²*Vietnam National University, VIETNAM*,
³*Vietnam Academy of Science and Technology, VIETNAM*,
⁴*Posts and Telecommunications Institute of Technology, VIETNAM*,
⁵*Sumitomo Chemical. Ltd, JAPAN*, and ⁶*National Chung Cheng University, TAIWAN*

We present a dielectrophoresis (DEP) enrichment microfluidic platform with built-in antibody-based capacitive sensor for tumor rare cells detection. We take the advantages of the effective DEP actuation, and the high sensitivity of differential capacitive sensing for quantitatively reading out, to produce advanced platform, toward single tumor cell detection for the rapid laboratory tests of cancers diagnoses and other metabolic diseases applications.

- W2B.003 THE CAPILLARY NUMBER EFFECT ON CELL VIABILITY IN MICROFLUIDIC ELASTO-FILTRATION DEVICES FOR VIABLE CIRCULATING TUMOR CELL ISOLATION 488**
C. Zhao¹, W. Ma³, X. Yu³, H. Su³, Z. Zhang³, Y. Zohar⁴, and Y.-K. Lee^{1,2}
¹*Hong Kong University of Science and Technology, HONG KONG*,
²*Sun Yat-sun University Cancer Center, CHINA*, and ³*University of Arizona, USA*

This paper reports a systematic study of the Capillary number (Ca) effect on cell viability in Microfluidic Elasto-Filtration (MEF) devices for ex vivo circulating tumor cell (CTC) isolation. CTC viability decreases with increasing Ca because of the higher hydrodynamic shear stress. A complete design rule for MEF chip is proposed, yielding 92% CTC capture efficiency, 4-log WBC depletion, and 85% CTC viability at an optimized Ca.

- W2B.004 A MICROFLUIDIC SENSOR FOR EVALUATION OF SOLUTE AND SOLVENT MEMBRANE PERMEABILITY IN INDIVIDUAL CELLS 492**
L. Huang¹, J.D. Benson², and M. Almasri¹
¹*University of Missouri, USA* and ²*University of Saskatchewan, CANADA*

This paper presents design, fabrication and testing of a microfluidic sensor for real time yeast cell permeability study. The device detects volume change by measuring impedances within 0.19s after mixing with different media. We believe that these are the first reports of individual cell permeabilities using electrical impedance techniques and we anticipate that any mammalian cell type in RBC that has over 3 orders of magnitude change in volume, can be measured by our microfluidic sensor.

- W2B.005 MICROFLUIDIC DELIVERY OF GENOME-EDITING MATERIALS INTO iPS-CARDIOMYOCYTES USING SYNERGISTIC ELECTROPORATION AND SHEAR STRESS 496**
Z. Xu¹, M. Malhi², J. Maynes², and Y. Sun¹
¹*University of Toronto, CANADA*, ²*Hospital for Sick Children, CANADA*, and ³*Shanghai University, CHINA*

This paper reports a microfluidic technique that use both electroporation and mechanical shear stress to create pores complementarily along different poles on cell membrane to deliver CRISPR genome-editing components into iPS (induced pluripotent stem cells) - cardiomyocytes. Without optimization, a transfection efficiency of 11.2% was achieved (vs. the highest transfection efficiency of 5% for iPS-cardiomyocytes reported in literature).

**Session W2C
Tactile**
ROOM 304A
10:30 - 11:45
W2C.001 FULLY-INTEGRATED, FULLY-DIFFERENTIAL 3-AXIS TACTILE SENSOR ON PLATFORM LSI WITH TSV-BASED SURFACE-MOUNTABLE STRUCTURE 500

Y. Hata¹, Y. Suzuki², M. Muroyama², T. Nakayama³, Y. Nonomura¹, R. Chand², H. Hirano²,
Y. Omura¹, M. Fujiyoshi¹, and S. Tanaka²

¹Toyota Central R&D Labs., Inc., JAPAN, ²Tohoku University, JAPAN, and ³Toyota Motor Corporation, JAPAN

We present a 2.8-mm-square surface-mountable MEMS-on-LSI integrated 3-axis tactile sensor. The MEMS part has a quad-seesaw-electrode structure for fully-differential capacitive 3-axis force sensing. The signal processing LSI is an original sensor platform LSI equipped with annular type through silicon vias (TSV). The MEMS and LSI were integrated by Au-Au bonding. The working test successfully demonstrated digital packet outputs through the TSV, and fully-differential 3-axis force sensing.

W2C.002 CAPACITIVE TACTILE SENSOR FOR QUADRUPLD SPATIAL RESOLUTION 504

M. Chandra, R. Chen, and C.-Y. Lo

National Tsing Hua University, TAIWAN

Unlike conventional arrangement of capacitors in tactile sensors, this work stacked two capacitors with a shared electrode. This arrangement reduced the required projective area of the capacitors from four to one, quadrupled the spatial resolution of the tactile sensor without losing its functionality and sensitivity. Theoretical design, numerical simulation, fabrication, and analysis were thoroughly conducted in this work.

W2C.003 HIGH PERFORMANCE FLEXIBLE TACTILE SENSOR ARRAY USING A LARGE AREA PLASTIC NANO-GRATING SUBSTRATE 508

J.-Y. Yoo, M.-H. Seo, J.-S. Lee, and J.-B. Yoon

Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper firstly reports a high-performance flexible tactile-sensor array using a large-area plastic nanograting substrate. Using a large area 200 nm-pitch plastic nanograting substrate, we shows 220 % enhancement in sensitivity with <0.29 device-uniformity standard deviation. Moreover, the fabricated sensor-array shows the high-robustness against repeated bending-release (>10000 cycles) with ROC=4 mm. Finally, our fabricated sensor showed the real-time capacitance change by various pressure.

W2C.004 ULTRASONIC TACTILE SENSOR INTEGRATED WITH TFT ARRAY FOR CONTACT FORCE MEASUREMENTS 512

C.H. Chuang, H.K. Weng, J.W. Cheng, and M.O. Shaikh

Southern Taiwan University of Science and Technology, TAIWAN

In this study, we propose an ultrasonic tactile sensor integrated with a thin-film transistor (TFT) array for real time contact force measurements and high resolution identification of object shape. Based on the 2D ultrasonic image of soft microstructure deformation, the force and contact area can be measured and recognized as the force smaller than 6N. In addition, the shape recognition ability can be enhanced by increasing the density of microstructures array.

W2C.005 CMOS-ON-LTCC INTEGRATED FINGERTIP SENSOR WITH 3-AXIS TACTILE AND THERMAL SENSATION FOR ROBOTS 516

S. Asano¹, M. Muroyama¹, T. Nakayama², Y. Hata³, and S. Tanaka¹

¹Tohoku University, JAPAN, ²Toyota Motor Corporation, JAPAN, and ³Toyota Central R&D Labs., Inc., JAPAN

We report a fully-integrated, small-footprint fingertip sensor, which allows robots to have 3-axis tactile and thermal sensation. The 3-axis force sensor is integrated with a CMOS LSI including a temperature sensor. The LSI offers flexible configurability of the force sensitivity and the sample rate, and measured digital data of the integrated sensor was decoded at the host. The materials of objects were successfully identified by measuring temperature change under the control of contact force.

**Session W2D
Resonant MEMS II**
ROOM 304B
10:30 - 11:45

- W2D.001 MEMS RELIABILITY STUDY IN SHOCK ENVIRONMENTS THROUGH NUMERICAL AND EXPERIMENTAL INVESTIGATIONS** 520
 G. Lehee¹, A. Calvar-Mimica¹, T. Chantrai¹, A. Charles¹, A. Jeanroy², P. Onfroy², M. Colin^{3,4}, and A. Berthelot^{3,4}
¹Safran Tech, FRANCE, ²Safran Electronics & Defense, FRANCE, ³CEA, LETI, FRANCE, and ⁴University Grenoble, FRANCE

We report a novel method to evaluate and improve the reliability of stops during design and validation phases of MEMS devices. Nonlinear in-plane stop contact behavior is modeled using steady-state and blast FEM. MEMS transient response including stops behavior is modeled with a lumped impact element approach. Eventually, theoretical survival rate is estimated and strongly compliant with experimental shock test results, thus allowing the specification of design rules for reliability improvement.

- W2D.002 MICROMACHINED INTEGRATED SHOCK PROTECTION VIA A SELF-ADAPTIVE NONLINEAR SYSTEM** 524
 K. Xu¹, F. Jiang², Y. Zhang³, W. Zhang¹, and Y. Hao¹
¹Peking University, CHINA, ²University of California, Los Angeles, USA, and ³Hong Kong Polytechnic University, HONG KONG

This paper presents an original design of a self-adaptive nonlinear system (SANS) for shock protection of MEMS. With increasing amplitudes of shock, it realizes nonlinear growth in shock resistance. This approach enables a generic batch fabrication without additional processes or excessive area expansion. SANS has been verified to provide superior shock robustness enhancement over conventional hard stop (~2 times) and flexible spring stop (~1.5 times).

- W2D.003 A QUALITATIVE TECHNIQUE TO STUDY STABILITY AND DYNAMICS OF MICRO-MACHINED INDUCTIVE CONTACTLESS SUSPENSIONS** 528
 K.V. Poletkin¹, Z. Lu², U. Wallrabe², J.G. Korvink¹, and V. Badilita¹
¹Karlsruhe Institute of Technology, GERMANY and ²University of Freiburg, GERMANY

A qualitative technique to study dynamics and stability of micro-machined contactless inductive suspensions (MIS) is presented, which provides a powerful analytical tool for a comprehensive study of a wide range of MIS designs. The main idea for this technique is to represent the induced eddy current into a levitated micro-object as a collection of m-eddy current circuits. As a result, a generalized linear model of MIS is developed.

- W2D.004 A NOVEL HONEYCOMB-LIKE DISK RESONANT GYROSCOPE** 532
 Q. Li, D. Xiao, X. Zhou, F. Ou, Z. Hou, and X. Wu
 National University of Defense Technology, CHINA

We report the design, fabrication and characterization of a novel honeycomb-like disk resonant gyroscope. It has the same topological structure with the natural honeycomb, giving it the advantages of high space utilization ratio and excellent mechanical characteristics. Testing results show that it has about 17140Hz resonant frequency. Q-factor and decay time constant under high level vacuum condition (0.004Pa) are about 81k and 1.507s respectively.

- W2D.005 A 0.5MHZ MODE-MATCHED PITCH OR ROLL ANNULUS GYROSCOPE WITH NANO-GAP SLANTED ELECTRODES FOR QUADRATURE CANCELLATION** 536
 H. Wen, A. Daruwalla, and F. Ayazi
 Georgia Institute of Technology, USA

This paper presents, for the first time, the effective quadrature cancellation using nano-gap slanted electrodes on a fabricated high frequency pitch/roll bulk acoustic wave (BAW) gyroscope to enable perfect mode-matching for sensitivity improvement and noise reduction. The HARPSS+ fabrication process developed in this work enables high-efficiency capacitive transduction in all desired orientations, which allows simultaneous fabrication of single-chip high-performance tri-axial BAW gyroscopes.

11:45 - 14:00 Lunch and Exhibit Inspection

Industry Session - Packaging/Testing (Room 301A)
12:30 - 12:55 NEXT WAVE OF ADVANCED PACKAGING SOLUTIONS FOR RF AND PHOTONICS

Vincent Lin, Corporate R&D/Technology Development
Advanced Semiconductor Engineering (ASE), TAIWAN

When Moore's law goes slow, driving force of connectivity and cloud services are still very strong. Data growth requirement exceed the improvement speed of any kind of individual chip technology (ex: CMOS), therefore, heterogeneous integration is the solution of de-bottleneck of bandwidth. OSAT now is not only driven by the requirement of digital CMOS, but also provide solutions of emerging technologies of RF and Photonics. RF module of mobile device and Si-Photonic module of data center are the key components of two ends of cloud services platform, both of them need high speed interconnection amount chips with different materials, includes compound semiconductor, silicon and passives or special crystal. Impedance matching and lower insertion loss are the key performance index. In this presentation, we will reveal new package platforms of both RF-module and Si-Photonics module; innovated solutions are proposed to enable further miniaturization while keeping high performance and functional integration.

12:55 - 13:20 MEMS WAFER-LEVEL TEST AND WLCSP FINAL TEST: REQUIREMENTS AND SOLUTIONS

Emanuele Bardo, Manager
SPEA, ITALY

MEMS testing is facing new challenges in terms of wafer-level solutions for production volumes. Although MEMS industry growth has been explosive over the last 10 years - and is forecast to continue, driven by IoT and automotive applications especially - no solution for the wafer-level test of MEMS functionalities has become a standard in production yet. Testing prior to packaging is beneficial for several reasons, resulting at the end in production cost reduction and faster time to market. And a reliable wafer-level test cannot be limited to the electrical characteristics of the devices. Dynamic testing of MEMS devices require a new-generation of test equipment, able to determine and analyse also the device mechanical functions by measuring its non-electrical behaviour. Field-proven equipment for the wafer-level sensor test of MEMS devices like accelerometers, gyroscopes, pressure sensors, silicon microphones, are absolutely needed and are expected to be adopted as a standard by the industry. Another test challenge concerns the growing adoption of the wafer-level chip scale packaging technology (WLCSP) for MEMS sensors and actuators, in both consumer and automotive fields. The adoption of a complete solution for the production final test of WLCSP MEMS will be essential. Such equipment must be able to perform the high-throughput, soft handling of the devices directly from the wafer ring (or strip), to stimulate and test the devices at tri-temp, to perform the finishing on reel after testing. This presentation will discuss about these challenges, providing possible solutions, raising open points and questions.

13:20 - 13:45 ADVANCES IN ALIGNED WAFER BONDING ENABLED BY ULTRA HIGH VACUUM PROCESSING

Bernhard Rebhan, Senior Scientist of Tech. Development Department
EVG Group, AUSTRIA

High volume aligned wafer bonding processes typically physically separate the wafer to wafer alignment process from the wafer bonding process. This wafer to wafer alignment is normally done in ambient atmosphere and the aligned wafer pair will be exposed to ambient atmosphere in the clean room and may even be temporarily stored in an ambient atmosphere buffer prior to bonding. While this process flow has worked well and enabled the amazing proliferation of MEMS devices in the last decade, it does have its limitation. The primary issue is exposure to the ambient atmosphere which limits the preprocessing that can be done and remain effective until the wafers are bonded. These preprocessing steps that are rendered ineffective by this exposure to ambient atmosphere can include surface dehydration, surface modification, and thermal processing.

13:45 - 14:10 REACHING THE LOWEST COST OF TEST IN MEMS BY USING PROBERS WITH PHYSICAL STIMULUS

Ari Kuukkala, Business Development Director
Afore, FINLAND

Due to constant MEMS sensor price dilution the industry is facing a huge cost pressure. In addition, there is a high demand for smaller, miniature size, sensors. Wafer level packaging technologies, chip scale (CSP) or fan out packaging (FO-WLP), are definitely responding to both of these challenges. However, the package type itself doesn't reduce the cost of test (COT), which is one of the biggest manufacturing costs of MEMS sensors. The presentation shows how the COT can be brought down by using probers with physical stimulus in MEMS final testing. The sensors can be fed directly from wafer dicing to the prober. The wafer ring with adhesive tape works as a carrier through the whole process. This method shortens tremendously the manufacturing process and decreases the investment costs. The other benefit of a prober with physical stimulus is much higher capacity compared to traditional test systems, such as Pick&Place based test systems. Thousands of sensors can be fed simultaneously to the prober and the time is mainly used for testing, not for loading and unloading like with P&P systems. One obvious benefit of prober with physical stimulus is its versatility. Regardless of the package type, the carrier remains the same. When changing from product to other only changeable part is the probe card. The product change is not only fast, but also economical. The handling of miniature size, light weighted, sensors is getting more complicated. Many of the P&P systems are limited to package size of 2x2 mm. New packaging technologies enable much smaller form factors, sensors smaller than 1x1 mm. The test method used with probers with real stimulus is also an ideal solution for handling such MEMS sensors. On the adhesive tape the sensors are well organized and the handling is smooth during the whole process. Two probers with physical stimulus are presented. The other one is for environmental sensor having stimuli for pressure, temperature, humidity or other gases. Another is meant for final testing of motion sensors: accelerometers, gyroscopes and magnetometers. A real case calculation concerning testing of 3-axis accelerometer shows how the final testing with a prober with real stimulus leads to lowest cost in the market.

14:00 - 16:00

Poster/Oral Session W3P (Refreshments Available)

Poster/Oral presentations are listed by topic category with their assigned number starting on page 58.

Session W4A Cell Manipulation	Session W4B Microfluidics II	Session W4C Accelerometers	Session W4D Optical Transducers II
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: A. Basu Wayne State University, USA N. Miki Keio University, JAPAN	Session Co-Chairs: C.-H. Lin, <i>National Sun Yat-sen University, TAIWAN</i>	Session Co-Chairs: Y. Chiu, <i>National Chiao Tung University, TAIWAN</i> D. Monk NXP, USA	Session Co-Chairs: J.-U. Bu Senplus, KOREA L. Lin, <i>University of California, Berkeley, USA</i>
16:00 - 16:15			
W4A.001 A MICRO CELL WAGON FOR INDIVIDUAL TREATMENT USING NON-THERMAL ATMOSPHERIC PRESSURE PLASMA	W4B.001 A 3D FILTER FOR PLASMA SEPARATION FROM WHOLE BLOOD	W4C.001 PARYLENE-ON-OIL ENCAPSULATION PROCESS FOR BIO-INSPIRED ANGULAR ACCELEROMETER	W4D.001 UNCOOLED LONG-WAVELENGTH INFRARED SENSOR USING CYTOCHROME C PROTEIN ON CMOS READ-OUT CIRCUITS
16:15 - 16:30			
W4A.002 MICROFABRICATED IN-CHIP MAGNETIC TWEEZERS FOR INTRA-EMBRYONIC MEASUREMENT	W4B.002 MICROFLUIDIC PLATFORM CAPABLE OF PERFORMING AUTOMATIC TISSUE SLIDE-BASED SELEX AND PHAGE DISPLAY FOR RAPID SCREENING OF AFFINITY REAGENTS SPECIFIC TO OVARIAN CANCER	W4C.002 WAFER-SCALE ENCAPSULATION OF FULLY DIFFERENTIAL ELECTRODES FOR MULTI-AXIS INERTIAL SENSING	W4D.002 SILICON MICROFABRICATED LINEAR SEGMENTED ION TRAP FOR QUANTUM TECHNOLOGIES
16:30 - 16:45			
W4A.003 A MULTIFUNCTIONAL EMBRYOS MANIPULATIVE MICROFLUIDIC CHIP WITH DYNAMIC FLOW RESISTANCE TRAPPING AND CO-CULTURE WITH STROMAL CELLS	W4B.003 SEQUENTIAL PRODUCTION OF VARIOUS TYPES OF ASYMMETRIC LIPID VESICLES USING PULSE JET FLOW	W4C.003 EPITAXIALLY ENCAPSULATED RESONANT ACCELEROMETER WITH AN ON-CHIP MICRO-OVEN	W4D.003 A RECONFIGURABLE COUPLED OPTICAL RESONATORS IN PHOTONIC CIRCUITS FOR PHOTON SHUTTING
16:45 - 17:00			
W4A.004 SOFT MICRO-FINGERS INTEGRATED WITH FIBERSCOPE FOR BOTH MANIPULATION AND <i>IN-SITU</i> OBSERVATION OF BIO-PARTICLE	W4B.004 AN EMULSION DIGITAL PCR QUANTITATIVE METHOD BASED ON MICROBEADS AND MICROPILLAR ARRAY CHIP	W4C.004 A NANO-G MEMS ACCELEROMETER FOR EARTHQUAKE MONITORING	W4D.004 AN AUTO-ALIGNED VERTICAL COMB DRIVE FOR LOW-COST VARIABLE OPTICAL ATTENUATORS
17:00 - 17:15			
W4A.005 ANDROID BASED PORTABLE CELL COUNTING SYSTEM FOR LABEL FREE QUANTIFICATION OF DEP MANIPULATED CANCER CELLS	W4B.005 FULLY DISPOSABLE AND OPTICALLY TRANSPARENT MICROFLUIDIC VISCOMETER BASED ON ELECTROFLUIDIC PRESSURE SENSOR	W4C.005 HIGH-DAMPED ACCELEROMETER BASED ON SQUEEZE-FILM DAMPING AND PIEZORESISTIVE NANO GAUGE DETECTION FOR VIBRATING ENVIRONMENTS	W4D.005 ISOTROPICALLY TUNABLE MEMS COLOR FILTER BY SURFACE PLASMON RESONANCE
17:15 - 17:30			
W4A.006 COMPUTATIONAL AND EXPERIMENTAL STUDY ON ION WIND SCHEME BASED AEROSOL SAMPLING FOR BIOMEDICAL APPLICATIONS	W4B.006 VIRTUAL VORTEX GEAR	W4C.006 AN ALUMINUM NITRIDE ON SILICON RESONANT MEMS ACCELEROMETER OPERATING IN AMBIENT PRESSURE	W4D.006 WHISPERING GALLERY MODE BASED ON-CHIP GLASS MICROBUBBLE RESONATOR FOR THERMAL SENSING

Session W4A
Cell Manipulation
ROOM 301A
16:00 - 17:30

- W4A.001 A MICRO CELL WAGON FOR INDIVIDUAL TREATMENT USING NON-THERMAL ATMOSPHERIC PRESSURE PLASMA 540**
 K. Tsukasaki, S. Kumagai, and M. Sasaki
Toyota Technological Institute, JAPAN

We developed a micro cell wagon device. The device took cells to where a non-thermal atmospheric pressure plasma (NTAPP) was generated in an experimental setup. The NTAPP can supply cells with reactive oxygen and nitrogen species which affect reactions in cells. Using the device, pollen was exposed to NTAPP. The exposure induced no apparent changes on pollen. The pollen was incubated on agar. We found that short exposure increased germination rates of pollen but long exposure increased.

- W4A.002 MICROFABRICATED IN-CHIP MAGNETIC TWEEZERS FOR INTRA-EMBRYONIC MEASUREMENT 544**
 X. Wang¹, M. Luo¹, Z. Xu¹, D.K. Luu¹, H. Pu², S. Xie², and Y. Sun^{1,2}
¹University of Toronto, CANADA and ²Shanghai University, CHINA

This paper reports a microfabricated magnetic tweezer device which, for the first time, enables a 5 μm (or smaller) magnetic bead to navigate three-dimensionally inside an embryo and perform intra-embryonic mechanical measurement. As a demonstration, a magnetic microbead was controlled to apply pico-newton forces to deform multiple locations on the inner cell mass inside a mouse embryo.

- W4A.003 A MULTIFUNCTIONAL EMBRYOS MANIPULATIVE MICROFLUIDIC CHIP WITH DYNAMIC FLOW RESISTANCE TRAPPING AND CO-CULTURE WITH STROMAL CELLS 548**
 T.-W. Lo¹, Y.-S. Chen¹, L.-Y. Ke¹, M.-S. Dong¹, Y.-X. Huang¹, H.-Y. Huang², and C.-H. Liu¹
¹National Tsing Hua University, TAIWAN and ²Chang Gung Memorial Hospital, TAIWAN

This microfluidic device integrates the various functions of embryos culture, such as dynamic flow resistance trapping, and co-culture with human stromal cells providing the growth factors. For the main function, embryos can be manipulated by fluidic field, which can keep the embryos rolling and make them grow better. It is expected that the quality and successful rate of embryos development can be improved by providing the physical stimulus to construct the environment similar to the uterus.

- W4A.004 SOFT MICRO-FINGERS INTEGRATED WITH FIBERSCOPE FOR BOTH MANIPULATION AND IN-SITU OBSERVATION OF BIO-PARTICLE 552**
 T. Ezaki, S. Otake, and S. Konishi
Ritsumeikan University, JAPAN

We report soft micro-fingers integrated with a fiberscope for both manipulation and *in-situ* observation of bio-particle. Soft micro-fingers are driven by a pneumatic balloon actuator (PBA) composed of polydimethylsiloxane (PDMS). Cellular aggregates in a micro-well-plate can be successfully manipulated and observed using developed micro-fingers. The viability of the cellular aggregates can be judged using fluorescence staining.

- W4A.005 ANDROID BASED PORTABLE CELL COUNTING SYSTEM FOR LABEL FREE QUANTIFICATION OF DEP MANIPULATED CANCER CELLS 556**
 M.K. Aslan and H. Klah
Middle East Technical University, TURKEY

Here, we present a novel portable system integrating microfluidic DEP channel with a CMOS imager connected to a cell phone for label and lens free detection, and real-time counting of MCF-7 cells. The DEP device is used for trapping cancer cells and the trapped cells are simultaneously imaged with a CMOS sensor placed underneath the device. Raw CMOS images are captured with an Android application which also automatically counts the detected cells with an accuracy of 90%.

- W4A.006 COMPUTATIONAL AND EXPERIMENTAL STUDY ON ION WIND SCHEME BASED AEROSOL SAMPLING FOR BIOMEDICAL APPLICATIONS 560**
 T.T. Bui¹, T.X. Dinh², C.-D. Tran³, T.C. Duc¹, and V.T. Dau⁴
¹Vietnam National University, VIETNAM, ²Ritsumeikan University, Shiga, JAPAN,
³University of Southern Queensland, AUSTRALIA, and ⁴Sumitomo Chemical, Ltd., JAPAN

In this paper, we report for the first time an application of the neutralized ion wind to develop an efficient electrostatic particle sampling system. The proposed approach allows sampling stage to be electrically floated and adds insignificant charge to the bioaerosol, thus reduces the potential damage to the microorganisms while provides design flexibility and good collecting efficiency.

Session W4B
Microfluidics II
ROOM 301B
16:00 - 17:30
W4B.001 A 3D FILTER FOR PLASMA SEPARATION FROM WHOLE BLOOD 564

Y. Liu¹, W. Dai¹, H. Li², W. Wu¹, and W. Wang¹
¹Peking University, CHINA and ²No 1 Hospital of Peking University, CHINA

This work presented a simple and efficient 3D filter for plasma separation from whole blood. The filter was an origami of Parylene membrane with different sized micropores and folding grooves. $1.64 \pm 0.08 \mu\text{m}$ micropores were designed for plasma filtration and $40 \mu\text{m}$ micropores functioned as a by-pass pathway for clogging-free operation. The device could achieve a high yield of 42%. Total proteins and blood glucose concentrations testing indicated the high quality of separated plasma.

W4B.002 MICROFLUIDIC PLATFORM CAPABLE OF PERFORMING AUTOMATIC TISSUE SLIDE-BASED SELEX AND PHAGE DISPLAY FOR RAPID SCREENING OF AFFINITY REAGENTS SPECIFIC TO OVARIAN CANCER 568

L.-Y. Hung¹, C.-Y. Fu¹, C.-H. Wang¹, Y.-J. Chuang², Y.-C. Tsai¹, Y.L. Lo¹, W.-B. Lee¹, S.-C. Shiesh², H.-Y. Chang¹, K.-F. Hsu², and G.-B. Lee¹
¹National Tsing Hua University, TAIWAN and ²National Cheng Kung University, TAIWAN

This paper reports a novel integrated microfluidic system capable of automating two kinds of on-chip tissue slide-based *in-vitro* screening processes, including a systematic evolution of ligands by exponential enrichment (SELEX) process and a phage display screening process. It is the first time that a solid biopsy (tissue slide) was used on an integrated microfluidic system for screening of two kinds of affinity reagents, including aptamers and peptides.

W4B.003 SEQUENTIAL PRODUCTION OF VARIOUS TYPES OF ASYMMETRIC LIPID VESICLES USING PULSE JET FLOW 572

M. Gotanda^{1,2}, K. Kamiya^{1,3}, T. Osaki^{1,4}, S. Fujii¹, N. Misawa¹, N. Miki^{1,2}, and S. Takeuchi^{1,4}
¹Kanagawa Academy of Science and Technology, JAPAN, ²Keio University, JAPAN,

³Japan Science and Technology Agency (JST), JAPAN, and ⁴University of Tokyo, JAPAN

We developed a device for sequentially asymmetric lipid vesicle formation, which applies pulse jet flow to an asymmetric planar lipid bilayer with multiple lipid components. Asymmetric planar lipid bilayers with multiple lipid components were formed by contacting various types of lipid monolayers using movable wells on a revolving table. We successfully produced two types of the asymmetric lipid vesicles containing red or green fluorescent lipids on the outer leaflet with our single device.

W4B.004 AN EMULSION DIGITAL PCR QUANTITATIVE METHOD BASED ON MICROBEADS AND MICROPILLAR ARRAY CHIP 575

Z. Cheng^{1,2}, K. Wang^{1,2}, Z. Wu^{1,2}, L. Zhou^{1,2}, Y. Bai^{1,2}, Z. Wang^{1,2}, H. Zhou¹, Q. Jin¹, J. Zhao¹, and H. Mao¹
¹Chinese Academy of Sciences, CHINA and ²University of Chinese Academy of Sciences, CHINA

We have developed a beads-based nucleic acid detection method combining emulsion digital PCR with microbeads and micropillar array chip. Comparing to the existing beads counting platform in the BEAMing experiment such as flow cytometry or acrylamide-fixed beads array, our method has reduced the cost and complexity of magnetic beads counting process.

W4B.005 FULLY DISPOSABLE AND OPTICALLY TRANSPARENT MICROFLUIDIC VISCOMETER BASED ON ELECTROFLUIDIC PRESSURE SENSOR 579

T.-A. Lee, W.-H. Liao, and Y.-C. Tung

Academia Sinica, TAIWAN

We develop a novel microfluidic viscometer with an embedded pressure sensor constructed using electrofluidic circuits, which are circuits built by filling ionic liquid into microfluidic channels. The viscometer can be used to measure viscosity of Newtonian and non-Newtonian fluid under various temperatures. It is made of PDMS with transparent circuit which makes it feasible to monitor samples under tests. In addition, the device is fully disposable, which is desired for biomedical applications.

W4B.006 VIRTUAL VORTEX GEAR 583

C.-H.D. Tsai, T. Akai, M. Horade, H. Ito, and M. Kaneko

Osaka University, JAPAN

An interesting phenomenon of microfluidic vortex rotating and transmitting like a set of gears has been experimentally observed, and is firstly reported here. We found that the vortices can be serially induced by increasing the driving pressure. Every two closed by vortices are having opposite direction of the swirling. In addition, we conduct experiments on two different channel designs, and the same input flow can result in inversely swirling flows on the output.

**Session W4C
Accelerometers**
ROOM 304A
16:00 - 17:30

- W4C.001 PARYLENE-ON-OIL ENCAPSULATION PROCESS FOR BIO-INSPIRED ANGULAR ACCELEROMETER 587**
H. Alrowais, M.-G. Kim, P. Getz, and O. Brand
Georgia Institute of Technology, USA

This paper reports on a wafer-level parylene-on-oil encapsulation process for a bio-inspired angular accelerometer with thermal transduction. The angular accelerometer's microtorus geometry, which is inspired by the semicircular canals, provides inherent linear acceleration insensitivity, while promoting in-plane angular acceleration. To show the feasibility of this process, thermal angular accelerometers were fabricated and tested, showing a sensitivity of $24.7\mu\text{V}/\text{deg/s}^2$

- W4C.002 WAFER-SCALE ENCAPSULATION OF FULLY DIFFERENTIAL ELECTRODES FOR MULTI-AXIS INERTIAL SENSING 591**
I.B. Flader, Y. Chen, D.D. Gerrard, and T.W. Kenny
Stanford University, USA

This work demonstrates, for the first time, a wafer-scale encapsulation process incorporating fully circumferential electrodes (in-plane and out-of-plane) for multi-axis inertial sensing. Bottom and top electrodes were incorporated in the device package using an epitaxial silicon reactor. By this method, we present fully differential, vacuum-encapsulated resonators with low parasitic feedthrough capacitance.

- W4C.003 EPITAXIALLY ENCAPSULATED RESONANT ACCELEROMETER WITH AN ON-CHIP MICRO-OVEN 595**
D.D. Shin, Y. Chen, I.B. Flader, and T.W. Kenny
Stanford University, USA

This paper reports on-chip ovenization of fully encapsulated resonant accelerometer to improve scale factor and bias stability over temperature. DETF resonator that shares the anchor with sensing beams is used as thermometer, and device is heated through on-chip heater defined in encapsulation layer. Preliminary results show improvements to passively temperature-compensated differential signal by threefold in bias stability, and by a factor of thirteen in scale factor stability over $-20\text{C}\sim 80\text{C}$.

- W4C.004 A NANO-G MEMS ACCELEROMETER FOR EARTHQUAKE MONITORING 599**
W.J. Wu, Z. Li, J.Q. Liu, J. Fan, and L.C. Tu
Huazhong University of Science and Technology, CHINA

We develop an in-plane nano-g MEMS accelerometer with operating range of more than 1 g using optimized periodic-sensing-array capacitance displacement transducers. The experimentally measured noise limited resolution is $30\text{ng}/\sqrt{\text{Hz}}$ at 1 Hz both under horizontal and vertical mounting conditions for the same device. The earthquake occurred in Taiwan was detected during a continuous gravity measurement.

- W4C.005 HIGH-DAMPED ACCELEROMETER BASED ON SQUEEZE-FILM DAMPING AND PIEZORESISTIVE NANOGAUGE DETECTION FOR VIBRATING ENVIRONMENTS 603**
B. Fain^{1,2}, A. Chaehoi^{1,2}, A. Berthelot^{1,2}, T. Verdot^{1,2}, F. Souchon^{1,2}, S. Delachanal^{1,2}, A. Koumela^{1,2},
A. Nowodzinski^{1,2}, H. Lhermet^{1,2}, G. Jourdan^{1,2}, P. Rey^{1,2}, and P. Robert^{1,2}
¹University Grenoble, FRANCE and ²CEA, LETI, FRANCE

We report the conception, the fabrication and the electrical testing of an overdamped silicon accelerometer dedicated to vibrating environments. Squeeze-film damping effects are implemented to drastically reduce the mechanical component bandwidth while keeping a satisfactory resolution. Such mechanical filtering of vibrations above 3 Hz is expected to strongly lower the mechanical overcharge of the structure that may occur when the MEMS is exposed to large parasitic vibrations and shocks.

- W4C.006 AN ALUMINUM NITRIDE ON SILICON RESONANT MEMS ACCELEROMETER OPERATING IN AMBIENT PRESSURE 607**
M.Y. Chao, A. Ali, S. Ghosh, and J.E.-Y. Lee
City University of Hong Kong, HONG KONG

We present an Aluminum Nitride (AlN) on Silicon (Si) resonant MEMS accelerometer with a calibrated differential sensitivity of 387ppm/g measured in ambient conditions (no vacuum). This marks the highest figure of sensitivity among piezoelectric AlN-based resonant accelerometers reported to date by nearly an order of magnitude.

Session W4D
Optical Transducers II
ROOM 304B
16:00 - 17:30

- W4D.001 UNCOOLED LONG-WAVELENGTH INFRARED SENSOR USING CYTOCHROME C PROTEIN ON CMOS READ-OUT CIRCUITS 611**
 P.H. Yen, S.F. Liang, and G.D.J. Su
National Taiwan University, TAIWAN

We make long-wavelength infrared detectors with COMS-MEMS and inkjet technology. MEMS techniques enable the creation of suspension structures required by microbolometers using a CMOS process. Thermal isolation structures can thereby be fabricated next to readout integrated circuits (ROIC) for infrared sensing. Then we use an inkjet printer to drop cytochrome c protein. The proposed method in this paper avoids time-consuming and expensive photolithography processes.

- W4D.002 SILICON MICROFABRICATED LINEAR SEGMENTED ION TRAP FOR QUANTUM TECHNOLOGIES 615**
 K. Choonee, G. Wilpers, and A.G. Sinclair
National Physical Laboratory, UK

This paper describes microfabricated linear segmented 3D RF Paul trap for atomic quantum technologies. Trapping of single 88Sr^+ ions is demonstrated and heating rate measurements are presented. High fabrication yields are obtained (80 % of the devices lying within $\pm 5 \mu\text{m}$ (or $\pm 3 \%$) of a target geometrical value) which is key for quantum information processing, where scalable architectures requiring arrays of interconnected ion traps with consistent parameters are required.

- W4D.003 A RECONFIGURABLE COUPLED OPTICAL RESONATORS IN PHOTONIC CIRCUITS FOR PHOTON SHUTTING 619**
 Z.Y. Li¹, J.G. Huang^{2,3}, Z.C. Yang¹, Y.L. Hao¹, Y.F. Jin¹, J.H. Wu³, T.N. Chen³, and A.Q. Liu²
¹Peking University, CHINA, ²Nanyang Technologies University, SINGAPORE, and ³Xi'an Jiaotong University, CHINA

We demonstrate a novel way to control the coupling rate in coupled ring resonators by controlling the nanowire between the two cavities, compared to state of the art where the coupling rate between different photonic cavities is extremely low due to less spatial overlapping. This study will open new ways to manipulate coupled photonic cavities.

- W4D.004 AN AUTO-ALIGNED VERTICAL COMB DRIVE FOR LOW-COST VARIABLE OPTICAL ATTENUATORS 622**
 J. Cheng¹, W. Liu¹, Q. Chen², N. Xu², Q. Sun², Y. Liu², W. Wang², and H. Xie³
¹Xian Technological University, CHINA, ²Wuxi WiO Technology Co., Ltd., CHINA, and ³University of Florida, USA

We develop an efficacy approach to realize an auto-aligned vertical comb-drive actuator. This actuator is a self-aligned vertical comb-drive fingers. This approach allow to realize a vertical comb-drive structure without bonding process and several silicon etch process, the process complexity and cost will be reduced, the device yield increases.

- W4D.005 ISOTROPICALLY TUNABLE MEMS COLOR FILTER BY SURFACE PLASMON RESONANCE 626**
 S.-C. Lo, Y.-T. Hu, Y.-C. Chen, C.-L. Pan, and C.-Y. Lo
National Tsing Hua University, TAIWAN

A tunable surface plasmon resonance (SPR) structure driven by microelectromechanical system (MEMS) was proposed and analyzed in this work. The MEMS isotropically expanded or compressed the suspended SPR structures to different extents on the xy-plane with nanometer metal disks distributed on a polydimethylsiloxane (PDMS) diaphragm; filtered the incident white light into various colors at different applied voltages.

- W4D.006 WHISPERING GALLERY MODE BASED ON-CHIP GLASS MICROBUBBLE RESONATOR FOR THERMAL SENSING 630**
 C. Zhang, A. Cocking, E. Freeman, Z. Liu, and S. Tadiadapa
Pennsylvania State University, USA

This paper reports on a high Q-factor, whispering gallery mode glass microbubble resonator with high temperature sensitivity. Using microfabrication methods, chip-scale glass microbubbles with ultra-smooth surface and sub-micrometer wall thickness are shown to support optical resonance modes with ultra-high Q-factors of 10^7 . The resonance is highly sensitive to temperature fluctuations (1.8 GHz/°C). As expected, the thermal sensitivity is observed to be independent of the microbubble sizes.

18:30 - 21:00
Conference Banquet

8:00	Registration		
Session Th1A Biosensors	Session Th1B Gas Sensors II	Session Th1C Fabrication II	Session Th1D Energy Storage
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: G.-B. Lee, <i>National Tsing Hua University, TAIWAN</i> W.-T. Park, <i>Seoul National University of Science & Technology, KOREA</i>	Session Co-Chairs: I. Park, <i>Korea Advanced Institute of Science and Technology (KAIST), KOREA</i> M. Sohgewa, <i>Niigata University, JAPAN</i>	Session Co-Chairs: K. Böhringer, <i>University of Washington, USA</i> F. Laermer, <i>Robert Bosch Corporate Research and Advance Development, GERMANY</i>	Session Co-Chairs: Y.-T. Cheng, <i>National Chiao Tung University, TAIWAN</i> C. Hierold, <i>ETH Zürich, SWITZERLAND</i>
8:30 - 9:00			
Th1A.001 INVITED SPEAKER ANALYSIS OF ENVIRONMENTAL BACTERIA AT SINGLE-CELL LEVEL	Th1B.001 INVITED SPEAKER PORTABLE MULTI-DIMENSIONAL GAS CHROMATOGRAPHY DEVICE FOR RAPID FIELD ANALYSIS OF CHEMICAL COMPOUNDS	Th1C.001 INVITED SPEAKER SELF-ASSEMBLY OF MICRO/NANOSYSTEMS ACROSS SCALES AND INTERFACES	Th1D.001 INVITED SPEAKER NANOENGINEERED DEVICES FOR SOLAR ENERGY CONVERSION
9:00 - 9:15			
Th1A.002 A COMPACT EXCLUSION-ENRICHMENT MICROFLUIDIC CHIP WITH INTEGRATED IMPEDANCE BIOSENSOR FOR LOW CONCENTRATION PROTEIN DETECTION	Th1B.002 PPB LEVEL GAS QUANTIFICATION BY BUBBLE CHROMATOGRAPHY	Th1C.002 MICRO-OBJECT ASSEMBLY WITH AN OPTICALLY ADDRESSED ARRAY	Th1D.002 FLEXIBLE HARSH ENVIRONMENT MICRO SUPERCAPACITORS USING DIRECT-WRITE 2D TRANSITION METAL CARBIDES
9:15 - 9:30			
Th1A.003 DROPLET FREQUENCY SENSOR: A NEW MODALITY FOR SENSITIVE, LABEL-FREE, INLINE BIOCHEMICAL DETECTION	Th1B.003 HYBRID METAMATERIAL ABSORBER ENHANCED SENSING OF CO ₂ GAS IN THE 5-8 μ M MID IR SPECTRAL WINDOW	Th1C.003 INDIVIDUALLY DETACHABLE POLYMER-SILICON MICRO-PARTS FOR VAPORIZABLE ELECTRONICS	Th1D.003 A MXENE BASED ALL-SOLID-STATE MICROSUPERCAPACITOR WITH 3D INTERDIGITAL ELECTRODE
9:30 - 9:45			
Th1A.004 LABEL-FREE DETECTION OF CORDYCEPS SINENSIS BY DUAL-GATE NANORIBBON-BASED ION-SENSITIVE FIELD-EFFECT TRANSISTOR BIOSENSOR	Th1B.004 MICRO VAPOR EXTRACTOR FOR ON-SITE DETERMINATIONS OF VOLATILE ORGANIC COMPOUNDS IN WATER AND BIOFLUIDS	Th1C.004 DROP-ON-DEMAND GENERATION OF ALUMINUM ALLOY MICRODROPLETS AT 950 °C USING THE STARJET TECHNOLOGY	Th1D.004 ATOMIC LAYER DEPOSITION OF TIN LAYER ON TiO ₂ NANOTUBES FOR ENHANCED SUPERCAPACITOR PERFORMANCE
9:45 - 10:00			
Th1A.005 A NOVEL METHOD FOR GENERATING MONODISPersed DROPLET ARRAY BY INKJET-PATTERNED HYDROPHILIC SYMBOLS FOR CONTROLLED REACTIONS	Th1B.005 DESIGN AND IMPLEMENTATION OF GAS SENSOR ARRAY BASED ON FLUORESCENCE QUENCHING DETECTION USING CMOS-MEMS PROCESS	Th1C.005 HIGH PERFORMANCE PROTEIN PHOTOLITHOGRAPHY USING PHOTOREACTIVE SILK LIGHT CHAIN AS THE RESIST: MATERIAL, METHOD AND MECHANISM	Th1D.005 SILICON ENCLOSED IN RGO/CNT SHELL-LIKE SCAFFOLD AS A MICRO LITHIUM-ION BATTERY ANODE

Session Th1A
Biosensors
ROOM 301A
8:30 - 10:00

- TH1A.001 INVITED SPEAKER**
ANALYSIS OF ENVIRONMENTAL BACTERIA AT SINGLE-CELL LEVEL 634
 M. Hosokawa^{1,2}, Y. Nishikawa¹, M. Kogawa¹, and **H. Takeyama**¹
¹Waseda University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

Since more than 99% of environmental bacteria are uncultivable, single-cell analysis is the powerful tool for obtaining their characteristics without cultivation. We have focused single cell analysis from the aspect of intercellular products and genome information. We have applied Raman microspectroscopy to *in situ* detection of bioactive compounds, and developed droplet-based microfluidics for analyzing massively parallel single-cell genome.

- Th1A.002 A COMPACT EXCLUSION-ENRICHMENT MICROFLUIDIC CHIP WITH INTEGRATED IMPEDANCE BIOSENSOR FOR LOWCONCENTRATION PROTEIN DETECTION** 638
 T.V. Quoc¹, M.-S. Wu², T.T. Bui³, T. Chu Duc³, and C.-P. Jen²
¹Vietnam Academy of Science and Technology (VAST), VIETNAM, ²National Chung Cheng University, TAIWAN, and ³Vietnam National University, VIETNAM

This paper presents a compact system for lowconcentration protein detection based on aneffectiveness concentrator which is relied onexclusion-enrichment effect (EEE) and a highlysensitivity lock-in impedance measurementtechnique. Experiment results suggested thatprotein concentration of down to sub-nanomolarcan be detected by the proposed system.

- Th1A.003 DROPLET FREQUENCY SENSOR: A NEW MODALITY FOR SENSITIVE, LABEL-FREE, INLINE BIOCHEMICAL DETECTION** 642
 R. Kebriaei and A.S. Basu
 Wayne State University, USA

This paper introduces the droplet frequency sensor (DFS), a novel sensor modality for sensitive, label-free, inline detection of proteins and analytes. The DFS measures the frequency of droplets formed in a flow-focusing junction. Due to changes in interfacial tension, the droplet frequency shifts predictably as biochemical analytes pass through the device. Initial experiments demonstrate a limit of detection as low as 12.5 femtomoles (200 pg), >100X better than UV-Vis spectroscopy.

- Th1A.004 LABEL-FREE DETECTION OF CORDYCEPS SINENSIS BY DUAL-GATE NANORIBBON-BASED ION-SENSITIVE FIELD-EFFECT TRANSISTOR BIOSENSOR** 646
 S. Ma^{1,2}, T. Luo¹, G. Wei¹, B. Gao², Y.-K. Lee², and A. Zhang¹
¹Xi'an Jiaotong University, CHINA and ²Hong Kong University of Science and Technology, HONG KONG

We report a dual-gate nanoribbon-based ion-sensitive field-effect transistor (NR-ISFET) biosensor system for direct label-free detection of Cordyceps sinensis's DNA (CorDNA). Compared with previous methods for CorDNA detection, the NR-ISFET biosensor shows smaller sample volume, lower detection concentration and shorter response time. Especially in dual-gate mode it exhibits a better sensitivity, the lower limit of detection, and improved specificity as compared to single solution-gate mode.

- Th1A.005 A NOVEL METHOD FOR GENERATING MONODISPERSED DROPLET ARRAY BY INKJET-PATTERNED HYDROPHILIC SYMBOLS FOR CONTROLLED REACTIONS** 650
 X. Lai, B. Lu, H. Wu, Z. Pu, H. Yu, and D. Li
 Tianjin University, CHINA

We proposed a novel device for the generation of monodispersed droplet array on superhydrophobic substrate modified by inkjet-printed hydrophilic symbols. Compared with previously reported droplet generation devices, the method in this paper is capable of pre-depositing reagents at the site of each droplet, and is able to trigger specific reactions such as recombinase polymerase amplification (RPA), leading to a simpler solution to controlled reactions.

Session Th1B
Gas Sensors II
ROOM 301B
8:30 - 10:00

- Th1B.001 INVITED SPEAKER**
PORTABLE MULTI-DIMENSIONAL GAS CHROMATOGRAPHY DEVICE FOR RAPID FIELD ANALYSIS OF CHEMICAL COMPOUNDS 654
X. Fan, J. Lee, H. Zhu, M. Zhou, R. Nidetz, K. Kurabayashi, S. Sayler, R. Neitzel, and R.J. Richardson
University of Michigan, USA

We report the progress made in the past few years in the development of a high performance portable multidimensional gas chromatography (GC) device that is capable of rapidly analyzing a large number of compounds with high sensitivity. We discuss the multi-dimensional GC architecture and its components, followed by a few field analysis examples using our portable GC devices.

- Th1B.002 PPB LEVEL GAS QUANTIFICATION BY BUBBLE CHROMATOGRAPHY** 660
A. Bulbul and H. Kim
University of Utah, USA

We explored the quantification capability of the bubble chromatography technique that we newly conceived. In the bubble chromatography a type of a gas can be identified by its size when it is introduced into a microfluidic stream to form a train of bubbles. The measurement showed that the bubble chromatography was able to quantify gas amounts down to 17.5 ppb with a linear response range between 1.99 pL and 1 μ L in volume.

- Th1B.003 HYBRID METAMATERIAL ABSORBER ENHANCED SENSING OF CO₂ GAS IN THE 5-8 μ M MID IR SPECTRAL WINDOW** 664
D. Hasan and C. Lee
National University of Singapore, SINGAPORE

A novel hybrid polymer-metamaterial absorber approach is proposed for enhanced and selective optical sensing of CO₂ gas in the 5-8 μ m mid IR spectral window. The scheme holds promise for ultra-compact integration with CMOS compatible read out electronics and all-optical reset with low hysteresis and high reliability.

- Th1B.004 MICRO VAPOR EXTRACTOR FOR ON-SITE DETERMINATIONS OF VOLATILE ORGANIC COMPOUNDS IN WATER AND BIOFLUIDS** 668
J. Wang¹, C. Zhan¹, E.T. Zellers¹, and J.A. Potkay^{1,2}
¹University of Michigan, USA and ²Veterans Administration Ann Arbor Healthcare System, USA

We have designed, fabricated, modeled, and tested a new passive, membrane-mediated microscale vapor extractor (μ VE) for extracting volatile organic compounds (VOCs) from \sim μ L volumes of water and biofluids. We have optimized the operation conditions and interfaced this microdevice to a new compact, micro-scale gas chromatograph (μ GC) prototype. This hybrid μ VE- μ GC microsystem will permit rapid field/clinical analyses of VOC water contaminants and urinary biomarkers.

- Th1B.005 DESIGN AND IMPLEMENTATION OF GAS SENSOR ARRAY BASED ON FLUORESCENCE QUENCHING DETECTION USING CMOS-MEMS PROCESS** 672
Y.-C. Lee¹, S.-W. Cheng^{1,2}, C.-L. Cheng¹, and W. Fang¹
¹National Tsing Hua University, TAIWAN and ²Taiwan Semiconductor Manufacturing Company, TAIWAN

This study implements the optical-based gas sensor array. The gas concentration is detected based on the fluorescence intensity. This design has three merits: (1) integration of multiple photo-sensors, thermal-isolation structure, and optical based gas-sensing films using CMOS and polymer dispensing technologies, (2) multiple optical sensors equipped with thermal compensation unit are monolithically integrated, (3) various sensing films can be prepared for multiple gases detection.

**Session Th1C
Fabrication II**
ROOM 304A
8:30 - 10:00

- Th1C.001** **INVITED SPEAKER**
SELF-ASSEMBLY OF MICRO/NANOSYSTEMS ACROSS SCALES AND INTERFACES 676
M. Mastrangeli
Max Planck Stuttgart, GERMANY

In this talk, I will show how general principles of self-assembly and specific aspects of fluidics can be conjugated across several physical scales and material interfaces to realize functional technological systems. I will exemplify the claims through embodiments selected from my research—including fabrication of liquid-filled sealed MEMS capsules, capillary integration of plastic electronic microsensors, and assembly of nanoparticle-based plasmonic structures— and propose an outlook of future developments for self-assembling transducers.

- Th1C.002** **MICRO-OBJECT ASSEMBLY WITH AN OPTICALLY ADDRESSED ARRAY** 682
 E.M. Chow, J.P. Lu, J.A. Bert, L.S. Crawford, S. Raychaudhuri, A. Plochowitz, B.B. Rupp, G. Burton, R.A. Lujan, Q. Wang, and Y.Wang, J. Kalb, I. Matei, P. Maeda, D. Davies, Y. Wang, and D.K. Biegelsen
PARC, USA

We present a micro-object assembly and transfer system. An electrostatic actuator array rapidly organizes micrometer scale parts into programmable patterns. The actuator array incorporates phototransistors and is optically addressed. The system aims to extend xerographic printing techniques to enable engineered microstructure and complex electronics.

- Th1C.003** **INDIVIDUALLY DETACHABLE POLYMER-SILICON MICRO-PARTS FOR VAPORIZABLE ELECTRONICS** 686
 V. Gund, A. Ruyack, A. Leonardi, K.B. Vinayakumar, C.K. Ober, and A. Lal
Cornell University, USA

We present a novel method to produce controlled transience using a hybrid polymer-silicon fabrication process. The ability to selectively eliminate components from conventional silicon substrates is desired to maintain information fidelity for secure applications. Our design transforms electronics into transient substrates by post-processing with etched grooves and a polymer film to hold the substrate together. The polymer can be selectively vaporized to remove silicon parts controllably.

- Th1C.004** **DROP-ON-DEMAND GENERATION OF ALUMINUM ALLOY MICRODROPLETS AT 950 °C USING THE STARJET TECHNOLOGY** 690
 B. Gerdes¹, M. Jehle¹, M. Domke², R. Zengerle¹, P. Koltay¹, and L. Riegger¹
¹University of Freiburg, GERMANY and ²Vorarlberg University of Applied Sciences, AUSTRIA

We present the drop-on-demand generation of liquid microdroplets from aluminum alloy melts with minimum diameters of 250 µm. The so called StarJet technology used to generate the droplets features a pneumatically actuated printhead that has been used to print micro droplets from solder before (melting point 220 °C). In this work a novel StarJet-printhead is presented that can be heated up to 950 °C and thus allows for printing of aluminum alloys.

- Th1C.005** **HIGH PERFORMANCE PROTEIN PHOTOLITHOGRAPHY USING PHOTOREACTIVE SILK LIGHT CHAIN AS THE RESIST: MATERIAL, METHOD AND MECHANISM** 694
 J. Jiang¹, W. Liu², S. Zhang², and T.H. Tao^{1,2}
¹Chinese Academy of Sciences, CHINA and ²University of Texas, Austin, USA

We report on wafer-scale high resolution patterning of bio-microstructures using silk fibroin light chain as the resist material. The enhanced patterning resolution, the improved etch resistance and the inherent biocompatibility of such protein-based photoresist provide new opportunities in fabricating large scale biocompatible functional microstructures.

**Session Th1D
Energy Storage**
ROOM 304B
8:30 - 10:00

Th1D.001	INVITED SPEAKER	
	NANOENGINEERED DEVICES FOR SOLAR ENERGY CONVERSION	698
	D.M. Bierman ¹ , A. Lenert ² , W.R. Chan ¹ , B. Bhatia ¹ , I. Celanovic ¹ , M. Soljagic ¹ , and E.N. Wang¹	
	¹ Massachusetts Institute of Technology, USA and ² University of Michigan, USA	

Nanoengineered materials have exciting, untapped potential to develop high performance solar energy conversion devices. In solar thermophotovoltaic devices, nanoengineered surfaces allow us to engineer the spectral properties and to define the active area of the emitter with respect to the absorber. Accordingly, we report solar-to-electrical conversion efficiencies of 6.8%, exceeding that of the underlying cell. In solar thermal receivers, we can tailor the nanostructure of silica aerogels to achieve both high thermally insulating and optically transparent properties. By incorporating these aerogels into solar thermal devices, we show significant improvements in energy conversion efficiency. These examples demonstrate the exciting potential of nanoengineering to realize next generation solar thermal energy systems.

Th1D.002	FLEXIBLE HARSH ENVIRONMENT MICRO SUPERCAPACITORS USING DIRECT-WRITE 2D TRANSITION METAL CARBIDES	702
	M. Wei ¹ , B. Li ² , X. Zang ¹ , W. Chen ³ , Y. Chu ^{1,4} , M. Sanghadasa ⁵ , and L. Lin ^{1,4}	
	¹ University of California, Berkeley, USA, ² Tsinghua University, CHINA, ³ Shanghai Jiao Tong University, CHINA, ⁴ Tsinghua-Berkeley Shenzhen Institute, CHINA, and ⁵ US Army, USA	

We report for the first time the flexible harsh environment micro supercapacitors using laser-processed 2D transition metal carbides. A laser based direct-write method is employed to realize fast conversion of molybdenum carbide from Mo ions on top of a flexible polymer substrate. Due to the ceramic and pseudo-capacitance nature of such material, we demonstrate a high specific capacitance micro supercapacitors with stable operations in both low and high harsh temperature environments.

Th1D.003	A MXENE BASED ALL-SOLID-STATE MICROSUPERCAPACITOR WITH 3D INTERDIGITAL ELECTRODE	706
	S. Xu, W. Liu, X. Liu, X. Kuang, and X. Wang	
	Tsinghua University, CHINA	

We report a novel 2D Transition Metal Carbides (MXene) based all-solid-state microsupercapacitor (MSC). Ti₃C₂T_x has been chosen to be the electrode material as it features high pseudocapacity, great conductivity and cyclability. Thick interdigital electrodes have been fabricated. The conformal coating of PE on Ti₃C₂T_x enhances not only the surface accessibility by ions, but also the electrode stability. The device shows a high specific capacitance and capacity retention.

Th1D.004	ATOMIC LAYER DEPOSITION OF TIN LAYER ON TiO₂ NANOTUBES FOR ENHANCED SUPERCAPACITOR PERFORMANCE	710
	K. Du ¹ , P. Lu ¹ , G. Liu ² , X. Chen ¹ , and K. Wang ¹	
	¹ University College of Southeast Norway, NORWAY and ² Nanjing University of Science and Technology, CHINA	

We develop an anodized TiO₂ nanotubes (TNT) coated with highly conductive titanium nitride (TiN) as supercapacitor electrode, which yields the enhanced supercapacitor performance (10.01 mF/cm²), 24.4 times higher than that of pristine TNT and outstanding retention (91.9%) after 2000 cycles. TNT-TiN electrodes could be considered as one of promising electrode materials for energy storage devices.

Th1D.005	SILICON ENCLOSED IN RGO/CNT SHELL-LIKE SCAFFOLD AS A MICRO LITHIUM-ION BATTERY ANODE	714
	X. Kuang, X. Liu, S. Xu, and X. Wang	
	Tsinghua University, CHINA	

We report a rGO/CNT/Si shell-like anode for Li-ion batteries by using the vacuum filtration method. The SiNPs are enclosed by a scaffold consisting of the stacked rGO shells and the CNT frame. The scaffold provides space for expansion of the SiNPs during the process of intercalation. The anode has been demonstrated to enjoy the high specific capacity (2372.77 mAh/g in initial cycle) and the superior recyclability (1438.31 mAh/g after 100 cycles) in a half-cell test.

10:00 - 10:30	Break and Exhibit Inspection
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Session Th2A Diagnosis	Session Th2B Materials	Session Th2C Pressure Sensors	Session Th2D Resonant MEMS III
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: Y.-K. Yoon <i>University of Florida, USA</i> F.-G. Tseng <i>National Tsing Hua University, TAIWAN</i>	Session Co-Chairs: D. Senesky <i>Stanford University, USA</i> M. Sasaki <i>Toyota Technological Institute, JAPAN</i>	Session Co-Chairs: J. Hsieh, <i>Asia Pacific Microsystems, Inc., TAIWAN</i> T. Tsuchiya <i>Kyoto University, JAPAN</i>	Session Co-Chairs: D. Horsley <i>University of California, Davis, USA</i> S.-S. Li, <i>National Tsing Hua University, TAIWAN</i>
10:30 - 10:45			
Th2A.001 USING BACTERIAL SELEX TO SELECT HIGHLY-SPECIFIC APTAMERS AND THEIR APPLICATIONS IN PAPER-BASED MICROFLUIDIC CHIPS FOR RAPID DIAGNOSIS OF MULTIPLE BACTERIA	Th2B.001 HIGH-K THIN FILMS FOR SIMULTANEOUS DIELECTRIC ACTUATION AND DETECTION OF M/NEMS FLEXURAL VIBRATION	Th2C.001 PRESSURE SENSITIVE IONIC GEL-FETS OF EXTREMELY HIGH SENSITIVITY OVER 2,200 KPA ⁻¹ OPERATED UNDER 2 V	Th2D.001 259 SECOND RING-DOWN TIME AND 4.45 MILLION QUALITY FACTOR IN 5.5 KHZ FUSED SILICA BIRDBATH SHELL RESONATOR
10:45 - 11:00			
Th2A.002 AN INTEGRATED PASSIVE MICROFLUIDIC DEVICE FOR RAPID DETECTION OF INFLUENZA A (H1N1) VIRUS BY REVERSE TRANSCRIPTION LOOP-MEDIATED	Th2B.002 PHONONIC DETECTION OF MORPHOLOGICAL PHASE TRANSITION IN ATOMIC-LAYERED HAFNIUM-ZIRCONIUM-OXIDE	Th2C.002 SUSPENDED GRAPHENE BEAMS WITH TUNABLE GAP FOR SQUEEZE-FILM PRESSURE SENSING	Th2D.002 TOPOLOGY OPTIMIZATION FOR REDUCTION OF THERMO-ELASTIC DISSIPATION IN MEMS RESONATORS
11:00 - 11:15			
Th2A.003 AN IMPEDANCE BIOSENSOR FOR SIMULTANEOUS DETECTION OF LOW CONCENTRATION OF SALMONELLA SEROGROUPS IN POULTRY SAMPLES	Th2B.003 A MEMS DEVICE FOR FRACTURE TOUGHNESS MEASUREMENT OF 2D NANO FILMS UNDER TEM IMAGING	Th2C.003 0.4mm×0.4mm BAROMETER SENSOR-CHIP FABRICATED BY A SCAR-FREE 'MIS' (MINIMALLY INVASIVE SURGERY) PROCESS FOR 0.01US\$/DIE PRODUCT	Th2D.003 A HIGH FOM LITHIUM NIOBATE RESONANT TRANSFORMER FOR PASSIVE VOLTAGE AMPLIFICATION
11:15 - 11:30			
Th2A.004 RT-PCR MICROMODULE BASED ON OLIGO(DT) MICROCOLUMN FOR MICRO TOTAL GENE EXPRESSION ANALYSIS SYSTEM	Th2B.004 MEMORIZING UV EXPOSURE ENERGY IN RESISTANCE-A SMART PATCH BASED ON CONDUCTIVE POLYMER	Th2C.004 CALIBRATION-LESS METHOD FOR MEASURING PRESSURE WITH MICROFABRICATED PIRANI GAUGES	Th2D.004 TRANSFER FUNCTION TUNING OF A BROADBAND SHOALING MECHANICAL AMPLIFIER NEAR THE ELECTROSTATIC INSTABILITY
11:30 - 11:45			
Th2A.005 MICROFLUIDIC MEASUREMENT OF RBC BENDING STIFFNESS CHANGES IN BLOOD STORAGE	Th2B.005 NANOELECTROMECHANICAL SYSTEMS-ENABLED TUNABLE METAMATERIALS	Th2C.005 SENSITIVITY IMPROVEMENT FOR CMOS-MEMS CAPACITIVE PRESSURE SENSOR USING DOUBLE DEFORMABLE DIAPHRAGMS WITH TRENCHES	Th2D.005 A 1.17 GHZ WIDEBAND MEMS FILTER USING HIGHER ORDER SHO LITHIUM NIOBATE RESONATORS
11:45 - 12:00			
Th2A.006 DESIGN AND PERFORMANCE OF A WIRELESS PRESSURE SENSING STENT	Th2B.006 MULTI-DIMENSIONAL MULTI-LEVEL SENSING NANOSTRUCTURE FOR HIGH-PERFORMANCE DETECTION TO TRACE-LEVEL DOPAMINE MOLECULES	Th2C.006 LOW-TEMPERATURE AND PRESSURE RESPONSE OF InAlN/GaN RING - SHAPED HIGH ELECTRON MOBILITY TRANSISTORS	Th2D.006 SELF-OSCILLATION FOR MODE LOCALIZED SENSORS

Session Th2A
Diagnosis
ROOM 301A
10:30 - 12:00

- Th2A.001 USING BACTERIAL SELEX TO SELECT HIGHLY-SPECIFIC APTAMERS AND THEIR APPLICATIONS IN PAPER-BASED MICROFLUIDIC CHIPS FOR RAPID DIAGNOSIS OF MULTIPLE BACTERIA 718**
 C.-H. Wang and G.-B. Lee
National Tsing Hua University, TAIWAN

A paper-based microfluidic system was further developed by using the selected specific aptamers and a biotin-streptavidin color reaction for rapid detection of these four bacteria.

- Th2A.002 AN INTEGRATED PASSIVE MICROFLUIDIC DEVICE FOR RAPID DETECTION OF INFLUENZA A (H1N1) VIRUS BY REVERSE TRANSCRIPTION LOOP-MEDIATED ISOTHERMAL AMPLIFICATION (RT-LAMP) 722**
 Y.-D. Ma, W.-H. Chang, C.-H. Wang, H.-P. Ma, P.-C. Huang, and G.-B. Lee
National Tsing Hua University, TAIWAN

This study presents a passive, self-driven microfluidic device which can rapid identify influenza A virus by using reverse transcription loop-mediated isothermal amplification (RT-LAMP). This is the first time that a passive microfluidic chip was demonstrated which could perform entire process including sample pretreatment, RT-LAMP application and Influenza A diagnosis.

- Th2A.003 AN IMPEDANCE BIOSENSOR FOR SIMULTANEOUS DETECTION OF LOW CONCENTRATION OF SALMONELLA SEROGROUPS IN POULTRY SAMPLES 726**
 I. Jasim¹, A. Abdullha¹, Z. Shen¹, S. Zhang¹, M. Alalem², M. Dewik², and M. Almasri¹
¹University of Missouri, USA and ²Lincoln University Jefferson City, USA

We designed, fabricated and tested a Microelectromechanical system (MEMS) impedance biosensor with three channels for the rapid simultaneous detection of multiple pathogens or pathogen strains with high specificity and sensitivity to detect as low as 7 cells/ml of Ready to Eat (RTE) Turkey samples. The performance of the device was excellent as evidenced by the focusing capability, high sensitivity (<100CFU/ml) and rapid turnaround time of 2 hours.

- Th2A.004 RT-PCR MICROMODULE BASED ON OLIGO(DT) MICROCOLUMN FOR MICRO TOTAL GENE EXPRESSION ANALYSIS SYSTEM 730**
 K. Nakagawa, K. Tsuda, K. Hattori, S. Ato, K. Kido, S. Fujita, and S. Konishi
Ritsumeikan University, JAPAN

We develop micromodule for reverse transcription polymerase chain reaction (RT-PCR). The micromodule consists of the column packed oligo(dT) beads and thermal control system. RT-PCR by the micromodule has been demonstrated using mRNA of β -actin. In a study, the size of obtained cDNA is determined 337 bp by the agarose gel electrophoresis. These results indicate that the target is sufficiently amplified. The developed micromodule can be integrated to the micro total gene analysis system.

- Th2A.005 MICROFLUIDIC MEASUREMENT OF RBC BENDING STIFFNESS CHANGES IN BLOOD STORAGE 734**
 Z. Xu¹, H. Pu², S. Xie², C. Wang^{1,3}, and Y. Sun^{1,2}
¹University of Toronto, CANADA, ²Shanghai University, CHINA, and ³Mount Sinai Hospital, CANADA

Existing microfluidic measurements of red blood cells (RBCs) all use the differently defined phenomenological parameter of deformation indices to characterize the mechanical property of RBCs, leading to controversial conclusions on whether RBCs change their deformability during blood storage. This paper presents the first microfluidic RBC stiffness measurement and reports the quantitative stiffness changes of RBCs over the blood storage process.

- Th2A.006 DESIGN AND PERFORMANCE OF A WIRELESS PRESSURE SENSING STENT 738**
 A. Bulbul and H. Kim
University of Utah, USA

We developed a complete fabrication method of a wireless pressure monitoring stent. A capacitive pressure sensor was fabricated on top of a stent wire and worked based on microfluidic amplification and fluidic digitization technique. To achieve better repeatability we maintained controlled evaporation of liquid inside the fluidic channel. The final stent device showed wireless resonance sensitivity of 162.4Hz/mmHg at a distance of 2 cm.

Session Th2B
Materials
ROOM 301B
10:30 - 12:00

- Th2B.001 HIGH-K THIN FILMS FOR SIMULTANEOUS DIELECTRIC ACTUATION AND DETECTION OF M/NEMS FLEXURAL VIBRATION 742**
 C. Fuinel, F. Mathieu, A. Laborde, L. Mazenq, C. Bergaud, and B. Legrand
University of Toulouse, FRANCE

We show for the first time that a nanometer-scale dielectric thin film can be used as an efficient electromechanical transducer to simultaneously actuate and detect the flexural vibration of micro/nanoresonators. In this study, the first flexural vibrating mode of 16 μ m long, and 350nm-thick cantilevers are actuated by a 15nm-thick silicon nitride layer, and observed close to resonance, at megahertz frequencies. We also extract and compare its transduction efficiency to the analytical model.

- Th2B.002 PHONONIC DETECTION OF MORPHOLOGICAL PHASE TRANSITION IN ATOMIC-LAYERED HAFNIUM-ZIRCONIUM-OXIDE 746**
 M. Ghatge, G. Walters, T. Nishida, and R. Tabrizian
University of Florida, USA

This paper presents a non-optical technique for high-resolution spectroscopy of polymorph films a few atomic layers thick. Acoustic phonons excited by AlN transducers are dispersed in the film under test. The synchronous interrogation of these phonons reveals the morphological properties and enables the detection of phase transitions. The technique is demonstrated for local detection of crystal phase transitions in 10nm hafnium zirconium oxide film subjected to *in-situ* rapid thermal annealing.

- Th2B.003 A MEMS DEVICE FOR FRACTURE TOUGHNESS MEASUREMENT OF 2D NANO FILMS UNDER TEM IMAGING 750**
 C. Cao¹, J.Y. Howe², D. Yin¹, T. Filleter¹, and Y. Sun¹
¹University of Toronto, CANADA and ²Hitachi High-Technologies Canada, CANADA

This paper reports a TEM-compatible MEMS device capable of measuring fracture toughness of 2D films, as the device allows stable *in-situ* electron irradiation of thin films and on-chip tensile test. Electron irradiation can create much more precise pre-defects on 2D films than traditional focused ion beam based approach. Our TEM compatible MEMS can be further used to perform mechanical tensile tests to study the fracture behavior of 2D films.

- Th2B.004 MEMORIZING UV EXPOSURE ENERGY IN RESISTANCE- A SMART PATCH BASED ON CONDUCTIVE POLYMER 754**
 D. Wen^{1,2}, Y. Liu¹, C. Yang³, H. Liu^{1,4}, Y. Wu^{1,4}, X. Li¹, W. Cai¹, Y. Cui¹, B. Zhao¹, H. Zhang², F. Bai², and L. Lin^{1,4}
¹University of California, Berkeley, USA, ²University of Electronic Science and Technology of China, CHINA,
³Analog Devices, USA, and ⁴Tsinghua-Berkeley Shenzhen Institute, CHINA

We have successfully demonstrated an all passive, battery free, wirelessly linked, smart patch sensor to record the UV exposures to human skins. Compared with the state-of-art technologies, two distinctive advancements have been achieved: (1) recording the accumulative UV exposures under sunlight; and (2) achieving ultrahigh sensitivity - 5 orders of sheet resistance drop within 2 hours of sunlight exposures.

- Th2B.005 NANOELECTROMECHANICAL SYSTEMS-ENABLED TUNABLE METAMATERIALS 758**
 Q. Wang, D. Mao, P. Liu, and L. Dong
Iowa State University, USA

MEMS-based tunable meta-atoms exhibit relatively large sizes, and thus their optical resonance wavelengths are difficult to reach near-to-mid infrared (IR) regime and the mechanical resonance frequencies are limited within several tens of kHz. We report a tunable metamaterial in the near-to-mid IR regime realized via nanocantilevers embedded within complementary split ring resonators. This metamaterial affords high modulation frequencies (several tens of MHz) and large amplitude modulation.

- Th2B.006 MULTI-DIMENSIONAL MULTI-LEVEL SENSING NANOSTRUCTURE FOR HIGH-PERFORMANCE DETECTION TO TRACE-LEVEL DOPAMINE MOLECULES 762**
 P. Xu¹, M. Liu¹, X. Li¹, T. Xu¹, and Y. Zhang²
¹Chinese Academy of Sciences, CHINA and ²Shanghai University, CHINA

We employed a novel multi-dimensional nanostructure constructed with three types of nano-building-block as electrochemical sensing material to detect trace dopamine which plays as neurotransmitter in body-fluids. The three building-blocks with different functions combined together exhibit synergistic effect during the detection to dopamine. The detection limit of the sensor to dopamine reaches sub-nM level.

**Session Th2C
Pressure Sensors**
ROOM 304A
10:30 - 12:00

- Th2C.001 PRESSURE SENSITIVE IONIC GEL-FETS OF EXTREMELY HIGH SENSITIVITY OVER 2,200 KPA⁻¹ OPERATED UNDER 2 V 766**
S. Yamada, T. Sato, and H. Toshiyoshi
University of Tokyo, JAPAN

Ionic gel is used for the first time on a ZnO field effect transistor to enhance the gate capacitance due to the electrical double layer, thereby developing an extremely sensitive tactile pressure sensor of 2,200 kPa⁻¹, which is at least 10 times greater than the conventional reports.

- Th2C.002 SUSPENDED GRAPHENE BEAMS WITH TUNABLE GAP FOR SQUEEZE-FILM PRESSURE SENSING 770**
S. Vollebregt, R.J. Dolleman, H.S.J. van der Zant, P.G. Steeneken, and P.M. Sarro
Delft University of Technology, NETHERLANDS

We present suspended graphene squeeze-film pressure sensors fabricated using an innovative process where the molybdenum catalyst layer for multi-layer graphene chemical vapor deposition is also the sacrificial layer to suspend the graphene. This allows for accurate control of the gap size under the beam by varying the Mo thickness and eliminates graphene transfer. Therefore, the approach is suitable for high volume fabrication of MEMS/NEMS sensors and resonators based on suspended graphene.

- Th2C.003 0.4mm×0.4mm BAROMETER SENSOR-CHIP FABRICATED BY A SCAR-FREE 'MIS' (MINIMALLY INVASIVE SURGERY) PROCESS FOR 0.01US\$/DIE PRODUCT 774**
Z. Ni, D. Jiao, H. Zou, J. Wang, and X. Li
Chinese Academy of Sciences, CHINA

We develop an as tiny as 0.4mm×0.4mm piezoresistive absolute pressure sensor (barometer) for as low-cost as 0.01US\$ product, which is widely demanded in smart-phone, drone and consumer-electronic market. It's fabricated by a novel scar-free MIS process (micro-holes inter-etch & sealing) to eliminate the seals from the diaphragm area, thereby achieving good performance of sensitivity=0.98mV/kPa/3.3V and nonlinearity=±0.32%.

- Th2C.004 CALIBRATION-LESS METHOD FOR MEASURING PRESSURE WITH MICROFABRICATED PIRANI GAUGES 778**
P.J. Newby¹, K. Kornelsen², C. Spits¹, and L.G. Fréchette¹
¹Université de Sherbrooke, CANADA and ²Teledyne Dalsa Semiconductor Inc., CANADA

We present a method for using Pirani vacuum gauges which does not require calibration against pressure. This is particularly useful for Pirani gauges integrated in enclosed vacuum packaged dies for hermeticity monitoring, where pressure cannot be controlled. Our method uses a model of the gauge which is fitted to the measured response of the gauge. In order to reduce uncertainty on certain inputs of the model, we combine measurements on several gauges with different geometries.

- Th2C.005 SENSITIVITY IMPROVEMENT FOR CMOS-MEMS CAPACITIVE PRESSURE SENSOR USING DOUBLE DEFORMABLE DIAPHRAGMS WITH TRENCHES 782**
W.-C. Lin¹, C.-L. Cheng¹, C.-L. Wu², and W. Fang¹
¹National Tsing Hua University, TAIWAN and ²Industrial Technology Research Institute, TAIWAN

We present a new capacitive pressure sensor implemented by TSMC 0.18 μm 1P6M CMOS-MEMS process. Features of this design is to exploit double deformable sensing diaphragms with trenches to enhance the sensitivity of capacitive pressure sensor due to stiffness reduction. The sensitivity of designed pressure sensor with trenches on double deformable electrodes is 0.26fF/kPa (within the absolute pressure range of 20kPa~110kPa), which is improved for 2.9-fold as compare with the single diaphragm.

- Th2C.006 LOW-TEMPERATURE AND PRESSURE RESPONSE OF InAlN/GaN RING - SHAPED HIGH ELECTRON MOBILITY TRANSISTORS 786**
C.A. Chapin, R.A. Miller, R. Chen, K.M. Dowling, and D.G. Senesky
Stanford University, USA

For the first time, an InAlN/GaN high electron mobility transistor (HEMT) is leveraged as the sensing element of a micro-pressure sensor and is electrically characterized from 0 to 14 psig at room temperature and -3°C. The microfabrication process, which uses an InAlN/GaN-on-Si substrate, enables monolithic integration with other electronic devices. These results suggest that InAlN/GaN can extend sensing capabilities in cold harsh environments.

**Session Th2D
Resonant MEMS III**
ROOM 304B
10:30 - 12:00

- Th2D.001 259 SECOND RING-DOWN TIME AND 4.45 MILLION QUALITY FACTOR IN 5.5 KHZ FUSED SILICA BIRDBATH SHELL RESONATOR** 790
T. Nagourney, J.Y. Cho, B. Shiari, A. Darvishian, and K. Najafi
University of Michigan, USA

Wine-glass mode shell resonators have applications in precision gyroscopes for navigation systems. A long vibratory decay time constant (τ) can lead to low gyroscope bias instability (B), increasing the duration of reliable navigation. We develop a fused silica resonator with a 259 s τ and 4.45 million quality factor (Q) at 5.5 kHz. This is the longest reported τ and highest Q for any resonator at this size and frequency and we believe it will help produce a gyroscope with $B < 0.01$ deg/hr.

- Th2D.002 TOPOLOGY OPTIMIZATION FOR REDUCTION OF THERMO-ELASTIC DISSIPATION IN MEMS RESONATORS** 794
D.D. Gerrard¹, Y. Chen¹, S.A. Chandorkar¹, G. Yu¹, J. Rodriguez¹, I.B. Flader¹, D.D. Shin¹, C.D. Meinhardt², O. Sigmund³, and T.W. Kenny¹
¹Stanford University, USA, ²University of California, Santa Barbara, USA, and
³Technical University of Denmark, DENMARK

This paper presents a topology optimization method for reducing thermo-elastic dissipation (TED) in MEMS resonators. This algorithm is performed on a clamped-clamped resonant beam to maximize the quality factor (Q). Optimal designs have a Q ten times higher than a solid beam and are 75% higher than previously optimized devices. Furthermore, new designs have intuitive topologies. Beams are fabricated in <111> silicon wafers and experimental measurements of Q agree well with simulation.

- Th2D.003 A HIGH FOM LITHIUM NIOBATE RESONANT TRANSFORMER FOR PASSIVE VOLTAGE AMPLIFICATION** 798
T. Manzanique, R. Lu, Y. Yang, and S. Gong
University of Illinois, Urbana Champaign, USA

This paper reports a lithium niobate resonant transformer that has been demonstrated with a passive open-circuit voltage gain of 35, among the highest for piezoelectric transformers to date. Such a high gain has been attained thanks to the very high figure of merit (89), defined as the product of the electromechanical coupling and quality factor. To our knowledge, this value, enabled by the pronounced piezoelectric properties of lithium niobate, is also the highest for two-port MEMS resonators.

- Th2D.004 TRANSFER FUNCTION TUNING OF A BROADBAND SHOALING MECHANICAL AMPLIFIER NEAR THE ELECTROSTATIC INSTABILITY** 802
V. Maiwald¹, Y. Chen², M. Müller¹, I.B. Flader², C. Roman¹, D.B. Heinz², D.D. Shin², T.W. Kenny², and C. Hierold¹
¹ETH Zürich, SWITZERLAND and ²Stanford University, USA

We present a tunable broadband shoaling mechanical amplifier and a method to extend its operation near the electrostatic pull-in instability. The model has been verified experimentally on a vacuum encapsulated silicon MEMS device. We show that by adding an appropriate mechanical compensation spring, the amplifier can be operated near the pull-in instability in a quasi linear fashion. Furthermore, electrostatic bandpass region and amplification tuning is shown.

- Th2D.005 A 1.17 GHZ WIDEBAND MEMS FILTER USING HIGHER ORDER SHO LITHIUM NIOBATE RESONATORS** 806
Y.-H. Song and S. Gong
University of Illinois, Urbana Champaign, USA

We design, analyze and demonstrate a Lithium Niobate wideband RF MEMS filter with a low insertion loss of 2.1 dB, a wide bandwidth of 4.9 %, and spurious-free passband response at 1.17 GHz. Such high performance was achieved by arraying resonators with pronounced 3rd order longitudinal shear horizontal mode resonances. The 3rd order mode is selected to attain a 3x higher resonant frequency, and subsequently enables filters beyond 1 GHz without resorting to costly fine-resolution lithography.

- Th2D.006 SELF-OSCILLATION FOR MODE LOCALIZED SENSORS** 810
J. Yang, J. Huang, J. Zhong, H. Zhang, and H. Chang
Northwestern Polytechnical University, CHINA

We for the first time realize closed-loop self-oscillation control for mode localized sensors. A symmetrical dual-modes weakly coupled resonators is used and its vibration modes can be selectively locked and the amplitude noises are greatly reduced. The test results show that the resolution (9.304 $\mu\text{N/m}/\sqrt{\text{Hz}}$) and signal to noise ratio (92.23dB) under closed-loop measurement are largely improved compared with those (1.724mN/m/ $\sqrt{\text{Hz}}$ and 45.86dB) under open-loop measurement.

12:00 - 13:00 Lunch

Session Th3A Magnetic	Session Th3B Mixes Session	Session Th3C Electro-Optical Transducers	Session Th3D Microactuators
ROOM 301A	ROOM 301B	ROOM 304A	ROOM 304B
Session Co-Chairs: B. Kim <i>University of Tokyo, JAPAN</i> A. Seshia <i>University of Cambridge, UK</i>	Session Co-Chairs: J. Brugger, <i>École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND</i> S. Shoji, <i>Waseda University, JAPAN</i>	Session Co-Chairs: C. Gorecki <i>Femto-st UBFC, FRANCE</i> M. Mastrangeli <i>Max Planck Stuttgart, GERMANY</i>	Session Co-Chairs: M. Maher <i>SoftMEMS LLC, USA</i> Y.-J. Yang <i>National Taiwan University, TAIWAN</i>
13:00 - 13:15			
Th3A.001 DUAL-RESONATOR MEMS MAGNETIC SENSOR WITH DIFFERENTIAL AMPLITUDE MODULATION	Th3B.001 WEARABLE LOW-POWER WIRELESS LUNG SOUND DETECTION ENHANCED BY RESONANT TRANSDUCER ARRAY FOR PRE-FILTERED SIGNAL ACQUISITION	Th3C.001 ANOMALOUS IMPROVED ELECTRON FIELD EMISSION FROM HYBRIDISED GRAPHENE ON MO TIP ARRAYS	Th3D.001 LOW VOLTAGE ACTUATION OF HIGH FORCE ELECTROSTATIC LATCHES
13:15 - 13:30			
Th3A.002 NOVEL MAGNETIC READOUT FOR HYBRID SPINTRONIC MEMS DEVICES	Th3B.002 MICROELECTROMECHANICAL DETECTOR OF INFRARED SPECTRAL SIGNATURES WITH NEAR-ZERO STANDBY POWER CONSUMPTION	Th3C.002 PLASMONIC SCATTERING RESONANCE ENHANCEMENT IN NANOCIVITY RESONATORS FOR FULL-COLOR PALETTES	Th3D.002 A NONLINEAR ELECTROSTATIC AC- TUATOR WITH NEAR ZERO IMPACT VELOCITY, LOW DRIVING VOLTAGE AND LARGE STABLE TRAVEL
13:30 - 13:45			
Th3A.003 RESONANT MAGNETIC SENSOR USING MAGNETIC GRADIENT FIELD FORMED BY PERMALLOY CONCENTRATOR	Th3B.003 ZINC OXIDE NANOROD INTEGRATED MICRODEVICE FOR MULTIPLEX VIRUS DETECTION	Th3C.003 POLYANILINE ELECTROCHROMIC MICRO-DISPLAY POWERED BY ON-CHIP MG/AGCL BATTERY FOR WIRELESS DATA TRANSFER OF DISPOSABLE BIO-SENSING CHIP	Th3D.003 4-TERMINAL MEMS RELAY WITH AN EXTREMELY LOW CONTACT RESISTANCE EMPLOYING A NOVEL ONE-CONTACT DESIGN
13:45 - 14:00			
Th3A.004 THE PERFORMANCE ENHANCEMENT SCHEME OF ON-CHIP SPIRAL INDUCTORS USING METAL-OXIDE BASED AAO NANOCOMPOSITE	Th3B.004 NANOFLUIDIC DIODE BIOSENSOR FEATURING A SINGLE NANOSLIT FOR LABEL-FREE DETECTION OF CARDIAC TROPONIN BIOMARKER	Th3C.004 CANDLE SOOT WITH BROADBAND HIGH ABSORPTANCE FOR APPLICATIONS OF INFRARED SENSORS	Th3D.004 FIRST STEPS OF A MILLIMETER-SCALE WALKING SILICON ROBOT
14:00 - 14:15			
Th3A.005 A LORENTZ FORCE MAGNETOMETER BASED ON A PIEZOELECTRIC-ON-SILICON RADIAL-CONTOUR MODE DISK	Th3B.005 BREAKING THE DIFFUSION-LIMIT OF THE NANO-PLASMOFLUIDIC BIOSENSING WITH TWO REGIMES OF AC ELECTROHYDRODYNAMIC FLOW	Th3C.005 ULTRA NARROWBAND INFRARED ABSORBERS FOR OMNI-DIRECTIONAL AND POLARIZATION INSENSITIVE MULTI-SPECTRAL SENSING MICROSYSTEMS	Th3D.005 STIMULI-RESPONSIVE MICROFIBER-BUNDLE ACTUATOR WITH HIERARCHICAL ALIGNMENT
14:15 - 14:30			
Th3A.006 A NOVEL POLYMER FILLED CMOS-MEMS INDUCTIVE-TYPE TACTILE SENSOR WITH WIRELESS SENSING CAPABILITY	Th3B.006 THICK SCALN FILM FOR HIGH EFFICIENT ULTRASONIC TRANSDUCER IN LOW FREQUENCY OF 81 MHZ	Th3C.006 AN ELECTRIC FIELD SENSOR WITH DOUBLE-LAYER FLOATING STRUCTURE FOR MEASUREMENT OF DC SYNTHETIC FIELD COUPLED WITH ION FLOW	Th3D.006 MULTISECTION BENDABLE RING-BUCKLE-TYPE SOFT ACTUATOR WITH PHASE CONTROL ABILITY FOR ARTIFICIAL ESOPHAGUS APPLICATIONS
14:30 - 14:45			
Th3A.007 MICRO- TO MILLIMETER SCALE MAGNETIC SHIELDING	Th3B.007 TUBULAR OPTOFLUIDICS AS A VERSATILE OPTICAL TOOLBOX	Th3C.007 SYNTHESIS OF SINGLE LAYER MoS ₂ ARRAY FOR SURFACE RAMAN ENHANCEMENT SPECTROSCOPY	Th3D.007 TUNABLE 3D MONOLITHIC GLASS DIELECTROPHORETIC ACTUATOR FOR OPTOMECHANICS

**Session Th3A
Magnetic**
ROOM 301A
13:00 - 14:45

- Th3A.001 DUAL-RESONATOR MEMS MAGNETIC SENSOR WITH DIFFERENTIAL AMPLITUDE MODULATION 814**
 S. Sonmezoglu¹, I.B. Flader², Y. Chen², D.D. Shin², T.W. Kenny², and D.A. Horsley¹
¹University of California, Davis, USA and ²Stanford University, USA

We report a new micromachined Lorentz force magnetometer that includes a matched-pair of closed-loop resonators with experimentally demonstrated temperature compensation over a dynamic temperature environment. The dual-resonator magnetometer based on differential amplitude modulation (AM) reduces the sensor's offset by a factor of 12 to 26 μT , and significantly suppresses the effect of the resonator's temperature coefficient of quality factor (TCQ) on the output.

- Th3A.002 NOVEL MAGNETIC READOUT FOR HYBRID SPINTRONIC MEMS DEVICES 818**
 R.A. Dias¹, E.E. Moreira², I. Ribeiro^{3,4}, M. Costa¹, H. Fonseca¹, S. Cardoso⁵, P. Freitas¹, L.A. Rocha^{1,2}, and J. Gaspar¹
¹International Iberian Nanotechnology Laboratory, PORTUGAL, ²University of Minho, PORTUGAL,
³Universidade Federal de Viçosa, BRAZIL, ⁴Ciência e Tecnologia do Espírito Santo, BRAZIL, and
⁵INESC-Microsystems and Nanotechnologies, PORTUGAL

We report on a novel spintronics magnetic readout for hybrid MEMS. This transduction method uses magnetic sensors (SVs) and permanent magnets to detect displacement and has the advantage of small form factor, straightforward readout electronics, xyz integrability, and does not require high aspect ratio silicon gaps, allowing to replace conventional capacitive transducers by a mechanism occupying much less chip area.

- Th3A.003 RESONANT MAGNETIC SENSOR USING MAGNETIC GRADIENT FIELD FORMED BY PERMALLOY CONCENTRATOR 822**
 W. Suwa, N. Inomata, M. Toda, and T. Ono
 Tohoku University, JAPAN

We have developed a resonant magnetic sensor using a magnetic concentrator consisted of asymmetric and facing Permalloy plates. The fabricated magnetic sensor was evaluated, and magnetic resolution of $5.1 \times 10^{-7} \text{ T}$ was achieved. The novel technique for magnetic sensing was demonstrated. The possibility that resolution can be improved to $1.7 \times 10^{-14} \text{ T}$ by downsizing the Si cantilever and using the sharp tip, narrow gap Permalloy concentrator was indicated.

- Th3A.004 THE PERFORMANCE ENHANCEMENT SCHEME OF ON-CHIP SPIRAL INDUCTORS USING METAL-OXIDE BASED AAO NANOCOMPOSITE 826**
 J.-H. Chen, Y.-M. Fu, and Y.T. Cheng
 National Chiao Tung University, TAIWAN

The paper presents a scheme to improve the performance of on-chip spiral inductors using Fe₃O₄-AAO nanocomposite. The enhancement principle is to eliminate eddy current loss but keep a high FMR frequency in terms of the additive of nonconductive magnetic nanorod structures. Experimental results show the nH inductors with the nanocomposite magnetic core can exhibit inductance enhancement up to GHz range with Q factor higher than 25.

- Th3A.005 A LORENTZ FORCE MAGNETOMETER BASED ON A PIEZOELECTRIC-ON-SILICON RADIAL-CONTOUR MODE DISK 830**
 S. Ghosh and J.E.-Y. Lee
 City University of Hong Kong, HONG KONG

We report a unique MEMS magnetometer based on a disk shaped radial contour mode thin-film piezoelectric on silicon (TPoS) CMOS-compatible resonator. This is the first device of its kind that targets operation in air as opposed that existing Lorentz force MEMS magnetometers that depend on vacuum. We exploit the chosen vibration mode to enhance coupling to deliver a field sensitivity of 0.22V/T under ambient conditions.

- Th3A.006 A NOVEL POLYMER FILLED CMOS-MEMS INDUCTIVE-TYPE TACTILE SENSOR WITH WIRELESS SENSING CAPABILITY 834**
 S.-K. Yeh, H.-C. Chang, and W. Fang
 Nation Tsing Hua University, TAIWAN

This study presents a novel wireless inductive type CMOS-MEMS tactile sensing unit composed of underneath sensing coil and deformable polymer layer. This tactile-sensing unit is implemented using TSMC 0.18 μm 1P6M CMOS process, in-house post-CMOS releasing, and polymer filling. Experiments show the tactile sensor has the sensitivity of 0.02%/mN within the sensing range of 0-80mN, and the wireless sensing ability is also demonstrated.

- Th3A.007 MICRO- TO MILLIMETER SCALE MAGNETIC SHIELDING 838**
 J.C. Wu¹, L. Li¹, J.C. Harrison¹, and R.N. Candler^{1,2}
¹University of California, Los Angeles, USA and ²California NanoSystems Institute, USA

We demonstrate micro- to millimeter scale, conformal, compact, and high performance magnetic shielding using electrodeposition. The flexibility in shield thickness and shape design, ease of component integration, and scalability through microfabrication will enable compact packaging for atomic, molecular, and optical platforms and non-reciprocal RF devices where the trend of miniaturization brings magnetic sources on-chip.

Session Th3B Mixes Session

ROOM 301B

13:00 - 14:45

- Th3B.001** **WEARABLE LOW-POWER WIRELESS LUNG SOUND DETECTION ENHANCED BY RESONANT TRANSDUCER ARRAY FOR PRE-FILTERED SIGNAL ACQUISITION** 842
A.A. Shkel and E.S. Kim
University of Southern California, USA

We report the implementation and evaluation of an array-based recognition system for low-power medical wheezing detection. A MEMS microphone array is designed and fabricated for pre-filtered acoustic signal acquisition, which simplifies the digital processing necessary for spectral filtering and wheezing recognition. The recognizer is evaluated, and the experimental results show that recognition processing duration and power consumption can be reduced by 94.5%.

- Th3B.002** **MICROELECTROMECHANICAL DETECTOR OF INFRARED SPECTRAL SIGNATURES WITH NEAR-ZERO STANDBY POWER CONSUMPTION** 846
V. Rajaram, Z. Qian, S. Kang, C. Cassella, N.E. McGruer, and M. Rinaldi
Northeastern University, USA

We demonstrate an always-alert infrared (IR) spectral signature detector capable of identifying a specific target using the energy present in the target's IR emission signature itself while consuming near-zero standby power. Using logically-connected plasmonically-enhanced thermomechanical relays, this work aims to revolutionize the battery life of remote sensors by activating the sensor only in the target's presence while keeping it turned OFF otherwise.

- Th3B.003** **ZINC OXIDE NANOROD INTEGRATED MICRODEVICE FOR MULTIPLEX VIRUS DETECTION** 850
X. Yu, Y. Xia, Y. Tang, W.-L. Zhang, Y.-T. Yeh, H. Lu, and S.-Y. Zheng
Pennsylvania State University, USA

We present the development of a zinc oxide nanorod-integrated microdevice for highly sensitive and specific virus detection. The 3D morphology of zinc oxide nanorods and their unique optical property boost virus detection sensitivity. The microfluidic biosensor platform can detect multiple viruses simultaneously by spatial encoding of capture antibodies. The captured viruses can be released by dissolving zinc oxide nanorods for subsequent off-chip analyses.

- Th3B.004** **NANOFLUIDIC DIODE BIOSENSOR FEATURING A SINGLE NANOSLIT FOR LABEL-FREE DETECTION OF CARDIAC TROPONIN BIOMARKER** 854
S. Yeasmin, X. Xing, L. Duan, and L. Yobas
Hong Kong University of Science and Technology, HONG KONG

We presents an integrated nanofluidic diode biosensor based on an asymmetric single nanoslit with a nominal width of 30 nm. The nanoslit dimension is fine-tuned by the highly conformal atomic layer deposition of Al_2O_3 and further modified with a layer of SiO_2 for improved sensing performance. The device has been demonstrated for electrical label-free detection of human cardiac troponin biomarker at clinically relevant concentrations across a range spanning over four orders of magnitudes.

- Th3B.005** **BREAKING THE DIFFUSION-LIMIT OF THE NANO-PLASMOFLUIDIC BIOSENSING WITH TWO REGIMES OF AC ELECTROHYDRODYNAMIC FLOW** 858
Y. Song¹, K. Goto², A. Stephens¹, M.T. Chung¹, Y.G. Park¹, and K. Kurabayashi¹
¹University of Michigan, USA and ²Nagoya University, JAPAN

We developed a label-free AC electrohydrodynamic-enhanced (AC-EHD) localized surface plasmon resonance biofunctional nanoparticle imaging technique to overcome performance barriers in diffusion-limited biosensing. We simultaneously considered two regimes of AC-EHD: electroosmotic and electrothermal effects to achieve optimal mixing performance for biologically relevant fluids with different ion concentrations in theory and experimentally proved the improvement of detection limit.

- Th3B.006** **THICK SCALN FILM FOR HIGH EFFICIENT ULTRASONIC TRANSDUCER IN LOW FREQUENCY OF 81 MHZ** 862
K.-H. Sano¹, R. Karasawa¹, and T. Yanagitani^{1,2}
¹Waseda University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

Large piezoelectricity in 43% Sc doped ScAlN thin film has been recently reported. Bulk ScAlN thick plates are attractive for the low frequency and high power ultrasonic applications such as actuators and medical ultrasonics because ScAlN possess lower mechanical and dielectric losses compared with well-used PZT. The thick ScAlN films, however, has not been reported. The electromechanical coupling coefficient kt^2 was determined to be 19% using the thickness extensional mode at 81 MHz.

- Th3B.007** **TUBULAR OPTOFLUIDICS AS A VERSATILE OPTICAL TOOLBOX** 866
D. Kopp, L. Lehmann, T. Brender, A. Dorn, and H. Zappe
University of Freiburg, GERMANY

We present a new technology which enables the versatile realization of a wide spectrum of optofluidic elements, including focus- and aberration-tunable lenses, prisms withadjustable tip and tilt, and variable apertures, as well as the combination of these into multi-element optical systems.

Session Th3C

Electro-Optical Transducers

ROOM 304A

13:00 - 14:45

- Th3C.001** **ANOMALOUS IMPROVED ELECTRON FIELD EMISSION FROM HYBRIDISED GRAPHENE ON MO TIP ARRAYS** 870
 N.L. Zhu^{1,2}, J. Chen¹, M.T. Cole², and W.I. Milne^{2,3}
¹Peking University, CHINA, ²University of Cambridge, UK, and ³Zhejiang University, CHINA

A new, efficient electron field emitter geometry, based on monolayer graphene coated well aligned Mo tip arrays, is here reported. The rather anomalous, yet nonetheless beneficial contributions of this hybridized nanostructured film morphology is evaluated and discussed. Efficient and stable field emission with low turn on fields has been observed. Incorporation of graphene and Mo tip array results in noteworthy improvements in emission of these nanoscale heterostructure devices.

- Th3C.002** **PLASMONIC SCATTERING RESONANCE ENHANCEMENT IN NANOCAVITY RESONATORS FOR FULL-COLOR PALETTES** 874
 J.R. Fan, W.G. Wu, J. Zhu, Y. Huang, Z.J. Chen, and Y.F. Mao
 Peking University, CHINA

We report a type of plasmonic palettes formed by an array of cross-shaped cavity nanostructures for multicolor image generation. And the nanocross-shaped antenna-hole pairs actually operate as cavity resonators and could realize surface plasmon excitation, resonating and coupling, which can impart intriguing optical properties. These features enable the nanotexted metasurfaces to implement full-gamut palettes through spatially color blending and continuously tunable coloration.

- Th3C.003** **POLYANILINE ELECTROCHROMIC MICRO-DISPLAY POWERED BY ON-CHIP MG/AGCL BATTERY FOR WIRELESS DATA TRANSFER OF DISPOSABLE BIO-SENSING CHIP** 878
 Y. Zhu, T. Tsukamoto, and S. Tanaka
 Tohoku University, JAPAN

We developed a 0.24 μ W electrochromic micro-display as 80 bps data transmitter for disposable bio-sensor chip. The driving system which can be instrumented in CMOS was also developed with on-chip Mg/AgCl battery. The pattern recognition program was developed for automatic data capturing.

- Th3C.004** **CANDLE SOOT WITH BROADBAND HIGH ABSORPTANCE FOR APPLICATIONS OF INFRARED SENSORS** 882
 R. Li^{1,2}, H. Mao¹, Y. Yang^{1,2}, Y. Jia¹, H. Xue¹, J. Xiong², and W. Wang¹
¹Chinese Academy of Sciences, CHINA and ²North University of China, CHINA

This work presents a highly infrared (IR) absorptive material obtained from candle soot. Such a material achieves an average absorptance of 75.1% in a waveband as broad as 1.5-25 μ m. By introducing such a material onto IR sensors, performance of the devices can be improved by 133%. Thus large-scale applications of the material in different IR sensors are predictable.

- Th3C.005** **ULTRA NARROWBAND INFRARED ABSORBERS FOR OMNI-DIRECTIONAL AND POLARIZATION INSENSITIVE MULTI-SPECTRAL SENSING MICROSYSTEMS** 886
 S. Kang¹, Z. Qian¹, V. Rajaram¹, A. Alù², and M. Rinaldi¹
¹Northeastern University, USA and ²University of Texas, Austin, USA

We have experimentally demonstrated wide-angle and polarization insensitive mid-infrared plasmonic absorbers with high absorptivity ($\eta > 91\%$) and the narrowest FWHM (225nm) reported to date, by optimizing geometry and fabrication process of an ultra-thin (400nm) metal-insulator-metal metamaterial structure. The unprecedented performance of such batch-microfabricated and lithographically defined infrared absorbers will introduce new classes of multi-spectral sensing and imaging microsystems.

- Th3C.006** **AN ELECTRIC FIELD SENSOR WITH DOUBLE-LAYER FLOATING STRUCTURE FOR MEASUREMENT OF DC SYNTHETIC FIELD COUPLED WITH ION FLOW** 890
 Q. Ma, K. Huang, Z. Yu, and Z. Wang
 Tsinghua University, CHINA

This paper presents a novel electric field sensor (EFS) based on a double-layer floating structure to measure the DC synthetic electric fields that are strongly-coupled with ion flows. The EFS has been fabricated and tested for measuring three independent field components to separate the DC electrical field. The results demonstrate that the EFS is able to measure the DC electrical field of high-voltage DC (HVDC) transmission lines that has strong coupling with ion flows.

- Th3C.007** **SYNTHESIS OF SINGLE LAYER MoS₂ ARRAY FOR SURFACE RAMAN ENHANCEMENT SPECTROSCOPY** 894
 X. Zhang¹, K. Yao¹, A. Yan¹, J. Li², M. Wei¹, B. Li¹, Y. Chu^{1,3}, and L. Lin^{1,3}
¹University of California, Berkeley, USA, ²Xiamen University, CHINA, and ³Tsinghua Berkeley Shenzhen Institute, CHINA

We present direct synthesis of high quality single-layer MoS₂ array with strong Surface-Enhanced Raman Scattering (SERS). Unprecedented accomplishments: sulfur terminated substrate for the synthesis of CVD MoS₂ array; SERS using the monolayer MoS₂ array with partially bowtie structure. First demonstration of SERS and PL on MoS₂ covered with Al₂O₃, which address the physical enhancement by Foster resonance energy transfer (FRET) and the hotspot in the Bowtie structure MoS₂ array.

**Session Th3D
Microactuators**
ROOM 304B
13:00 - 14:45

- Th3D.001 LOW VOLTAGE ACTUATION OF HIGH FORCE ELECTROSTATIC LATCHES 898**
J.T. Greenspun and K.S.J. Pister
University of California, Berkeley, USA

We design and fabricate an electrostatic latch capable of restraining forces over 170 mN with voltages as low as 38 V. To produce the highest force at the lowest voltage, a high k dielectric is used to separate the two electrically active leads of the latch.

- Th3D.002 A NONLINEAR ELECTROSTATIC ACTUATOR WITH NEAR ZERO IMPACT VELOCITY, LOW DRIVING VOLTAGE AND LARGE STABLE TRAVEL 902**
X.J. Xiang, X.H. Dai, S. Sun, G.F. Ding, and X.L. Z.
Shanghai Jiao Tong University, CHINA

We propose a nonlinear electrostatic actuator which utilizes the nonlinear mechanical properties of the classical clamped-guided beam springs with large deformation to slow the movable plates to near zero impact speed and acquire lower driving voltage than the linear spring counterpart, and extend the stable travel to about 56.5% of the initial gap.

- Th3D.003 4-TERMINAL MEMS RELAY WITH AN EXTREMELY LOW CONTACT RESISTANCE EMPLOYING A NOVEL ONE-CONTACT DESIGN 906**
Y.-H. Yoon, Y.-S. Jin, C.-K. Kim, S.-C. Hong, and J.-B. Yoon
Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper reports a unique 4-terminal MEMS relay (actuation is electrically isolated with signal passage) employing a novel one-contact design to overcome high contact resistance problem of the conventional 4-terminal MEMS relay which utilizes a typical two-contact design. The fabricated 4-terminal MEMS relay with the one-contact design demonstrated a contact resistance of 18 mΩ, which is two order-of-magnitude lower value than that of the two-contact design.

- Th3D.004 FIRST STEPS OF A MILLIMETER-SCALE WALKING SILICON ROBOT 910**
D.S. Contreras, D.S. Drew, and K.S.J. Pister
University of California, Berkeley, USA

This paper shows the first steps of a silicon microrobot. The robot measures 5mm×6mm and weighs 18mg. Based on a combination of planar silicon linkages and linear electrostatic inchworm motors the robot moves by flipping the chip vertically and having the end of the linkage actuate along the ground.

- Th3D.005 STIMULI-RESPONSIVE MICROFIBER-BUNDLE ACTUATOR WITH HIERARCHICAL ALIGNMENT 914**
S. Nakajima¹, R. Kawano², and H. Onoe²
¹Keio University, JAPAN and ²Tokyo University of Agriculture and Technology, JAPAN

We describe a stimuli-responsive microfiber-bundle actuator that has hierarchical alignment from molecular scale to macroscopic scale. We succeeded in aligning the orientation of molecular scale polymer chains in the stimuli-responsive hydrogel microfiber, which enhances the shrinkage of axial direction of the microfiber. We also demonstrated a macro-scale structure by bundling the microfibers. The actuation of the bundled microfiber was confirmed by stimulating with temperature.

- Th3D.006 MULTISECTION BENDABLE RING-BUCKLE-TYPE SOFT ACTUATOR WITH PHASE CONTROL ABILITY FOR ARTIFICIAL ESOPHAGUS APPLICATIONS 918**
G.-H. Feng and H.-W. Hsu
National Chung Cheng University, TAIWAN

A multisection bendable actuator with a soft ring-buckle-type arm pair in each section is reported. The actuator is made of ionic polymer metal composite (IPMC) with our newly developed fabrication process. Novel flip lock connectors and parylene cables are fabricated and further integrated with the IPMC actuator to effectively provide squeezing pressure and electrical signals. A flexible tube is created and assembled with the IPMC actuator as an active esophagus mimic for testing.

- Th3D.007 TUNABLE 3D MONOLITHIC GLASS DIELECTROPHORETIC ACTUATOR FOR OPTOMECHANICS 922**
T. Yang and Y. Bellouard
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We report a dielectrophoresis-based 3D monolithic micro-actuator fabricated and tuned by femtosecond laser. This actuation principle suppresses the need for electrodes on the mobile elements and is useful for manipulating optical components. We then demonstrate the tuning of the nonlinear behavior of the actuator at resonant mode by locally tailoring the material properties of the resonating elements using laser. This generic tuning principle suggests high potential in tunable sensors.

14:45 - 15:00	Transition Break
15:00 - 15:30	Award Ceremony and Closing Remarks
15:30	Conference Adjourns

■ M - Monday	14:00 - 16:00
■ T - Tuesday	14:00 - 16:00
■ W - Wednesday	14:00 - 16:00

MONDAY - Mechanical/Physical Sensors and Microsystems

- M3P.001** **3D PRINTED "SMART SCREW" WITH BUILT-IN LC SENSING CIRCUIT FOR WIRELESS MONITORING** 926
 S.-Y. Wu, C.-C. Lin, D.-Y. Lin, A.-L. Chen, C.-S. Chuang, W.-C. Huang, and S.-H. Liu
Industrial Technology Research Institute (ITRI), TAIWAN

"Smart screw", which is fabricated by metallic 3D printing, contains an inductor capacitor resonant circuit, of which the resonance frequency is determined by the gap of the structure inside the smart screw. As the gap is changed due to external force or the deformation of the smart screw, the resonance frequency will shift or vanish and be detected wirelessly in real time. This work enables an innovative scheme for built-in sensing application for high value mechanical components.

- M3P.002** **A FRONT-SIDE NON-SOI FABRICATED TRI-AXIS CAPACITIVE ACCELEROMETER WITH ELECTROMECHANICAL SIGMA-DELTA MODULATORS INTERFACE** 930
 F. Chen¹, Y. Zhao¹, H.S. Zou¹, M. Kraft², and X. Li¹
¹Chinese Academy of Sciences, CHINA and ²University of Liege, BELGIUM

We present a novel front-side fabricated tri-axis capacitive accelerometer with a dual quantization electromechanical sigma delta modulator interface circuit. The accelerometer is fabricated using bulk-micromachining from the front-side of a (111) silicon wafer, which has advantages for IC-compatible fabrication. The MEMS chip size is 2.6mm×2.6mm. The cross-axis sensitivity was in the order of 1% to 3%. The output noise was in the order of 2mg/√Hz, with a one hour bias drift of 3mg.

- M3P.003** **A NOVEL HYBRID CONTACTLESS SUSPENSION WITH ADJUSTABLE SPRING CONSTANT** 934
 K.V. Poletkin
Karlsruhe Institute of Technology, GERMANY

This paper reports a micro-fabricated prototype of a novel hybrid contactless suspension, in which a vertical component of stiffness is decreased in a controlled way. The decreasing is performed by the electrostatic field generated by a set of electrodes and acting on electromagnetically levitating a conductive disk shaped proof mass. The preliminary results accommodating with nonlinear modelling prove the concept and showed the successful levitation of the PM within electrostatic field.

- M3P.004** **A SYSTEM FOR VECTOR MEASUREMENT OF AERODYNAMIC WALL SHEAR STRESS** 938
 C. Barnard, D. Mills, and M. Sheplak
University of Florida, USA

A sensor system for vector measurement of aerodynamic shear stress is developed. Utilizing serpentine tethers, variable gap comb-finger capacitors, and a dual-frequency synchronous modulation interface circuit, the system is able to provide real-time measurement of mean and fluctuating wall shear stress components with true directional capability. Calibrations are performed with a laminar flow cell and acoustic plane wave tube, yielding a sensitivity of 0.14 mV/Pa and 4kHz resonance.

- M3P.005** **AIN/6H-SiC SAW RESONATOR FOR HIGH TEMPERATURE WIRELESS SAW SENSOR** 942
 W.Z. Wang, Y. Ruan, and Z. You
Tsinghua University, CHINA

We designed and fabricated a Surface acoustic wave (SAW) resonator based on the AIN/6H-SiC multilayer structure. The results show that highly c-axis-oriented AIN thin films are obtained. Besides, in order to investigate its high-temperature (from 25°C to 300°C) performances, a high temperature testing system was established and the temperature coefficient of frequency (TCF) values is -0.04969 MHz/°C, which makes the SAW resonator a potential temperature sensor in high temperature applications.

- M3P.006** **BREAKING THE SIZE BARRIER OF CAPACITIVE MEMS MICROPHONES FROM CRITICAL LENGTH SCALE** 946
 W. Sui¹, W. Zhang¹, K. Song², C.-H. Cheng³, and Y.-K. Lee¹
¹Hong Kong University of Science and Technology, HONG KONG, ²Xiangtan University, CHINA, and
³Hong Kong Polytechnic University, HONG KONG

Based on the synergy of a theoretical one-dimensional (1D) model and the experimental validation of fabricated capacitive microphones using the PolyMUMPs process, we identify the existence of a critical diaphragm radius, the inflection point on the microphone's sensitivity-radius curve. To overcome this miniaturization barrier, we propose a new microphone structure. The corresponding sensitivity remains the same, while the radius reduces by 17% in comparison with the previous design.

- M3P.007** **DESIGN AND FABRICATION OF WAFER-LEVEL PACKAGED MEMS PIRANI GAUGE WITH SURROUNDED HEAT SINKS** 950
Y. Kong, B. Jiao, L. Zhang, S. Yun, and D. Chen
Chinese Academy of Sciences, CHINA

We present a wafer-level packaged MEMS Pirani gauge with surrounded heat sinks and enhanced dynamic range and sensitivity. The gauge is $1.4\text{mm} \times 1.2\text{mm} \times 0.5\text{mm}$ using the CMOS-MEMS compatible process. With a hole on the edge of the device, it could be widely and flexibly used for the characterization of vacuum packaged MEMS devices.

- M3P.008** **DOUBLE MZI MICRO-OPTO-MECHANICAL PRESSURE SENSORS FOR INCREASED SENSITIVITY AND PRESSURE RANGE** 954
V. Rochus¹, R. Jansen¹, B. Figeys¹, F. Verhaegen^{1,2}, R. Rosseel³, P. Merken³, S. Lenci¹, and X. Rottenberg¹
¹imec, BELGIUM, ²Katholieke Universiteit Leuven, BELGIUM, and ³Royal Military Academy, BELGIUM

This paper presents novel integrated Micro-Opto-Mechanical Pressure Sensors exhibiting excellent measurement precision in a large pressure range. The performance gain compared to classical designs is obtained by using a phase shift and by combining two Mach-Zendher Interferometers on a single membrane. A balanced design and a power tap output allow to de-embed the noise generated by the laser and eases bandwidth requirements, allowing the use of an off-the-shelf laser diode.

- M3P.009** **EXPERIMENTAL AND NUMERICAL ANALYSIS OF COMPLETE ACOUSTIC BAND GAPS IN THREE-DIMENSIONAL PHONONIC CRYSTALS** 958
F. Lucklum, F. Bunge, and M.J. Vellekoop
University of Bremen, GERMANY

We present the acoustic characteristics of additively manufactured 3D phononic crystals for different cubic unit cell geometries. Numerical analysis of band structure and phononic band gaps is experimentally validated by acoustic transmission in different characteristic spatial directions and supplemented by numerical transmission analysis. The elements form the building blocks of phononic-fluidic systems for measuring physical properties such as fluid density, speed of sound, and concentration.

- M3P.010** **FABRICATION OF CARBON NANOTUBE-COATED FABRIC FOR HIGHLY SENSITIVE PRESSURE SENSOR** 962
S. Pyo¹, E. Jo¹, D.-S. Kwon¹, W. Kim¹, W. Chang², and J. Kim¹
¹Yonsei University, KOREA and ²Kitronyx, Inc., KOREA

This paper reports a highly sensitive pressure sensor using CNT-coated polyester fabric. We produced conductive fabric with simple and cost-effective dip-coating process using CNT ink. When the pressure is applied, the highly porous structure of the fabric allows the dramatic improvement of the mechanical contacts between fibers, leading to more electrical contacts in the CNT networks. We observed decrease in resistance under pressure and the maximum sensitivity reached $\sim 10.63\%/kPa$.

- M3P.011** **HIGH ELECTROMECHANICAL COUPLING PIEZOELECTRIC MICRO-MACHINED ULTRASONIC TRANSDUCER (PMUT) ELEMENTS FOR MEDICAL IMAGING** 966
K.M. Smyth, C.G. Sodini, and S.-G. Kim
Massachusetts Institute of Technology, USA

We aim to realize high performance piezoelectric micro-machined ultrasonic transducers (pMUTs) through the development of a validated, analytical multi-domain single cell equivalent circuit model that is scaled to optimize multi-cell elements in a 1D array. The optimized elements are fabricated via a commercially viable, wafer-scale manufacturing process. A top-down fabrication approach facilitates achievement of high pMUT cell packing density and state-of-the-art electromechanical coupling.

- M3P.012** **HIGH TEMPERATURE COEFFICIENT OF RESONANT FREQUENCY INDUCED BY THERMAL STRESS USING A DOUBLE-SUPPORTED MECHANICAL RESONATOR WITH A SIMPLE STRUCTURE FOR HIGHLY THERMAL SENSING** 970
N. Inomata and T. Ono
Tohoku University, JAPAN

A resonant frequency changes of some shape double-supported mechanical resonators are investigated for highly sensitive thermal measurements using mechanical resonant sensors. The resonant frequency changes of the Y, T, I and arrow shape resonators are experimentally evaluated changing the temperature, and compared with the theoretical thermal stress change. The experimental resonant frequency change and theoretical thermal stress has a good agreement.

- M3P.013** **LOW POWER SUB-MILLIGRAM RESONANT MEMS LOAD SENSOR** 974
C. Do, A. Ganesan, and A.A. Seshia
University of Cambridge, UK

This work introduces an implementation of a load sensor using a vacuum packaged MEMS resonator. The load sensor is designed to reduce creep and hysteresis issues by eliminating additional adhesive layers found in many conventional load cells and previously developed MEMS devices. A prototype sensor demonstrates a resolution of 0.1mg over a load range of 300mg with very high linearity. An energy efficient front-end CMOS readout circuit consumes only 5 μW from a 1.2V supply.

M3P.014 MICROSCALE LIQUID MARBLE-BASED TILT MOTION SENSOR USING OPTICAL FIBER FABRY-PEROT INTERFERENCE 978

C. Li^{1,2}, X. Li¹, X. Yu¹, X. Peng¹, and S. Fan¹

¹Beihang University, CHINA and ²Science and Technology on Metrology and Calibration Laboratory, CHINA

We demonstrate a miniature and low-cost liquid marble-based optical fiber tilt angle sensor prototype by using Fabry-Perot interference. A mercury marble, working as a light reflector, is dispensed into a capillary tube preprocessed by hydrophobic agent. The gravitational acceleration solved by tilt angle in the range of 0-90° shows a good fitted linear sensitivity, in agreement well with the governing model incorporating with the effect of contact angle hysteresis between droplet and substrate.

M3P.015 NEW PARALLELOGRAM 3D-DISPLACEMENT SENSOR FOR MICRO PROBING AND DIMENSIONAL METROLOGY 982

D. Metz and A. Dietzel

Braunschweig University of Technology, GERMANY

Silicon parallelogram linkages have been developed, modeled, and optimized for the use in tactile micro measurement techniques. On wafer level produced linkages incorporate highly sensitive piezo-resistors as diffusion doped resistive paths and can measure displacements with a good linearity over a wide range. With a combination of three linkages a 3D micro probing system can be constructed with an isotropic mechanical behavior and low mechanical stiffness.

M3P.016 POLYMER BASED THICKNESS SHEAR MODE ACOUSTIC RESONATOR FOR SENSING OF FLUID COMPLEX SHEAR MODULUS 986

S. Bhadra¹ and K. Walus²

¹McGill University, CANADA and ²University of British Columbia, CANADA

This paper describes a new low-cost high-quality acoustic device for complex shear modulus measurement of fluid. The sensor is based on thickness shear mode (TSM) piezoelectric resonator. It consists of stretched and poled polyvinylidene fluoride (PVDF) films utilizing the shear piezoelectric properties of PVDF. Experiments demonstrate that the sensor can measure the change of complex shear modulus with a sensitivity of 0.035 kHz/Pa and detection limit of 107.95 Pa over 50-900 Pa range.

M3P.017 ENERGETIC ION RADIATION EFFECTS ON A SILICON CARBIDE (SiC) MULTIMODE RESONATING DIAPHRAGM 990

H. Chen¹, V. Pashaei¹, W. Liao², C.N. Arutt², H. Jia¹, M.W. Mcurdy², C.A. Zorman¹, R.A. Reed², R.D. Schrimpf², M.L. Alles², and P.X.-L. Feng¹

¹Case Western Reserve University, USA and ²Vanderbilt University, USA

Harsh environments, such as radiation scenarios, have made very high demands for performance, stability and lifetime of semiconducting materials. Silicon carbide (SiC), with exceptional mechanical properties and chemical inertness, is one of the best materials that could meet the requirements. Here we report on measuring radiation effects of oxygen ions impacting on SiC diaphragm resonators.

M3P.018 SELF-POWERED, HIGHLY SENSITIVE PRESSURE SENSOR BASED ON THIN-FILM SOLAR CELL AND PRESSURE-RESPONSIVE POROUS ELASTOMER FILM 994

D. Kwon, K. Na, K. Kang, J.-Y. Lee, and I. Park

Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper reports a novel flexible optical pressure sensor based on a porous elastomer film as a light transmission medium with ultra-high sensitivity and simplicity. The pore-closing behavior under external pressure and corresponding change of light transmittance of porous elastomer film were investigated. Finally, the optical pressure sensor was integrated with thin film solar cell to modulate the generated electrical current towards self-powered sensing platform.

M3P.019 SINGLE-USE FLOW SENSOR BASED ON THE DIFFERENTIAL PRESSURE PRINCIPLE EMPLOYING THE RADIAL EXPANSION OF A LOW-COST SILICONE TUBE 998

S. Kartmann¹, F. Koch¹, R. Zengerle¹, P. Koltay^{1,2}, and A. Ernst²

¹University of Freiburg, GERMANY and ²BioFluidix GmbH, GERMANY

We present a flow sensor consisting of low-cost consumable parts, to minimize the risk of cross-contamination in medical applications. The consumable component consists of two simple silicone tubes and a capillary, which can be exchanged easily and cost-effectively after use. We characterized the flow sensor based on the differential pressure principle in the range from 0 up to 50 µL/s. The sensor showed a good linearity and consistency with the reference and a sensor resolution of 0.4 µL/s.

- M3P.020 THERMOMECHANICAL NOISE OF ARRAYED CAPACITIVE ACCELEROMETERS WITH 300-NM-GAP SENSING ELECTRODES 1002**
T. Tsuchiya, Y. Matsui, Y. Hirai, and O. Tabata
Kyoto University, JAPAN

Thermomechanical noise of arrayed 80- μm -square capacitive accelerometers with 300-nm-gap sensing electrodes was evaluated. Following the size effect, we predicted and demonstrated that 10 \times 10 array of the one-tenth sized accelerometer had the same scale factor as that of millimeter sized one. From the damping coefficient estimated using electrical equivalent circuit modeling, the thermomechanical noise was below 3 $\mu\text{g}/\sqrt{\text{Hz}}$ at 100Pa, which is low enough for instrument applications.

- M3P.021 ULTRA-LOW NOISE TRANSIMPEDANCE AMPLIFIER FOR HIGH-PERFORMANCE MEMS RESONANT GYROSCOPES 1006**
J.-K. Woo, C. Boyd, J. Cho, and K. Najafi
University of Michigan, USA

We present a transimpedance amplifier for high-performance MEMS gyroscopes. The circuitry uses a digitally-controlled T-network floating resistor as feedback resistor. This new architecture is highly advantageous due to its ability to get low-noise, high feedback gain stability, and a large voltage swing, all of which are critically important for a high-performance gyroscope. When combined with a high-Q MEMS gyroscope, this readout circuit produces a near-navigation-grade gyroscope performance.

- M3P.022 WIDE BANDWIDTH CAPACITIVE ACOUSTIC EMISSION SENSOR WITH STOPBAND MOVABLE ELECTRODES 1010**
H. Yang, K. Sun, B. Pei, C. Dou, and X. Li
Chinese Academy of Sciences, CHINA

This paper presents for the first time a capacitive acoustic emission (AE) sensor with movable electrodes, which operate at stopband. Stopband electrodes cannot be excited by an AE signal, while the substrate vibrates with the signal. The change in the capacitance between the stopband electrodes and substrate is proportional to the amplitude of the AE signal. As bandwidth and sensitivity are not limited by the mechanical properties of the movable electrodes, the sensor features a wide bandwidth.

TUESDAY - Mechanical/Physical Sensors and Microsystems

- T3P.001 A BIAxIAL RESONANT TILT SENSOR WITH TWO-STAGE MICROLEVERAGE MECHANISMS 1013**
H. Ding, X. Le, Y. Ma, and J. Xie
Zhejiang University, CHINA

This paper firstly reports a biaxial resonant tilt sensor with two-stage microleverage mechanisms. The two-stage microleverage possesses higher amplification factor than the single-stage counterpart. For biaxial measurements, the decoupling beams are utilized. The proposed sensor has high sensitivity (X-axis: 4.351Hz/deg and Y-axis: 5.257Hz/deg) and low cross-axis sensitivity (X-axis: 0.1801Hz/deg and Y-axis: 0.2021Hz/deg) for a ± 40 degree biaxial tilt angle range compared to state of the art.

- T3P.002 A MEMS BASED INTEGRATED THREE AXIAL ELECTROCHEMICAL SEISMIC SENSOR 1017**
L.H. Chen^{1,2}, D.Y. Chen¹, J.B. Wang¹, Z.Y. Sun^{1,2}, G.L. Li^{1,2}, and J. Chen¹
¹Chinese Academy of Sciences, CHINA and ²University of Chinese Academy of Sciences, CHINA

This paper firstly presents an integrated three-axis electrochemical seismic sensor based on MEMS technology. The integrated device can detect three-axis vibration through the decoupling of four sensing units. Instead of huge volume in conventional three-axis sensor, it has an extremely small size same as single axis sensor. MEMS technology is used in the fabrication progress of the sensing unit.

- T3P.003 A NOVEL SELF-POWERED PIEZOELECTRIC THREE-AXIS MEMS MAGNETIC SENSOR 1021**
P.-C. Yeh, H. Duan, and T.-K. Chung
National Chiao Tung University, TAIWAN

This paper demonstrated a self-powered piezoelectric three-axis MEMS magnetic sensor. The sensor consists of a silicon diaphragm, a PZT thin-film, and two patterned Ni thick-films. When three-axial magnetic fields are applied to the sensor, alternating magnetic forces/torques are induced in two Ni-films and corresponding different piezoelectric responses are produced. The results show the sensor successfully senses three-axial magnetic fields and has a decent linearity in the range of 5G-70G.

- T3P.004 A WEARABLE PRESSURE AND TEMPERATURE SENSOR ARRAY USING POLYSILICON THIN FILM ON POLYIMIDE 1025**
Z. Wu and C.H. Ahn
University of Cincinnati, USA

We report a high sensitive flexible and wearable pressure and temperature sensor array with polysilicon thin film (PTF) developed on polyimide at low temperature. The developed pressure sensor has high sensitivity of 1.01 mV/ kPa and resolution of 100 Pa, and temperature sensor has high sensitivity of 2.26 mV/ $^{\circ}\text{C}$ and resolution of 0.1 $^{\circ}\text{C}$. The array with high sensitivity, resolution and low cross talk can be applicable for the electronic skin, prostheses and biomedical monitoring.

- T3P.005 ANEMOMETER WITH THREE-DIMENSIONAL DIRECTIONALITY FOR DETECTION OF VERY LOW SPEED AIR FLOW AND ACOUSTIC PARTICLE VELOCITY DETECTING CAPABILITY** 1029
Z. Luo, Z. Li, C. Gao, Y. Hao, and Y. Jin
Peking University, CHINA

We develop a micro-fabricated anemometer with three-dimensional directionality based on thermal Thomas flowmeter principle, which is capable of measuring very low airflow speed. This sensor has three layers of resistive platinum beams. Experiments on speed lower than 50 mm/s are conducted, showing acceptable repeatability and obvious directionality. To explore its potential, we expose it to acoustic flow and observed response reveals its capability of detecting acoustic particle velocity.

- T3P.006 CAPACITIVE SENSING ELECTRODES WITH REDUCED SQUEEZE-FILM DAMPING** 1033
A. Sorger¹, J. Classen², and J. Mehner¹
¹Chemnitz University of Technology, GERMANY and ²Robert Bosch GmbH, GERMANY

We report on a new design of closing-gap capacitive electrodes which significantly reduces the squeeze-film damping of the sense electrodes in MEMS inertial sensors with only minor reduction of electrical sensitivity. The design is realized using a novel surface micromachining process featuring an additional polysilicon layer. We present a comprehensive proof of concept by means of CFD and electric field simulations as well as SEM images and measurement data.

- T3P.007 DESIGN AND IMPLEMENTATION OF A CMOS-MEMS MICROPHONE WITHOUT THE BACK-PLATE** 1037
W.-J. Mao, C.-L. Cheng, S.-C. Lo, Y.-S. Chen, and W. Fang
National Tsing Hua University, TAIWAN

This study exploits the CMOS-MEMS technology to demonstrate a condenser microphone without back-plate. The reference electrodes are fixed to substrate, and thus no back-plate is required. To reduce unwanted deformations resulted from residual-stresses and temperature variation, the acoustic diaphragm and sensing electrodes are formed by pure-dielectric and symmetric metal-dielectric layers. The design enables the CMOS-MEMS microphone having good temperature stability

- T3P.008 EFFECT OF STRESS ON SPLIT MODE GYROSCOPE BIAS: AN EXPERIMENTAL STUDY** 1041
Y. Zhao, Z.H. Wang, G.M. Xia, Q. Shi, and A.P. Qiu
Nanjing University of Science and Technology, CHINA

The effect of external stress on split mode gyroscope bias is identified by experimental approach for the first time in this paper. Two mechanisms are validated through a series of verification experiment, namely, variation of quadrature error and in-phase leakage from drive axis. Both of them are believed arisen from anchors' unbalanced displacement due to applied stress.

- T3P.009 EXPERIMENTAL STUDY OF THE ACOUSTOELASTIC EFFECT ON THE SENSITIVITY OF SURFACE ACOUSTIC WAVE SENSORS** 1045
A. Teshigahara, T. Takahata, Y. Yamamoto, and H. Tei
Denso Corporation, JAPAN

We investigate the sensitivity deterioration phenomenon of SAW sensors. Assuming that the acoustoelastic effect causes this phenomenon and that the effect can be characterized with two coefficients for stress components parallel and perpendicular to SAW propagation direction, we develop a method to quantify these coefficients. We find that the coefficient for the stress parallel to the propagation direction causes sensitivity deterioration for Sc doped AlN film on 6H-SiC substrate structure.

- T3P.010 FREQUENCY FLUCTUATIONS IN MONO- AND POLYSILICON RESONATORS: A NEW LIMIT OF DETECTION** 1049
M. Sansa, I. Ouerghi, M. Gely, T. Alava, T. Ernst, G. Jourdan, and S. Hentz
CEA, LETI, FRANCE

It has been recently shown that resonance frequency fluctuations degrade the limit-of-detection of high-purity monocrystalline resonating sensors. A thorough literature study has shown this is likely the case for a wide variety of resonators. Here we provide additional insight into the physical source of these fluctuations: our results suggest that defect motion in the crystalline structure of the material is not a major source of fluctuations in silicon resonators.

- T3P.011 HIGH FILL FACTOR PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS ON TRANSPARENT SUBSTRATES** 1053
G.-L. Luo¹, S. Fung¹, Q. Wang¹, Y. Kusano¹, J. Lasiter², D. Kidwell Jr.², and D.A. Horsley¹
¹University of California, Davis, USA and ²Qualcomm Technologies, Inc., USA

In this study, it proposed the approaching of high fill-factor AlN PMUTs on the glass substrate from design, manufacturing, measurement, and analysis. It provides the novel ultrasonic device with optical transparency and lower parasitic capacitance.

- T3P012 PRECISE CURRENT SENSING USING A PIEZOELECTRIC CANTILEVER BASED CURRENT SENSOR 1057**
W. Xian¹, X. Li¹, D.F. Wang^{1,2}, T. Kobayashi², T. Itoh³, and R. Maeda²
¹Jilin University, CHINA, ²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN and
³University of Tokyo, JAPAN

A position and pose free solution is proposed based on the modification of equivalent circuit model of piezoelectric cantilever. A system of equations in regard to variables including amplitude of objective current is established. By solving the system, amplitude of objective current can be derived. Experimental results prove validity of the proposed model and solution. Measurement errors are decreased significantly from range of 3.04% to 12.9% to range of 0.11% to 0.74%.

- T3P013 MAXIMUM FORCE CAPACITY OF LEGS OF A FRUIT FLY DURING LANDING MOTION 1061**
H. Takahashi, R. Furuya, T. Yano, K. Ito, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on measurement of landing force of a fruit fly using a MEMS force plate. By measuring the landing force, we found that the maximum force correlated with the landing velocity, which varied from several to 100 times larger than its weight. The experimental result suggested that there was the threshold value of the maximum landing force per weight, which determined the landing mode; contacting with six legs and colliding bodily to the ground according to the landing velocity.

- T3P014 MONOLITHIC TRI-AXIS CANTILEVER HIGH-SHOCK ACCELEROMETERS FABRICATED WITH A SINGLE-SIDED PROCESS IN (111) WAFERS 1065**
H.S. Zou^{1,2}, J.C. Wang¹, H.F. Bao¹, F. Chen¹, and X.X. Li^{1,2}
¹Chinese Academy of Sciences, CHINA and ²University of the Chinese Academy of Sciences, CHINA

Monolithic tri-axis micro-cantilever high-g shock accelerometers are developed by using a single-sided micromachining process in (111) silicon wafer for the first time. No double-wafer bonding process is needed so very high mechanical strength is ensured and wafer bonding induced residue stress can be avoided. The 3D micro-structure sizes of all the three-axis cantilever sensing structures can be well controlled, thereby achieving uniform high-performance for all the three sensors.

- T3P015 ON THE CO-INTEGRATION OF A THERMO-RESISTIVE FLOW-RATE SENSOR IN A MULTI-PARAMETER SENSING CHIP FOR WATER NETWORK MONITORING 1069**
F. Shaun¹, E. Nefzaoui¹, H. Regina¹, W. Cesar², F. Marty¹, M. Capochichi-Gnambodoe¹,
P. Poulichet¹, F. Peressutti¹, S. Sarkar¹, and T. Bourouina¹
¹Université Paris-Est, FRANCE and ²Fluigent, FRANCE

Motivated by the need for multi-parameter sensing chip for monitoring water networks, we address here the specific case of a flow rate sensor where the main challenge is the substrate material. Instead of using conventional low thermal conductivity materials such as glass, silicon has to be used absolutely. Indeed, a silicon substrate enables the co-integration of various kinds of sensors on the same chip as shown here. We study an optimized low power micro-machined flowrate sensor.

- T3P016 PRESSURE AND TEMPERATURE DETERMINATION WITH MICROMACHINED GAN/SI SAW BASED RESONATORS OPERATING IN THE GHZ FREQUENCY RANGE 1073**
A. Müller¹, G. Konstantinidis², A. Stefanescu¹, I. Giangu¹, A. Stavrinidis²,
M. Pasteanu¹, G. Stavrinidis², and A. Dinescu¹
¹IMT Bucharest, ROMANIA and ²FORTH-IESL-MPG Heraklion, GREECE

Experimental development of membrane supported single resonator GaN/Si SAW sensor structures, operating in the 3-12 GHz frequency range, is described. Advanced nano-lithographic and micromachining techniques have been used in manufacturing. Rayleigh and Lamb resonance frequency peak shifts vs. pressure and temperature were used for simultaneous determinations of these parameters. Very high values for the pressure and temperature sensitivities have been obtained due to high frequency operation.

- T3P017 RESEARCH ON THE PACKAGING RELIABILITY AND DEGRADATION MODELS OF QUALITY FACTORS FOR A HIGH VACUUM SEALED MEMS GYROSCOPE 1077**
C.H. He^{1,2,3}, Y.P. Wang¹, Q.W. Huang², Q.C. Zhao¹, Z.C. Yang¹, D.C. Zhang¹, and G.Z. Yan¹
¹Peking University, CHINA, ²Science and Technology on Reliability Physics and Application of Electronic Component Laboratory, CHINA, and ³Midea Group Co., Ltd., CHINA

This paper reports a novel evaluation method for MEMS gyroscopes' packaging reliability. Based on the principles of thermodynamics and hydromechanics, the relationships among quality factors, air pressure, and gas number, as well as degradation models of them, are deducted for the first time. Experimental tests demonstrate that the relationships between the reciprocals of quality factors and accelerated aging time are exponential, which accord with the theoretical analysis.

- T3P.018 SENSITIVE RESONANT GAS SENSOR OPERATING IN AIR WITH METAL ORGANIC FRAMEWORKS COATING 1081**
 N. Jaber, S. Ilyas, O. Shekhah, M. Eddaoudi, and M.I. Younis
King Abdullah University of Science and Technology (KAUST), SAUDI ARABIA

We report a sensitive and practical resonant gas sensor that is uniformly coated with metal organic frameworks (MOFs) and excited near the higher order modes for a higher attained sensitivity. The sensor is operated under ambient conditions of pressure and temperature. A significant frequency shift (KHz) is demonstrated

- T3P.019 STUDY ON THE INFLUENCE INDUCED BY ELECTRICAL COUPLING AMONG INTERCONNECTION LINES IN MEMS GYROSCOPES 1088**
 M.J. Li, Y.P. Wang, Q.C. Zhao, C.H. He, L.T. Lin, J.F. Yang, and G.Z. Yan
Peking University, CHINA

The existence and influence of the electrical coupling among interconnection lines in MEMS gyroscopes are analyzed in detail. Furthermore, a novel compensation method is developed to eliminate the influence resulting from the electrical coupling. It is achieved by adding a simple electrical coupling compensation circuit to the readout. Bias drift tests of the gyroscope with and without compensation under full temperature range are conducted, which verify the proposed method is effective.

- T3P.020 TOWARDS A WIRELESS CHIP LESS SMART CURRENT SENSOR SYSTEM BASED ON GIANT MAGNETORESISTANCE 1092**
 V.V. Kondalkar, X. Li, S.S. Yang, and K. Lee
Ajou University, KOREA

We developed highly sensitive, wireless and chipless current sensor system by using a giant magnetoresistance (GMR) magnetic sensor and one-port surface acoustic wave (SAW) reflective delay line for real time power monitoring in a current-flowing conductor. The developed system consists of a GMR magnetic sensor for current sensing, a one-port SAW delay line for the chipless transceiver system, two antennas, and a network analyzer as the reader.

- T3P.021 VACUUM PACKAGED CANTILEVER SENSOR MOUNTED WITH A MAGNETIC PARTICLE FOR MAGNETIC FORCE DETECTION 1096**
 G. Xue, M. Toda, and T. Ono
Tohoku University, JAPAN

The vacuum packaged cantilever with a small magnet is fabricated successfully, and applied to map the magnetic field gradient and radical density at the atmospheric condition based on magnetic force sensing. The variations of the resonant frequency and resonant amplitude of the cantilever can be mapped to the magnetic field, respectively. Finally, the magnetic force caused by electron spin resonance (ESR) of a standard radical polymer, DPPH, is detected at atmospheric environment.

- T3P.022 WIDE-RANGE TEMPERATURE DEPENDENCE STUDIES FOR DEVICES LIMITED BY THERMOELASTIC DISSIPATION AND ANCHOR DAMPING 1100**
 J. Rodriguez, D.D. Gerrard, S. Chandorkar, Y. Chen, G.M. Glaze, I.B. Flader, C.H. Ahn, E.J. Ng, and T.W. Kenny
Stanford University, USA

We present measurements of the quality factor (Q) over a wide temperature range for devices dominated by thermoelastic dissipation (TED) and for devices dominated by anchor damping. We are able to completely account for the various dissipation modes in these devices through the use of TED models. The anchor damping contribution in these resonators has a strong temperature dependency.

WEDNESDAY - Mechanical/Physical Sensors and Microsystems

- W3P.001 A FLEXIBLE SENSOR SYSTEM IN FOIL FOR COMBINED ABSOLUTE PRESSURE AND FLOW VELOCITY MEASUREMENTS 1104**
 M. Schwerter, M. Gäding, M. Leester-Schädel, and A. Dietzel
Braunschweig University of Technology, GERMANY

This work reports a foil integrated, flexible pressure- and hot-film sensor system for measuring flows over curved surfaces. The miniaturized rigid silicon piezoresistive pressure transducer with enclosed reference cavity allows absolute pressure sensing. Together with a foil-based hot-film transducer both transducers are embedded in a combination of thin epoxy resin with polyimide. This in-foil sensor system is surface passive and waterproof and can be bended to a radius of 20 mm.

- W3P.002 A MICRO-CASTING METHOD FOR SOLENOID COIL FABRICATION 1108**
 J. Gu, Z. Guo, H. Yang, and X. Li
Chinese Academy of Sciences, CHINA

In this paper, we for the first time present a method that can fabricate solenoid coil by casting. The named micro-casting method is like macro-scale casting, however micro-scale liquid phenomena is introduced as a gating system to overcome high surface-tension. Together with silicon bulk micromachining, integrated solenoid coils can be fabricated in batch and on single-stage forming by the micro-casting method.

- W3P.003 A SYMMETRICALLY ARRANGED ELECTRODES FOR CORONA DISCHARGE ANEMOMETRY 1112**
 N.T. Van¹, T.T. Bui², T.X. Dinh³, T. Terebessy⁴, T.C. Duc², and V.T. Dau⁵
¹Military Institute of Science and Technology, VIETNAM, ²Vietnam National University, VIETNAM,
³Ritsumeikan University, JAPAN, ⁴Clearview Traffic Group Limited, UK, and
⁵Sumitomo Chemical, Ltd., JAPAN

This paper presents a novel anemometry based on bipolar corona discharge probe with symmetrically arranged parallel electrodes, which is potentially applicable for *in-situ* measurement. Experimental study on the anemometry characteristics demonstrates the possibility of measuring a wide range of air flow rate/ flow velocity, i.e., up to 80 l/m.

- W3P.004 A WEARABLE TACTILE SENSOR BASED ON ELECTRICAL-CONTACT-RESISTANCE (ECR) VARIATION WITH HIGH SENSITIVITY FOR HEALTH MONITORING 1116**
 W.-L. Chen, Y.-C. Liao, and Y.-W. Lu
 National Taiwan University, TAIWAN

A wearable tactile device on fabrics based on Electrical Contact Resistance (ECR) variation mechanism is developed. It is screen-printed with conductive materials and optimized with different conductive materials to further enhance the device sensitivities. Device characteristics and practical applications are investigated in monitoring human wrist pulses with wireless module and smartphone, showing fast response and high sensitivity for IOT and medical applications.

- W3P.005 ARTIFICIAL HAIR CELL FLOW SENSOR WITH BALL JOINT 1120**
 J.-W. Chon, D.H. Kim, J.C. Ahn, M.G. Kim, L.G. Tran, and W.-T. Park
 Seoul National University of Science and Technology, KOREA

We present octopus-shaped artificial flow sensor for measuring flow's velocity and direction. Arranging commercial PRT (piezo-resistive) pressure sensors and placing octopus-shaped artificial hair cell by 3d printing technology with ball joint connection, we're able to measure not only 106 mm/s flow rate at water tunnel but also resolve the direction as angle 10° by wind pressure.

- W3P.006 COPLANAR DIFFERENTIAL CAPACITIVELY COUPLED CONTACTLESS CONDUCTIVITY DETECTION (CD-C4D) SENSOR FOR MICRO OBJECT INSIDE FLUIDIC FLOW RECOGNIZATION 1124**
 H.T.T. Thuy¹, L.D. Quang², V.T. Dau³, N.N.T. Kim², C.L. Van², M. Aoyagi⁴, K. Kikuchi⁴, and T.T. Bui²
¹Posts and Telecommunications Institute of Technology, VIETNAM, ²Vietnam National University, VIETNAM,
³Sumitomo Chemical, Ltd, JAPAN, and ⁴National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

This paper presents a novel coplanar differential capacitively coupled contactless conductivity detection (CD-C4D) sensor for detection of objects with dimension in micro scale. The differential capacitance changed due to the present of a micro object in the fluidic flow is detected and used to determine the properties (i.e., dimension, electrical property) and moving speed of object in the fluidic flow.

- W3P.007 DEVELOPMENT OF A CMOS-MEMS GYROSCOPE USING PURE-OXIDE AND SYMMETRIC METAL-OXIDE STACKING STRUCTURES 1128**
 C.-Y. Ho, F.-Y. Li, and W. Fang
 National Tsing Hua University, TAIWAN

This study exploits the concepts of pure-oxide and symmetric metal-oxide films to design and implement a CMOS-MEMS gyroscope. Thus, the unwanted after-process deformation due to the thin film residual stresses and the unwanted in-use thermal deformation due to the CTE mismatch of metal-dielectric films are significantly reduced. Preliminary result shows a flat structure (radius of curvature, ROC ≥ 80mm) with 500µm×470µm footprint is achieved.

- W3P.008 EFFECTIVE MECHANICAL TRIMMING OF MICRO SHELL RESONATOR WITH T-SHAPE MASSES 1132**
 K. Lu, W. Li, Z. Hou, D. Xiao, Y. Wu, X. Wu, and M. Zhuo
 National University of Defense Technology, CHINA

We propose a novel method to reduce a frequency mismatch between degenerate modes of micro shell resonators (MSR) with T-shape masses caused by potential fabrication imperfections using femtosecond laser ablation. A significant reduction of the frequency split of the wineglass modes is achieved in the trimming experiments with an imperfect fused silica (FS) MSR, which further demonstrates the feasibility of the method.

- W3P.009 FABRICATION OF A LOW LEAKAGE CURRENT TYPE IMPEDANCE SENSOR TO MONITOR SOIL WATER CONTENT FOR SLOPE FAILURE PROGNOSTICS 1136**
M. Futagawa¹, S. Ogasahara¹, T. Ito¹, M. Komatsu², Y. Fuwa³, H. Hirano¹, I. Akita⁴, K. Kusano⁵, and M. Watanabe⁶
¹Shizuoka University, JAPAN, ²Okayama University, JAPAN, ³Shinsyu University, JAPAN,
⁴Toyoashi University of Technology, JAPAN, ⁵LAPIS Semiconductor Miyagi Co., LTD., JAPAN, and
⁶LAPIS Semiconductor Co., LTD., JAPAN

A low-leakage-current type impedance sensor chip with shield structures have been fabricated. The low limit detection of soil-water-content measurement was improved compared with that of the other semiconductor type sensors. The shield structures were fabricated under the impedance sensor areas. To measure weak signal current eliminated the leakage current, we proposed a new operation circuit to separate the leakage current. Our sensor achieved to measure low water content 10 % or less.

- W3P.010 GRIPPING CONTROL OF DELICATE AND FLEXIBLE OBJECT BY ELECTROMOTIVE MANIPULATOR WITH PROXIMITY AND TACTILE COMBO MEMS SENSOR 1140**
R. Araki¹, F. Suga¹, T. Abe¹, H. Noma², and M. Sohgewa¹
¹Niigata University, JAPAN and ²Ritsumeikan University, JAPAN

We have demonstrated usefulness of the electromotive manipulator system with a developed MEMS sensor to skillful gripping of the flexible object. The mainly material of this MEMS sensor is Si, and it is responsive to light by the photoconductive effect and force by a microcantilever with a strain gauge layer. The sensor can detect both proximity and contact, and the direction of applied force can also be detected.

- W3P.011 HIGH RESOLUTION FLEXIBLE STRAIN SENSORS FOR BIOLOGICAL SIGNAL MEASUREMENTS 1144**
Y. Wu^{1,2}, L. Beker², I. Karakur², W. Cai^{2,3}, J. Elwood², X. Li^{2,4}, J. Zhong², M. Zhang⁵, X. Wang^{1,5}, and L. Lin^{1,2}
¹Tsinghua-Berkeley Shenzhen Institute, CHINA, ²University of California, Berkeley, USA,
³South China University of Technology, CHINA, ⁴Southeast University, CHINA, and
⁵Graduate School at Shenzhen, CHINA

This paper presents a PDMS/graphite-based flexible strain sensing system for a variety of wearable device applications. Innovative claims include: the use of a serpentine electrode structure for high resolution finger motion monitoring; finger-tip pressure monitoring; monitoring of arterial pulse waves with high resolution. The results show angular motion detection with resolution of 15-degree; fingertip pressure detection up to 12 kPa; and clear identifications of the 3 peaks in pulse-waves.

- W3P.012 ITO THIN FILM THERMOCOUPLE FOR TRANSIENT HIGH TEMPERATURE MEASUREMENT IN SCRAMJET COMBUSTOR 1148**
X.H. Jin, B.H. Ma, T. Qiu, and J.J. Deng
Northwestern Polytechnical University, CHINA

We develop ITO thin film thermocouples for capturing the transient wall temperature of scramjet. Besides optimal sputtering and annealing processes, a protective bilayer is used to improve the sensor's thermal stability and reliability. The dynamic temperature of scramjet's inner wall during the combustion was successfully captured for the first time.

- W3P.013 MEMS-BASED PRESSURE SENSOR WITH A SUPEROLEOPHOBIC MEMBRANE FOR MEASURING DROPLET VIBRATION 1152**
T.-V. Nguyen, H. Takahashi, and I. Shimoyama
University of Tokyo, JAPAN

We report on a sensor design to measure the vibration of small droplet. The sensor consists of a piezoresistive cantilever and a chamber covered with a superoleophobic membrane. Since the sensor has a simple sensing scheme and can be disposable, the proposed method can be used to measure viscosity of small droplets for point-of-care application.

- W3P.014 MULTI-SENSOR PLATFORM LSI ENABLING DIFFERENT SENSORS TO BE EVENT-DRIVEN AND CONNECTED TO COMMON DIFFERENTIAL BUS LINE 1156**
M. Muroyama¹, T. Nakayama², Y. Hata³, and S. Tanaka¹
¹Tohoku University, JAPAN, ²Toyota Motor Corporation, JAPAN, and ³Toyota Central R&D Labs., Inc., JAPAN

This paper presents a multi-sensor platform LSI for versatile applications including next generation robots. For a unified system implementation, the proposed LSI provides the followings: several principle sensor readout circuits, 8-single or 4-differential multi-channels for multi-axis sensing, outputs as a haptic driver controller, flexible system parameter configuration, a RS485 compatible differential signal serial bus communication method, and event-driven response.

- W3P.015 OPTIMIZATION AND FABRICATION OF A TWO AXIS FLUXGATE MAGNETIC SENSOR WITH HIGH SENSITIVITY 1160**
S.-J. Chen, P.-H. Hsieh, H.-Y. Hsu, and H.-M. Chen
National Central University, TAIWAN

We develop a two-axis micro fluxgate magnetic sensor with a thick excitation and sensing coils. Two sensors are connected to double the sensitivity, and two excitation coils are used to saturate a single electromagnetic core. With a lock-in amplifier circuit, two-axis measurements are successfully demonstrated.

- W3P.016 PRESSURE SENSOR BASED ON ORGANIC SINGLE CRYSTAL AIR-GAP TRANSISTOR 1163**
M.J. Pereira¹, C. Ayela¹, L. Hirsch¹, I. Dufour¹, A. Briseno², M. Matta¹, Y. Olivier³, L. Muccioli¹, A. Crosby², and G. Wantz¹
¹University of Bordeaux, FRANCE, ²University of Massachusetts, USA, and ³University of Mons, BELGIUM

We used single rubrene crystals on air-gap transistors to fabricate low-pressure sensors. We show that the variation of contact resistance when the transistor is under pressure leads to a better charge injection and by consequence to an increase of drain current.

- W3P.017 RESISTIVE PRESSURE SENSORS INTEGRATED WITH A CORIOLIS MASS FLOW SENSOR 1167**
D. Alveringh¹, T.V.P. Schut¹, R.J. Wiegerink¹, W. Sparreboom², and J.C. Lötters^{1,2}
¹University of Twente, NETHERLANDS and ²Bronkhorst High-Tech BV, NETHERLANDS

We report on a novel resistive pressure sensor that is completely integrable with a Coriolis mass flow sensor on one chip, without the need for extra fabrication steps or different materials. Two pressure sensors are placed in-line with the Coriolis sensor and do not introduce extra internal volumes to the fluid path. This enables the measurement of the pressure drop of the Coriolis mass flow sensor and delta-P flow sensing, and thus, real-time viscosity characterization.

- W3P.018 SENSITIVITY IMPROVEMENT OF NO-BACK-PLATE MEMS MICROPHONE USING POLYSILICON TRENCH-REFILLED PROCESS 1171**
S.-C. Lo¹, J.-J. Wang¹, M. Wu², and W. Fang¹
¹National Tsing Hua University, TAIWAN and ²GlobalMEMS Co. LTD., TAIWAN

This study demonstrates the no-back-plate MEMS condenser microphone for sensitivity improvement and preventing in-use pull-in and in-process stiction between diaphragm. Merits of this study are: (1)the implemented HAR sensing electrodes provide required sensing capacitance, (2)obtained the larger out-of-plane deformation by smaller thickness flat diaphragm, (3)utilized poly-Si trench-refilled process to define different thickness and sensing electrodes.

- W3P.019 SURFACE CARRIER CONCENTRATION EFFECT ON ELASTIC MODULUS OF PIEZOELECTRIC MEMS SILICON CANTILEVERS 1175**
J.-T. Lin¹, P.D. Shuvra¹, W. Liao², S. McNamara¹, K.M. Walsh¹, C.N. Arutt², H. Gong², J.L. Davidson², M.L. Alles², and B.W. Alphenaar¹
¹University of Louisville, USA and ²Vanderbilt University, USA

We develop the first experimental measurement of the silicon elastic modulus with changing surface carrier concentration. Measurements are made of an electrostatically driven MEMS silicon resonator using piezoresistive sensing. To produce the correlation, accompanied temperature effect from light sources is filtered. This work demonstrates the high sensitivity of resonant properties to surface effects, and shows how a MEMS device can function as a probe of interfacial charge transfer.

- W3P.020 TRIBOELECTRIC AND MICROFLUIDIC INTEGRATED SELF-GENERATED TACTILE SENSOR 1179**
Q. Shi, H. Wu, T. He, H. Wang, S.S. Periyal, D. Hasan, and C. Lee
National University of Singapore, SINGAPORE

We develop and characterize a flexible self-generated tactile sensor based on liquid-solid triboelectrification and electrostatic induction with microfluidic design. The tactile sensor has multiple elements to enable the accuracy sensing of pressure. The proposed microfluidic sensor shows great potential for diversified applications such as tactile sensor, pressure/force sensor, and human motion monitor, etc.

- W3P.021 WASHABLE THREAD BASED STRAIN SENSOR FOR SMART TEXTILE 1183**
H. Rezaei Nejad, M.P. Punjiya, and S. Sonkusale
Tufts University, USA

Here we report fabrication of a facile stretchable and washable thread-based strain/force sensor, which can be sewn into wearable textiles and is capable of measuring human physiological motion. The sensor fabrication is simple and low cost. The fabricated sensor is also unidirectional.

- W3P.022 WIDEBAND, LOW-NOISE ACCELEROMETER WITH OPEN LOOP DYNAMIC RANGE OF BETTER THAN 135DB 1187**
F. Edalatfar, S. Azimi, A.Q.A. Qureshi, B. Yaghootkar, and B. Bahreyni
Simon Fraser University, CANADA

We are reporting the design principles and experimental verification for a high performance accelerometer with an operating bandwidth of 4.5kHz, noise limit of 350ng/√Hz, sensitivity of ~2pF/g, open loop dynamic range of better than 135dB, and cross axis sensitivity of less than 30dB while operating at atmospheric pressure.

MONDAY - Materials, Fabrication and Packaging Technologies

- M3P.023** **250°C WAFER-LEVEL VACUUM SEALING USING ELECTROPLATED COPPER BONDING FRAME PLANARIZED BY FLY-CUTTING** 1191
M.S. Al Farisi, K. Tanaka, H. Hirano, and S. Tanaka
Tohoku University, JAPAN

This paper reports a novel wafer-level heterogeneous integration and vacuum packaging technology by thermo-compression bonding using electroplated Cu frame planarized by fly-cutting. High grain boundary density on the Cu surface induced by fly-cutting process enables vacuum bonding at temperature as low as 250°C, achieving less than 100 Pa sealed cavity pressure. Availability of the technology for microstructured wafers is also demonstrated, yielding bonding shear strength higher than 200 MPa.

- M3P.024** **A PARYLENE BONDING BASED FABRICATION METHOD FOR GRAVIMETRIC RESONANT BASED MASS SENSORS** 1195
F. Gökçe¹, E. Aydın¹, M. Kangül¹, T.B. Töral¹, Ö. Zorlu², Ö. Şardan-Sukas¹, and H. Külah¹
¹*Middle East Technical University, TURKEY* and ²*Mikro Biyosistemler Elektronik Sanayi ve Ticaret A.Ş., TURKEY*

A fabrication method utilizing parylene bonding for resonant based sensors is presented. First, parylene bonding was experimentally tested and compared with the literature. Then, resonators located on top of a microchannel were fabricated using the method, for the first time in the literature. Simulations and experimental results verify proper operation of the fabricated resonators, and the applicability of the method for fabrication of other micro devices.

- M3P.025** **BONDING STRENGTH CHARACTERIZATION OF EUTECTIC-BASED WLP USING MOLECULAR DYNAMICS AND WAFER LEVEL SHEAR TESTING** 1199
T. Aono^{1,2}, A. Kazama¹, R. Okada¹, T. Iwasaki¹, and Y. Isono²
¹*Hitachi Ltd., JAPAN* and ²*Kobe University, JAPAN*

This paper evaluated the bonding shear strength of eutectic-based wafer-level-packaging (WLP) for MEMS accelerometers. The WLP condition was considered from molecular dynamics (MD) simulations and shear tests of WLP accelerometer followed by the energy dispersive X-ray spectrometry analysis. The MD simulations have found an obvious correlation between the bonding temperature, the diffusion mechanism of solder materials, and the fracture behavior of WLP.

- M3P.026** **DIRECT COMPARISON OF STICTION PROPERTIES OF OXIDE COATED POLYSILICON AND SMOOTH SINGLE CRYSTAL SILICON** 1203
D.B. Heinz, I.B. Flader, Y. Chen, G.D. Vusakin, L. Comenencia Ortiz, and T.W. Kenny
Stanford University, USA

We directly compare process and in-use stiction in identical sets of devices fabricated in rough oxide-coated polysilicon and smooth, oxide-free single crystal silicon. The poly-si devices show reduced process stiction due to surface roughness, enabling higher yield on compliant structures, but in-use stiction is higher than for single crystal devices. Our ultra-high purity, vacuum encapsulation process allows measurement of surface adhesion properties in the absence of environmental variation.

- M3P.027** **ELECTRON REGULATED 3D NANOSTRUCTURING OF NATURAL SILK FIBROIN PROTEIN REVEALED BY NEAR-FIELD NANO-SPECTROSCOPY** 1207
N. Qin¹, S. Zhang², and T.H. Tao^{1,2}
¹*Chinese Academy of Sciences, CHINA* and ²*University of Texas, Austin, USA*

In this work, we report on the discovery of the full β -sheet structural evolution in natural silk fibroin protein due to electron-protein interaction and its application in complex 3D protein nanofabrication. Using near-field infrared imaging and nano-spectroscopy, the electron regulated silk fibroin protein polymorphic transitions is revealed at the resolution approaching the molecular limit.

- M3P.028** **HYDROGEL INFUSED CARBON NANOTUBE BUNDLE FOR FLOW SENSING APPLICATIONS** 1211
M. Bora¹, A.G.P. Kottapalli¹, J.M. Miao², and M.S. Triantafyllou^{1,3}
¹*Singapore-MIT Alliance for Research and Technology (SMART), SINGAPORE*,
²*Nanyang Technological University (NTU), SINGAPORE*, and
³*Massachusetts Institute of Technology, USA*

We investigate a novel approach to develop a biomimetic sensor for flow sensing applications. The sensor incorporates a combination of structures inspired from biological flow sensors of fishes. It includes a carbon nanotubes bundle encapsulated in a soft polymer gel structure that mimics the material and mechanical properties of natural sensors. The sensor is microfabricated and experimentally characterized for flow sensing. It has a simplified design as compared to those reported earlier.

M3P.029 MECHANICAL STRENGTH OF 2.5D PARYLENE C MICROPORE-ARRAYED FILTRATION MEMBRANE 1215

W. Dai¹, Y. Liu¹, Y. Fu², H. Xu¹, F. Su³, J. Wu², and W. Wang¹

¹Peking University, CHINA, ²Tsinghua University, CHINA, and ³Beihang University, CHINA

This work experimentally studied the mechanical strength of the previously reported Parylene C based micropore-arrayed filtration membrane with a high porosity. The results indicated that the membrane, though with a high porosity, is strong enough and has a negligible pore size variation (<33 nm) during an up-to 150 mL/min filtration.

M3P.030 MICROMACHINING OF GORILLA GLASS 1218

G. Chen, C.-H. Hsu, and M.M.-C. Cheng

Wayne State University, USA

This paper presents micromachining of gorilla glass, which is a new tough and transparent substrate, but has not been used in MEMS yet. Several etching methods have been investigated in this study, including laser micromachining and wet etching based on hydrofluoric acid (HF). The process was optimized with an additive of hydrochloric acid (HCl) to reduce surface roughness. The microcantilevers made of Gorilla glass is capable to bend 12 degrees without breaking.

M3P.031 MEMS PACKAGING METHOD WITHOUT ANY HEATING OR EXTERNAL FORCE USING ADHESIVE BONDING ASSISTED BY CAPILLARY FORCE 1221

C.-H. Han, C.-K. Kim, Y.-H. Yoon, M.-H. Seo, S.-D. Ko, and J.-B. Yoon

Korea Advanced Institute of Science and Technology (KAIST), KOREA

We report a simple MEMS packaging method without any heating or external force to avoid damage of the MEMS device. Adhesive material is absorbed into the bonding interface perfectly only by capillary force. No extra set up of controlling the temperature or pressure is required. Then we tested moisture penetration test and also packaged a fabricated MEMS LC-resonator within it.

M3P.032 SURFACE MODIFICATION OF NEURAL STIMULATING/RECORDING ELECTRODES WITH HIGH-PERFORMANCE PLATINUM NANO-LEAF COATINGS 1225

K. Xia¹, B. Sun¹, Q. Zeng¹, T. Wu¹, and M.S. Humayun^{1,2}

¹Chinese Academy of Sciences, CHINA and ²University of Southern California, USA

This paper reports a novel surface modification method using platinum (Pt) nano-leaf coatings which can significantly improve electrochemical performances of microelectrodes arrays (MEAs) for neural stimulating or recording. Three dimensional nano-leaves have been deposited on Pt electrodes using a constant potential electro deposition.

M3P.033 WORLD-FIRST ELECTRONIC IMAGING OF SUBCRITICAL SLIP GROWTH IN SINGLE CRYSTAL SILICON UNDER FATIGUE LOADING 1229

S. Kamiya, A. Kongo, H. Sugiyama, and H. Izumi

Nagoya Institute of Technology, JAPAN

Silicon slips under fatigue loading. Traces of subcritical slip growth in single crystal silicon was successfully pictured with electron beam induced current technique, where intensity of the current generated by electron beam through p-n junctions fabricated over stress concentration areas was plotted in correspondence to beam scan in a microscope. Fatigue fracture takes place in silicon therefore likely with accumulation of slip deformation in areas of stress concentration.

TUESDAY - Materials, Fabrication and Packaging Technologies

T3P.023 3D PRINTED STAINLESS STEEL MICROELECTRODE ARRAYS 1233

R.C. Roberts and N.C. Tien

University of Hong Kong, HONG KONG

We report the design and fabrication of high-density high-aspect-ratio stainless steel microelectrode arrays (MEAs), 3D printed using micro laser sintering from stainless steel powder with 5µm vertical and 30µm lateral resolution. The electrical and mechanical characteristics of printed 316L and 17-4PH steel are investigated. 10 by 10 MEAs with 1.5mm tall tapered electrodes are realized via interlocking sacrificial supports, enabling customizable 3D MEAs for biomedical and energy applications.

T3P.024 ADVANTAGES OF ALD OVER EVAPORATION DEPOSITION FOR HIGH-K MATERIALS INTEGRATION IN HIGH POWER CAPACITIVE RF MEMS 1237

G. Croizier¹, P. Martins¹, M. Le Baillif¹, R. Aubry¹, S. Bansropun¹, M. Fryziel², N. Rolland², and A. Ziaei¹

¹Thales Research and Technology, FRANCE and ²IEMN, FRANCE

We report a study over a wide range of high-K dielectric materials (Al₂O₃, HfO₂, TiO₂, ...) deposited by different techniques (Evaporation, ALD, PEALD, ...) for high power RF applications. Main results show that ALD technique is matching McPherson trend. Furthermore, ALD materials are promising to meet high power requirements for capacitive RF MEMS switches. As a result, ALD HfO₂ was integrated in capacitive RF MEMS switches in order to improve their RF performances, power handling and reliability.

T3P.025 CYLINDRICAL ELECTROCHEMICAL SENSOR FABRICATED BY ROTATED INKJET PRINTING ON FLEXIBLE SUBSTRATE FOR GLUCOSE MONITORING 1241

Z. Pu, X. Zhang, H. Wu, J. Wu, H. Yu, and D. Li
Tianjin University, CHINA

This paper reports a novel electrochemical sensor fabricated on the flexible cylindrical substrate with bigger working electrode surface by a new rotated inkjet printing method to overcome the challenge of hypoglycemia detection. The proposed rotated inkjet printing technique enables directly patterning microstructures on cylindrical surface which overcome the limit of the traditional planar micromachining by lithography.

T3P.026 DRY ETCHING AND LOW-TEMPERATURE DIRECT BONDING PROCESS OF LITHIUM NIOBATE WAFER FOR FABRICATING MICRO/NANO CHANNEL DEVICE 1245

T. Tsuchiya¹, K. Sugano², H. Takahashi¹, H. Seo³, Y. Pihosh³, Y. Kazoe³, K. Mawatari³, T. Kitamori³, and O. Tabata¹
¹Kyoto University, JAPAN, ²Kobe University, JAPAN, and ³University of Tokyo, JAPAN

We have developed dry etching process of lithium niobate (LN) wafer using NLD-RIE to fabricate both micro- and nano-channels for investigating proton diffusion enhancement in ferroelectric nanochannels. We have also developed low-temperature direct bonding process between LN wafers. Two hundred parallel nanochannel array of 200-nm deep and wide and 400 μm long in microchannel inlet were fabricated. We succeeded in measuring a very high proton diffusion coefficient as $1.2 \times 10^{-8} \text{ m}^2/\text{s}$.

T3P.027 FABRICATION AND CHARACTERIZATION OF HYDROGEL MEMS RESONATORS VIA DYNAMIC MASK LITHOGRAPHY 1249

Y. Yoon, S. Kim, and J. Lee
Sogang University, KOREA

We report a new fabrication method for various types of MEMS resonators using hydrogel via dynamic mask lithography and dry state sacrificial process. The various free-standing hydrogel resonators including cantilever, doubly clamped beams, and membrane are thoroughly verified with resonant characteristics, and pressure sensing application is also demonstrated.

T3P.028 WITHDRAWN

T3P.029 MICRO ELECTRO-DISCHARGE PATTERNING USING LIQUID-PHASE MICROELECTRODES 1257

R. Huang^{1,2}, Y. Yi², W. Yu^{1,2}, and K. Takahata²
¹Harbin Institute of Technology, CHINA and ²University of British Columbia, CANADA

We demonstrate the first patterning method based on micro electro-discharge machining (μEDM) that uses the microelectrodes in a liquid form, developed to address a variety of problems associated with the electrode wear, one of the most fundamental issues of the μEDM technology. We show that Galinstan, a non-toxic liquid alloy supplied via a capillary nozzle, can be used as the machining electrode to create discharge pulses on samples for arbitrary patterning on their surfaces.

T3P.030 PIEZORESISTANCE FOR POLYCRYSTALLINE AGGREGATES REPRESENTED BY CRYSTALLITE ORIENTATION DISTRIBUTION FUNCTION 1261

T. Ando and T. Toriyama
Ritsumeikan University, JAPAN

We derived an overall piezoresistance tensor for polycrystalline aggregates in terms of crystallite orientation distribution function (CODF) and cubic single crystal piezoresistance tensor. We found that the deviatoric part of overall tensor is a function of the preferred orientation of the single crystals and number of independent tensor components is three. The experimental evidence shows that the variation of texture strength plays a main role to represent the piezoresistance anisotropy.

T3P.031 SIMPLE AND COST-EFFECTIVE METHOD FOR FABRICATION OF OPTICALLY TRANSPARENT SUPERHYDROPHOBIC THIN FILM USING REUABLE PUA MOLD AND ROLL-TO-ROLL MACHINE 1265

J.-H. Kwak¹, H.-B. Kim¹, J.-S. Park¹, J.-H. Park¹, J.-H. Lee², S.-H. Lee², M.-K. Kwak², and D.-W. Lee¹
¹Chonnam National University, KOREA and ²Kyungpook National University, KOREA

We propose a cost-effective method for mass production of optically transparent super-hydrophobic film. Thanks to the proposed PUA mold and the roll to roll system, continuous production of super-hydrophobic film is possible, which will be a basis for mass production. Feasibility of the thin film is successfully demonstrated using various methods. The experimental results reveal that the proposed method has potential to extend the utility of the optically transparent super-hydrophobic film.

- T3P.032 THROUGH-SILICON VIA ARRAYS MANUFACTURED BY PHOTO ASSISTED ELECTROCHEMICAL ETCHING AND COPPER ELECTROPLATING UNDER SC-CO₂ ENVIRONMENT 1269**
H.-C. Chuang, H.-M. Yang, C.-H. Wu, J. Sánchez, and J.-H. Shyu
National Taipei University of Technology, TAIWAN

We developed a fabrication of through silicon vias by photo-assisted electrochemical etching and copper electroplating under supercritical carbon dioxide (sc-CO₂) environment. Photo-Flo (PF) solution, tetrabutylammonium perchlorate (TBAP) and the effect of ohmic contact thickness over etching uniformity were studied. Electroplating under sc-CO₂ environment with no additives was performed to achieve TSV structures with aspect ratio of 1:35 in the short plating time of 2.5 hours.

WEDNESDAY - Materials, Fabrication and Packaging Technologies

- W3P.023 A BONDING METHOD BETWEEN POLY(LACTIC ACID) (PLA) AND POLY(METHYL METHACRYLATE) (PMMA) FOR MICROFLUIDIC CHIPS 1273**
H.L. Duong and P.C. Chen
National Taiwan University of Science and Technology, TAIWAN

We present a novel method to bond PLA and PMMA for microfluidic applications. The mechanism behind this method is based on the polymer dissolution, molecular diffusion, and re-crosslinking of polymer chains. To successfully and rapidly form a strong bond (>13 bars), ethanol treatment and UV irradiation followed by post-annealing were used. Several inspections including leakage test, cross-sectional image by microscope, and pressure bursting test were conducted to analyze the bonding quality.

- W3P.024 BATCH TRANSFER APPARATUS FOR CHIPS RESULTING IN ENLARGED PITCH USING STRETCHABLE SILICON SPRING 1277**
W.-L. Sung¹, K. Huang¹, J.-Y. Huang², and W. Fang²
¹*imec, TAIWAN and* ²*National Tsing Hua University, TAIWAN*

This study presents an expansion apparatus for batch transfer of chips using silicon strips connected by stretchable springs. Chips are placed in the silicon strips and the pitches are changed as the strips are expanded. Merits of this approach: (1) narrow springs can be fabricated to minimize strain and provide robustness; (2) large expansion (>10x) can be achieved. Accurate positioning (<10μm) of >10000 chips and durability of the apparatus for >10000 operation cycles are demonstrated.

- W3P.025 DEEP REACTIVE ION ETCHING TECHNIQUE INVOLVING USE OF 3D SELF-HEATED CATHODE 1281**
G. Han, Y. Murata, D. Ohkawa, M. Sohagawa, and T. Abe
Niigata University, JAPAN

This paper reports deep reactive ion etching technique employing 2D or 3D self-heated stage as the etching stage of a regular reactive ion etcher. The stage was designed based on the simulation results and its heating characteristics on application of RF power were evaluated. The temperature of the 3D stage increases rapidly to 350 C° because of the low thermal capacitance of the stage. The application of the etching to various kinds of minor metals were investigated.

- W3P.026 ELECTRICAL CONDUCTIVITY ENHANCEMENT OF 1D GLASSY CARBON NANOSTRUCTURE USING RAPID THERMAL ANNEALING 1285**
Y. Lim¹, J.H. Chu², D.H. Lee¹, S.-Y. Kwon¹, and H. Shin¹
¹*Ulsan National Institute of Science and Technology (UNIST), KOREA and* ²*University of California, Santa Barbara, USA*

Rapid thermal annealing process enabling significant enhancement of electrical conductivity of 1D glassy carbon nanostructures fabricated using carbon-MEMS was developed. The carbon/oxygen and G-/D-band ratios that are strongly correlated to the electrical conductivity were changed depending on the pyrolysis temperature. The architecture of a suspended carbon nanowire also plays strong role on RTA-based conductivity enhancement by up to 14 % compared to carbon nanowire built on the substrate.

- W3P.027 HERMETICITY AGAINST HYDROGEN OF CAVITIES SURROUNDED BY SILICON 1288**
S. Iwai, S. Yoshita, K. Kanno, H. Suzuki, T. Mishima, and T. Yoshida
Yokogawa Electric Corporation, JAPAN

We report hydrogen permeation through polysilicon thin film and/or single crystal silicon out of cavities filled with hydrogen and estimate the activation energy of the permeation between 450°C and 700°C. Being calculated from our data, the time required for permeation at 200°C of the cavity which is strictly covered by silicon is 10^{^5} times longer than that of the cavity which has diffusion pathways formed by silicon dioxide.

W3P.028 LONG-TERM HERMETIC VACUUM WAFER-LEVEL PACKAGING WITH COPPER-TIN THIN FILMS 1292

 T. Akashi¹, H. Funabashi¹, H. Takagi², Y. Hata¹, Y. Omura¹, and M. Fujiyoshi¹
¹Toyota Central Research and Development Laboratories, Inc., JAPAN and

²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

We first present hermetic vacuum wafer-level packaging (WLP) technology with copper-tin (CuSn) thin films and report its long-term vacuum hermeticity. Under the optimized conditions, shear strength reached 74 MPa and the fabricated cavity had been kept vacuum for 1.8 years. An ultra-low outgassing residual gas analyzer revealed that the cavity pressure was 407 Pa. The fabricated cavity demonstrated that WLP with CuSn thin films can achieve remarkable vacuum hermeticity.

W3P.029 POLYMERIC STRAIN GAUGES AS PRESSURE SENSOR FOR MICROFABRICATED ORGAN-ON-CHIPS 1296

 W.F. Quiros-Solano^{1,2}, N. Gaio¹, C. Silvestri¹, G. Pandraud¹, and P.M. Sarro¹
¹Delft University of Technology, NETHERLANDS and ²Instituto Tecnológico, COSTA RICA

PEDOT:PSS strain gauges embedded in PDMS membranes fabricated using a full wafer-level fabrication process and reaching reproducible small features are reported. The devices are characterized using a customized setup which provides mechanical stretch while dynamically reading the electrical resistance. The process is tailored to fabricate pressure sensors and microelectrodes for a flexible substrate-based Organ-on-Chip platform.

W3P.030 SPIN CROSSOVER MATERIALS FOR MEMS ACTUATION: FILM INTEGRATION AND CHARACTERIZATION 1300

M.D. Manrique-Juarez, S. Rat, L. Mazonq, F. Mathieu, I. Ségué, T. Leïchlé, L. Nicu, L. Salmon, G. Molnár, and A. Bousseksou

Université de Toulouse, FRANCE

As a substantial step toward the objective of creating molecule-based nanomechanical systems, in this work we describe the integration of spin crossover (SCO) molecules into silicon MEMS and we study the mechanical properties of the SCO film to extract both, Young's Modulus (E) and film stress (Σ) by measuring the resonant frequency shifts of coated mechanical devices using optical interferometry.

W3P.031 WAFER-TO-WAFER TRANSPORTABLE GOLD PARTICLE PLUG FOR SPOT VACUUM SEALING OF MEMS 1304

 T. Ogashiwa¹, K. Totsu², M. Nishizawa³, H. Ishida⁴, K. Inoue¹, Y. Sasaki¹, M. Miyairi¹, S. Tanaka², and M. Esashi²
¹Tanaka Kikinzoku Kogyo K.K., JAPAN, ²Tohoku University, JAPAN, ³MEMS CORE Co.Ltd, JAPAN, and

⁴SUSS Microtec K.K., JAPAN

In case of conventional vacuum packages for MEMS, a common issue is the outgas generation at wafer bonding operation. This paper presents a spot vacuum sealing method of through-silicon via (TSV) with transportable Au particle plug by thermo-compression bonding in vacuum chamber below 200 degree C. The Au particle plug can keep a lower cavity pressure and its hermeticity at the same time.

MONDAY - Nanoscale Materials, Devices and Fabrication
M3P.034 EVOLUTIONARY KINETIC MONTE CARLO METHOD FOR THE SIMULATION OF ANISOTROPIC ETCHING OF Z-CUT, AT-CUT AND BT-CUT QUARTZ 1308

 H. Zhang¹, Y. Xing¹, J. Zhang¹, M.A. Gosálvez², Y. Li¹, and Y. Zhang¹
¹Southeast University, CHINA and ²University of the Basque Country, SPAIN

This study explores the use of the Evolutionary Kinetic Monte Carlo method (EKMC) to describe the etch rate anisotropy of quartz and three-dimensional microstructures and topography etched on Z-cut, AT-cut and BT-cut substrates. The EKMC can properly transform the (facet specific) macroscopic etch rates of several crystal planes into suitable values for the (atom specific) microscopic removal probabilities, leading to etch rate errors and micro-structure errors that remain within 5%.

M3P.035 GRADIENT LITHOGRAPHY USING GRADED TIP ARRAY 1312

 J. Wu¹, K. Tao², and J.M. Miao¹
¹Nanyang Technological University, SINGAPORE and ²Northwestern Polytechnical University, CHINA

A new strategy is developed to create the polydimethylsiloxane (PDMS) tip array with graded apex size, which is employed to fabricate gradient patterns with the lateral feature sizes changing from sub-100 nm to several microns on one single substrate over macroscopic (cm²) areas. The gradient structures can be produced in both near-field photolithography and soft contact printing. The formation of gradient feature size is ascribed to gradient contact areas between tips and substrates.

M3P.036 PERMANENT ENCAPSULATION OF NANOPARTICLE PATTERNS FORMED BY INKJET PRINTER FOR TRANSPARENT AND FLEXIBLE ANTI-COUNTERFEIT APPLICATIONS 1316

 A.K. Thokchom¹, J. Park², Q. Zhou¹, D. Ha¹, J. Park¹, K. Lee¹, and T. Kim²
¹Ulsan National Institute of Science & Technology (UNIST), KOREA and

²Sogang University, KOREA

The self-assembly and deposition mechanisms of nanoparticles in droplets on a substrate are of significant importance in many inkjet printing-based industrial applications such as microelectronics, display systems, and paint manufacturing. In this study, we describe the underlying lack mechanisms of the self-assembly and deposition behavior of nanoparticles in inkjet-printed.

M3P.037 TRANSFER-CONDITON OPTIMIZATION OF AN ELECTROCHEMICAL-BASED NANOIMPRINT LITHOGRAPHY FOR 1:1 TRANSFER OF THIN-FILM EDGE ELECTRODE 1320

Y. Li¹, H. Toshiyoshi², and H. Fujita²

¹Toshiba Corporation, JAPAN and ²University of Tokyo, JAPAN

A mold with a functional layer is introduced on the top surface of protrusion to improve contact uniformity and thereby to improve transfer uniformity and reproducibility. Design of experiments (DOE) is conducted to optimize the transfer conditions of thin-film edge electrode lithography for high resolution. As a result, 1:1 transfer of oxide pattern with a line-width of 25nm was achieved successfully.

TUESDAY - Nanoscale Materials, Devices and Fabrication

T3P.033 A FAST RESPONSE BREATH DETECTION SYSTEM BASED ON BRIDGE TIED CNT SENSOR FABRICATED BY MICROMACHINING 1324

B. Sun, Y. Wang, H. Li, C. Zhang, S. Sun, Y. Sun, and G. Ding

Shanghai Jiao Tong University, CHINA

This paper reports on a novel implanting micromachining technology. By using this method, for the first time, we could implant both ends of one dimensional nano-scale materials into micro-scale metal materials at room temperature. Micro gas sensor with carbon nanotube (CNT) bridging a pair of Au electrodes was fabricated. Direct contact and strong interactions between CNTs and the electrodes contribute to its stable electronic performance.

T3P.034 FABRICATION OF NANO-SCALE HIGH ASPECT RATIO ULTRA SHARP TIPS FOR NANO-MECHANICAL STRUCTURES AT LOW THERMAL BUDGET 1328

P. Wang, A. Michael, S.H. Chen, I. Chuang, and C.Y. Kwok

University of New South Wales, AUSTRALIA

We present a novel low temperature nanofabrication approach that enables the formation of ultra-sharp ($r < 2.5\text{nm}$), high aspect ratio (> 50), and high density nanotip array ($> 10^8/\text{mm}^2$). Array of the high aspect ratio tips are integrated with 460nm wide cantilever beam with high precision and yield. This approach allows the integration of high aspect ratio sharp nanotip arrays on nano-mechanical structure in a CMOS compatible fashion for the first time.

T3P.035 HYBRID NANOPILLAR FORESTS WITH BROADBAND HIGH ABSORPTANCE 1332

Y. Yang^{1,2}, H. Mao¹, Y. Jia¹, H. Xue¹, J. Xiong², W. Wang¹, and B. Jiao¹

¹Chinese Academy of Sciences, CHINA and ²North University of China, CHINA

In this paper, hybrid nanopillar forests (HNFs) are prepared based on a plasma repolymerization technique followed with a metal-nanoparticle deposition step. With these HNFs, high absorptance in a wavelength range of 1.5-25 μm is achieved, and it is regarded as a combined result from light trapping effect and surface Plasmon resonance (SPR) property. With such a feature, the HNFs are expected can be used as an effective absorber in infrared sensors thus to pursue higher performance.

T3P.036 SYNTHESIS AND INTEGRATION OF 2D IRON PHOSPHATE SHEETS FOR ENERGY STORAGE DEVICES 1336

E. Kao, H.-S. Jang, X. Zang, and L. Lin

University of California, Berkeley, USA

This work presents (1) synthesis and assembly of 2D, poly-crystalline phosphate sheets greater than $50\mu\text{m}^2$ in area, and (2) 3x improved capacitance of an Iron-Phosphate-Polypyrrole battery/supercapacitor (3.6 mF/cm^2) over bare Polypyrrole (PPY) films, and (3) 20x improved capacitance of an FePO_4 -Carbon Nanotube (CNT) battery/supercapacitor (20.8 mF/cm^2) over bare CNT-based electrodes.

T3P.037 TUNABLE MID-INFRARED BIOSENSORS BASED ON GRAPHENE METASURFACES 1340

Y. Zhu¹, Z. Li¹, Y. Hao², J. Hone¹, N. Yu¹, and Q. Lin¹

¹Columbia University, USA and ²Nanjing University, CHINA

We develop an actively tunable infrared biosensor based on metasurfaces that enable ultrasensitive detection of biomolecules. Molecular vibrational signal can be achieved on monolayer protein. Human IgG concentration down to 30 pM was resolved from the plasmonic resonance shift, corroborated by the increase in the intensities of amide I and II bands. Varying the optical conductivity of graphene actively tuned the plasmonic resonance toward amide I and further enhance its spectral intensity.

WEDNESDAY - Nanoscale Materials, Devices and Fabrication

W3P.032 A HIGHLY SERS-ACTIVE AND FLEXIBLE DROPLET BASED ON CARBON-METAL COMPOSITE NANOPARTICLES 1344

H. Mao¹, R. Li², C. Huang¹, Y. Jia¹, W. Wang¹, A. Ming¹, and J. Xiong²

¹Chinese Academy of Sciences, CHINA and ²North University of China, CHINA

This work presents a new surface-enhanced Raman scattering (SERS)-active substrate using candle-soot flame deposition. By rolling a droplet on the SERS substrate, a SERS-active droplet can be obtained, which shows 26.5 times higher SERS signals than the SERS substrate. The highly SERS-active droplet can be directly adopted for SERS detections with less focusing requirements, or be transferred to any other substrates or targets for further detections.

W3P.032 A HIGHLY SERS-ACTIVE AND FLEXIBLE DROPLET BASED ON CARBON-METAL COMPOSITE NANOPARTICLES 1344

H. Mao¹, R. Li², C. Huang¹, Y. Jia¹, W. Wang¹, A. Ming¹, and J. Xiong²
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W3P.033 GHZ SURFACE ACOUSTIC WAVE ULTRAVIOLET SENSOR BASED ON PHOTO-CONDUCTIVE LAMELLAR MOLYBDENUM DISULFIDE 1348

P. Zhou, X. Wang, C. Chen, N. Wang, Y. Yu, and H. San
 Xiamen University, CHINA

This paper reports a high sensitive ultraviolet (UV) sensor based on Zinc Oxide (ZnO) surface acoustic wave resonator (SAWR) device using photo-conductive lamellar Molybdenum Disulfide (MoS₂). This single port SAWR with resonant frequency of 1.02 GHz was fabricated using electron beam lithography (EBL) technique. The lamellar MoS₂ were covered on SAWR surface. The SAWR UV sensor exhibited a maximum sensitivity of 4.15 ppm/(μW/cm²) under illumination of 365 nm UV light.

W3P.034 INKJET-PRINTED AG MICRO-/NANOSTRUCTURE CLUSTERS ON CU SUBSTRATES FOR IN-SITU PRE-CONCENTRATION AND SURFACE-ENHANCED RAMAN SCATTERING 1352

Q. Zhou, A.K. Thokchom, D. Kim, and T. Kim
 Ulsan National Institute of Science and Technology (UNIST), KOREA

Here, we describe a novel method for SERS substrates using inkjet printing that allows AgNO₃ solution to be regularly injected onto a superhydrophobically functionalized Cu substrate. As a sample drop containing analytes and Au nanoparticles (Au-NPs) evaporates on the Cu substrate, the analytes and Au-NPs are delivered to the hydrophilic Ag nanoplate array (Ag-NPA), facilitating simple, easy, and *in-situ* pre-concentration and sensitive SERS detection.

W3P.035 THE LEVEL SET SIMULATION FOR COMPLEX MICROSTRUCTURES IN QUARTZ WET ETCHING 1356

Y. Zhang¹, J. Zhang¹, Y. Xing¹, H. Zhang¹, M.A. Gosálvez², and X. Qiu¹
¹Southeast University, CHINA and ²University of the Basque Country, SPAIN

We develop the Level Set Method (LSM) to simulate the etching process of complicated structures of quartz. This method is different from atomic approaches like CCA or Monte Carlo, which need to calibrate many parameters of the simulation model. Based on the proposed method complex micro structures like crossed grooves, mesa arrays can be well simulated.

W3P.036 VERTICALLY ALIGNED CARBON NANOTUBES FOREST BASED FLEXIBLE STRAIN SENSOR FOR INTERNET OF THINGS APPLICATIONS 1360

C.H. Yang, C.C. Su, K.P. Hsieh, Y.R. Li, K.Y. Yeh, and S.H. Chang
 National Taiwan University, TAIWAN

We fabricated wearable strain sensors by iron-filled vertically-aligned carbon nanotubes (VA-CNTs) by directly depositing CNTs on bendable foil based substrate with Ferrocene (Fe(C₅H₅)₂). The fabrication provides a forward potential for large-scale industrial manufacturing and flexible electronics design. The gauge factor (367) is higher than commercial strain sensors and previous works with mobile computing scenario by synchronous embedded Internet of Thing (IoT)-sensing system.

MONDAY - Composite Materials/ Polymers, Devices and Fabrication

M3P.038 1MPa RESISTANT MEMS SLIDE VALVE DRIVEN BY AN EXTERNAL ACTUATOR FOR HIGH POWER FLUIDIC APPLICATIONS 1364

H. Takao^{1,2}, S. Takemasa¹, K. Terao^{1,2}, and F. Shimokawa^{1,2}
¹Kagawa University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

This paper reports a durable MEMS slide valve with enhanced controllability by long-stroke actuation and high pressure resistance more than 1MPa. The features of the microvalve are realized by combination of precise processing accuracy of MEMS and powerful driving force of external actuator. This microvalve copes with both high pressure resistance more than 1MPa and highly accurate flow controllability below 10ml/min for the first time.

M3P.039 COMPOSITE RUBBER ELECTRET FOR ELECTROMECHANICAL LOAD DETECTION 1368

J.-J. Wang, C.-E. Lu, S.-C. Lo, Y.-C. Su, and W. Fang
 National Tsing Hua University, TAIWAN

This study has demonstrated design and fabrication of stretchable rubber electrets. Features of proposed devices: (1)implemented using casting and stacking of multi-layer rubbers, (2)each rubber layer consists of patterned microstructures to control the piezoelectricity. Fabrication processes include surface coatings, elastic electrodes, micro-plasma discharges to produce functions as electrets. Experiments also demonstrate applications for acoustic pressure detections.

- M3P.040 FULL SYSTEM FOR PIEZOELECTRIC ORGANIC MEMS RESONATORS OPERATING IN LIQUID MEDIA 1372**
P.-H. Ducrot¹, I. Dufour¹, L. Nicu², F. Mathieu², and C. Ayela¹
¹Bordeaux University, FRANCE and ²Toulouse University, FRANCE

We develop a full system enabling the integrated resonance frequency measurements of piezoelectric organic MEMS resonators in liquid media. The resonators contain a piezoelectric layer made of PVDF-TrFE for both the actuation and the read-out. They are included into a watertight enclosure associated with a PCB and a dedicated electronic card, allowing electric measurements in liquid media. Viscosity measurement of water/glycerol mixtures, without any knowledge of the mass density, are presented.

- M3P.041 PHOTO-TUNABLE MOLECULAR RECOGNIZING SMART MATERIAL FOR GAS SENSING 1376**
K. Nakanishi, F. Sassa, and K. Hayashi
Kyushu University, JAPAN

We developed a dynamic photo-tunable gas adsorbent based on photo sensitive smart material and molecularly imprinted polymer (MIP) technology. Gas adsorption properties of the material, mixture of photochromic materials and polymethyl methacrylate, can be controlled reversible and continuously by irradiation of different wavelength light. As a result, a single QCM gas sensor coated with the developed adsorbent can detect gas molecules with photo-tunable sensitivity.

TUESDAY - Composite Materials/ Polymers, Devices and Fabrication

- T3P.038 3D WL MEMS WITH TSV LAST TECHNOLOGY'S MECHANICAL ANALYSIS 1380**
H.-Y. Lee, C.-C. Kuo, C.-T. Wang, Y.-C. Lee, M.-H. Chen, H.-L. Tarng, and C.-P. Hung
Advanced Semiconductor Engineering, Inc., TAIWAN

This paper introduces two structures of TSV LAST technology, standard flow and short flow. The standard flow TSV LAST structure shows better warpage control result, and the short flow TSV LAST structure can reduce the manufacture cost and shorten procedures up to 20%. This paper also reports two warpage control solution: (1) low modulus and low CTE passivation material, and (2) a balance layer design that the warpage issue can be improved more than 30% and 20%, respectively.

- T3P.039 COMPOSITION DISTRIBUTION STUDY OF RE-GENERATED BULK FIBROIN BASED ON NANO-SCALE ABSORPTION SPECTROSCOPY 1384**
K. Liu¹, L. Sun¹, J. Jiang¹, and H. Tao^{1,2}
¹Chinese Academy of Sciences, CHINA and ²University of Texas, USA

In this study, composition distribution difference of methanol-treated silk film between the surface and interior was identified for the first time. Nano-IR (nano infrared radiation) absorption spectroscopy was employed to study the composition distribution in the cross section of silk film.

- T3P.040 LASER PRINTED GRAPHENE ON POLYIMIDE ELECTRODES FOR MAGNETOHYDRODYNAMIC PUMPING OF SALINE FLUIDS 1387**
M.A. Khan¹, I.R. Hristovski², G. Marinaro¹, H. Mohammed¹, and J. Kosel¹
¹King Abdullah University of Science and Technology (KAUST), SAUDI ARABIA and ²University of British Columbia, CANADA

We report for the first time a magnetohydrodynamic pump, whose electrodes are made by laser printing of polyimide. The electrodes exhibit a low sheet resistance of 22.75 ohms/square. The pump is implemented in a channel of 240 sq mm cross-section and has an electrode length of 5 mm. When powered by 7.3 V voltage, 12.43 mA/cm² current density, it produces 13.02 mm/s flow velocity.

- T3P.041 STUDY OF THE ELECTRO-RESPONSIVENESS AND SURFACE TEXTURING OF PEDOT:PSS FOR SMART MEMS INTERFACE APPLICATIONS 1391**
C. Duc¹, A. Vlandas¹, G.G. Malliaras², and V. Senez¹
¹University of Lille, FRANCE and ²Ecole Nationale Supérieure des Mines, FRANCE

We characterize the impact of electrical stimuli on the wettability and volume of immersed PEDOT:PSS films. At low voltage (<1V), we demonstrate a 30° modulation of the contact angle controlled by electrowetting and not by electrochemical reactions. Thus, the contact angle range can be tuned by chemical functionalization. The polymer presents a small swelling (<4%) when the potential is turned from 0.2V to -0.8V. We develop processes to texture the PEDOT:PSS surface at nanoscale and microscale.

WEDNESDAY - Composite Materials/ Polymers, Devices and Fabrication

- W3P.037 A GREEN CHEMISTRY SYNTHESIS OF AG NANOPARTICLES AND THEIR CONCENTRATED DISTRIBUTION ON PDMS ELASTOMER FILM FOR MORE SENSITIVE SERS DETECTION 1395**
J. Zhu^{1,2}, X. Chen¹, J. Fan¹, Y. Mao¹, Z. Chen¹, W. Wu¹, and Y. Jin¹
¹Peking University, CHINA and ²Shenzhen Graduate School of Peking University, CHINA

This paper reports a simple and convenient method to fabricate a surface-enhanced Raman scattering (SERS) substrate. It includes a green chemistry synthesis of Ag nanoparticles (NPs) and a process of coating a monolayer of the Ag NPs on a polydimethylsiloxane (PDMS) elastomer film. Due to the transparent and flexible property of this highly sensitive SERS substrate, it exhibits great potential in *in-situ* detection of solid or irregular objects.

W3P.038 DEVELOPMENT OF EPIDERMAL GROWTH FACTOR- POLYCAPROLACTONE NANOFIBER MESH AND BEAD FOR WOUND HEALING 1399

W.-C. Lin¹, C.-S. Wu², and I.-T. Yeh¹

¹National Sun Yat-sen University, TAIWAN and ²Kaohsiung Veterans General Hospital, TAIWAN

The biocompatible PCL2B200 nanofiber mesh and beads containing epidermal growth factor (EGF) were fabricated separately by using our developed electrospun process for the tissue regeneration applications. The drug release behaviours of two fabricated EGF nanoscaffolds were characterised for 480 hours. The EGF nanofiber mesh performed the quicker released speed and higher release amount, leading to a better proliferation and cell viability than beads that was proved by using the MTT assay.

W3P.039 MASS FABRICATION OF FLEXIBLE PIECES WITH HYDROPHOBIC SURFACE FOR UNDERWATER VEHICLE COATING 1403

L. Song¹, J. Chen¹, L. Xu¹, Z. Wang¹, N. Zhu¹, Y. Xia², and S. Ma²

¹Peking University, CHINA and ²Xiamen University, CHINA

Bio-inspired structures on flexible polymer targeting functional characteristics such as antifouling or drag reduction are important to underwater vehicle coating. We develop the regular micro-honeycomb hydrophobic surface with aspect-ratio > 3 and nanoscale roughness, achieved by a high throughput replication method of microinjection molding and low surface energy film conformal coating, which offers commercial potential.

W3P.040 SYNTHESIS AND CHARACTERISATIONS OF TEMPERATURE-RESPONSIVE DRUG DELIVERY HYDROGEL FOR MEDICAL APPLICATIONS 1406

W.C. Lin¹, Y. Kotsuchibashi², and S.H. Liou¹

¹National Sun Yat-sen University, TAIWAN and ²Shizuoka Institute of Science and Technology, JAPAN

The imiquimod-PMEO₂MA hydrogel film was fabricated as a drug release pad for the keloid therapy in this research. The physiochemical properties of the synthesised PMEO₂MA hydrogel, including swelling/deswelling behaviour and temperature response, were characterised to understand the loaded amount and released speed of the imiquimod. Similarly, protein adsorption and cytotoxicity of developed hydrogel pad were measured to understand the biological properties for the keloid therapy treatment.

MONDAY - Chemical Sensors and Microsystems

M3P.042 A DISPOSABLE MICROCAPSULE ARRAY CHIP FOR ON-SITE MULTI-TARGET DETECTION OF IONS IN WATER 1410

E. He¹, F. Zheng², L. Cai², H. Xu², D. Guo¹, and Z. Li²

¹Tsinghua University, CHINA and ²Peking University, CHINA

We develop a disposable and inexpensive microcapsule array chip for on-site multi-target detection of ions in water. Indicating solutions detecting eight different kinds of ions (hydrogen, lead, hexavalent chromium, fluorine, nitrite, nickel, copper and iron) are pre-sealed in the 4×4 microcapsule arrays with the use of ice-printing technique. The result of ion concentration can be qualitatively detected by naked eyes or quantitatively detected with image processing within minutes.

M3P.043 ASYMMETRIC ION SELECTIVE MEMBRANE FORMED WITH STRUCTURAL SURFACE FORCE FOR HIGH-PERFORMANCE NITRATE IONS DETECTION IN VEGETABLES 1414

P.-Y. Su and C.-H. Lin

National Sun Yat-sen University, TAIWAN

This paper presents a microfluidic chip with asymmetric ion selective membrane (ISM) for high performance detecting nitrate ions in vegetables. Various geometries of microstructures assisted with neighboring air sheath flows are used to trap trace amount of polymer liquid for the formation of ion selective membrane. The nitrate concentrations in two vegetable of cucumber and bok choy with different washing protocols are successfully detected using the developed microdevice.

M3P.044 CHARGE SENSITIVE FLUID SENSOR FOR CHEMICAL AND BIOLOGICAL APPLICATIONS 1418

M. Heigl¹, K. Neumeier¹, G. Spitzlsperger², C. Kutter¹, and I. Eisele¹

¹Fraunhofer Research Institution for Microsystems and Solid State Technologies (EMFT), GERMANY and

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A new field-effect transistor (FET) based transducer concept for measuring both, liquid and gaseous media is presented. It is based on a Faraday cup and a floating electrode, which is connected to the gate of a MOS transistor. The SOI based technological realization allows a new degree of freedom for more flexible measurements as compared to conventional FET based transducers.

M3P.045 DISPOSABLE COLORIMETRIC GEOMETRICBARCODE SENSOR FOR FOOD QUALITY MONITORING 1422

Y. Chen, G. Fu, Y. Zilberman, W. Ruan, S. Kabiri Ameri, E. Miller, and S. Sonkusale

Tufts University, USA

We present a disposable paper-based optical sensor arranged as a color-changing barcode for monitoring food spoilage. The barcode sensor is embedded in the food packaging and monitored using smart phone. Different geometric shapes are assigned to each dye for ease of their identification. The sensor fabrication is low-tech and easy to perform. A smart phone provides a non-contact metric of food freshness/spoilage.

M3P.046 ELECTRONIC NOSE FOR DETECTION OF TOXIC VOLATILE ORGANIC COMPOUNDS IN AIR 1425

 Z. Xie¹, M.V.R. Raju¹, B.S. Brown², A.C. Stewart¹, M.H. Nantz¹, and X.-A. Fu¹
¹University of Louisville, USA and ²Centre College, USA

This work demonstrates an approach of novel thiols to functionalize gold nanoparticles for fabricating gas sensors for detecting toxic volatile organic compounds. The designed thiols with molecular recognition motif for interaction with target analytes dramatically increase both selectivity and sensitivity of the sensors. The sensor showed linear response relationship in a broad vapor concentration range from 0.1 ppb to 1000 ppm of various organic compounds.

M3P.047 FLEXIBLE AND TRANSPARENT NO₂ SENSOR USING FUNCTIONALIZED MoS₂ WITH LIGHT-ENHANCED RESPONSE 1429

Y. Kang, S. Pyo, D.-H. Baek, and J. Kim

Yonsei University, KOREA

This paper reports the visible-light assisted gas sensing properties of SnO₂-functionalized MoS₂ for the first time. Under visible light illumination, photo-induced carrier separation allows to sensitive detection of gas species, because increased number of electrons in SnO₂ can participate in the reaction with gas molecules. The flexible and transparent sensor was able to detect NO₂ at different concentrations, from 9 down to 3 ppm at room temperature and under visible light illumination.

M3P.048 HIGH SENSITIVE MICRO THERMAL CONDUCTIVITY DETECTOR WITH SANDWICH STRUCTURE 1433

F. Feng, B. Tian, L. Hou, Z. Yu, H. Zhou, X. Ge, and X. Li

Chinese Academy of Sciences, CHINA

This paper reports a new micro thermal conductivity detector (μ TCD) with sandwich structure. μ TCD's sensitive part is a suspended cross-mesh structure that includes a Pt thermistor protected by two SiNx layers and a cross-mesh support made of top silicon of SOI. The μ TCD has the better reliability, smaller excess dead volume and less process time compared to the state of the art. Experimental results show that the detector demonstrates a high sensitivity without pre-concentrator.

M3P.049 LOW-COST METAMATERIAL-ON-PAPER CHEMICAL SENSOR 1437

A. Sadeqi and S. Sonkusale

Tufts University, USA

We present a disposable low cost paper-based sensor for sensing chemicals based on their intrinsic dielectric properties. The sensor is based on resonance shift in metamaterials due to the change in capacitance of each resonator unit cell. Key novelty in the design is the implementation of metamaterial on ubiquitous paper substrate. This paper-based metamaterial-inspired sensor is fabricated in a totally cleanroom-free process.

M3P.050 MICROFABRICATED DIRECTIONAL COUPLER-BASED BIOSENSOR FOR AFFINITY SENSING 1441

K. Uchiyamada, K. Okubo, K. Asakawa, and H. Suzuki

University of Tsukuba, JAPAN

A directional coupler (DC) was used to fabricate an affinity sensor based on the measurement of surface refractive index changes. The DC sensor consisted of two parallel polymer waveguides was formed with a SU-8 photoresist by electron beam. Changes observed using the sensor agreed well with those anticipated by simulation. Real time monitoring of the binding of streptavidin to biotin immobilized on the DC surface was conducted. With a 560- μ m long DC, achieved detection limit was 11.3 μ g/ml.

M3P.051 ROTATING INTERFERENCE FILTER SPECTROMETER FOR THE DETECTION OF ETHYLENE IN THE RIPENING PROCESS OF CLIMACTERIC FRUIT 1445

 A. Eberhardt¹, K. Schmitt², and J. Wöllenstein^{1,2}
¹University of Freiburg, GERMANY and ²Fraunhofer Institute for Physical Measurement Techniques IPM, GERMANY

We present the recent progress of our rotating interference filter spectrometer for the detection of ethylene in the ripening process of climacteric fruit. The detection limit could be improved to ~2 ppm by a factor of ~15 at a simultaneously better long-term stability compared to the state of the art.

M3P.052 MODE-LOCALIZED TRIO CANTILEVER ARRAY FOR PICOGRAM ORDER MASS SENSING 1449

 D. Zhou¹, X. Li¹, J. He¹, X. Liu¹, and D.F. Wang^{1,2}
¹Jilin University, CHINA and ²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

This paper reports a methodology based on mode localization which, for the first time, verifies the possibility of discriminating two different analytes with a coupled three-cantilever array theoretically and experimentally. This simplifies the structure of present cantilever array sensors used to identify multiple analytes. Meanwhile, such a methodology provides a new idea on the detection of multiple toxic substances in the surroundings.

- M3P.053** **VERTICALLY INTEGRATED CMOS-MEMS CAPACITIVE HUMIDITY SENSOR AND A RESISTIVE TEMPERATURE DETECTOR FOR ENVIRONMENT APPLICATION** 1453
 S.-C. Chen, V.P.J. Chung, D.-J. Yao, and W. Fang
National Tsing Hua University, TAIWAN

This study demonstrates the vertical integrated environment sensor with a capacitive relative humidity sensor and a resistive temperature detector using the TSMC 0.18 μ m 1P6M CMOS process. Features of this study are: (1) multiple sensing unit could be vertically implemented and integrated in one chip; (2) fast response humidity sensor are realized based on fence-shape capacitor with polyimide filler; (3) simple post-CMOS processes using metal wet etching and pneumatic dispensing of PI.

TUESDAY - Chemical Sensors and Microsystems

- T3P.042** **A LOW-COST NITRIC OXIDE GAS SENSOR BASED ON BONDED GOLD WIRES** 1457
 S. Schröder^{1,2}, H.K. Gatty¹, G. Stemme¹, N. Roxhed¹, and F. Niklaus¹
¹KTH Royal Institute of Technology, SWEDEN and ²SenseAir AB, SWEDEN

This paper reports a novel, simple and cost-effective approach for fabricating amperometric nitric oxide (NO) sensors using a conventional automated wire bonding tool. Working and counter electrodes are made of 360 vertically standing bond wires with a height of 1.24 mm, resulting in electrodes with extremely high aspect ratios of 49.6 and thereby increases the surface area of the electrodes. The proposed concept is scalable and no modification of the wire bonder is required.

- T3P.043** **WITHDRAWN**

- T3P.044** **CORRUGATED-CORE SANDWICH-STRUCTURED SELF-POWERED ACTIVE GAS SENSOR WORKABLE UNDER WIDE RANGE OF EXTERNAL IMPACTS** 1465
 A.S.M. Iftekhhar Uddin and G.-S. Chung
University of Ulsan, KOREA

We develop a self-powered active hydrogen sensor using a corrugated-core sandwich-structured triboelectric nanogenerator. The working capability of the sensor can be tuned by varying the corrugated sheet's orientation in the sandwich plates and/or stacking two single-unit structures in parallel. We expect that the superior sensing properties, high stability, and enhanced workability of the sensor under a broad variety of impacts will pave the way for next-generation self-powered active sensors.

- T3P.045** **DYNAMIC MODELING OF STERIC EFFECTS ON POLARIZABLE ELECTRODES** 1467
 P.H. Gordon and E.C. Kan
Cornell University, USA

We present a new dynamic ionic transport model close to the interface of a polarizable electrode with explicit expression in the drift-diffusion formalism for the steric effect based on a revised Einstein relation. We also present experimental validation and extraction of the steric ion size by the potential step responses.

- T3P.046** **FILM BULK ACOUSTIC RESONATOR BASED GAS SENSOR: A SENSITIVE DETECTOR FOR GAS CHROMATOGRAPHY** 1471
 Y.W. Wang¹, C.Y. Ao¹, Z.P. Hui¹, X. Yan², J.Z. Hu², Y. Chang^{1,2}, H.M. Qu², X.X. Duan², and W. Pang²
¹China Marine Development and Research Center, CHINA and ²Tianjin University, CHINA

We report a miniaturized sensitive gravimetric gas sensor based on film bulk acoustic resonator (FBAR). The sensitivity of the FBAR gas sensor is enhanced 10 ~ 20 times after coating with nanomaterials (metal organic frameworks (MOFs)). A facile coating process of MOFs on FBARs is disclosed for the first time. Furthermore, utilizing FBAR sensors as detectors is firstly demonstrated in a prototype of chromatographic instrument by facile hyphenation of FBAR with commercial separation column.

- T3P.047** **WITHDRAWN**

T3P.048 HIGHLY SENSITIVE AND INTEGRATED VOC SENSOR BASED ON SILICON NANOPHOTONICS 1479

 Z.Y. Li¹, G. Zhang², Z.C. Yang¹, Y.L. Hao¹, Y.F. Jin¹, and A.Q. Liu²
¹Peking University, CHINA and ²Nanyang Technological University, SINGAPORE

An integrated volatile organic compounds (VOC) sensor using silicon photonic ring resonator system is presented in this paper. The relative high sensitivity (1.7 pm/ 1000 ppm for acetone), high stability (<1 pm drift) and fast response time (~20 s) make it a perfect candidate in VOC safety monitoring and warning.

T3P.049 MASS SPECTROMETRY PESTICIDE SCREENING WITH PAPER-BASED MICROFLUIDIC CASSETTE FOR 2D PAPER CHROMATOGRAPHY AND ELECTROSPRAY IONIZATION 1483

C.-H. Chen and C.-H. Lin

National Sun Yat-sen University, TAIWAN

This paper presents a novel paper-based microfluidic cassette for 2D paper chromatography and electrospray ionization (ESI) for rapid mass spectrometry screening of pesticides in vegetable. Instead of using conventional bulky HPLC/MS systems, liquid sample is directly applied on the cassette for sample separation with paper chromatography and then enriched with the second paper chromatography for enhancing the sensing performance of ESI-MS detections.

T3P.050 NETWORKS OF ULTRA-SMALL PD/MG BIMETALLIC NANOWIRES AS HIGH PERFORMANCE WEARABLE HYDROGEN SENSOR 1487

K. Hassan and G.-S. Chung

University of Ulsan, KOREA

We develop hydrogen sensor using ultra-small bimetallic palladium/magnesium nanowires network on commercial filtration membrane. The sensor exhibits enhanced hydrogen sensing properties and offers wearable applications. The formation of a network of discrete Pd/Mg nanowires shows H₂ sensing properties at 25°C with remarkable amenities, such as a large detection range (10-40,000 ppm). For a 1% H₂, a response time of ~ 6 s is observed, which is enhanced with the dealing of bending (~ 4 s).

T3P.051 SELF-ALIGNED PRECISE UPLOAD OF Pd-MODIFIED MESOPOROUS In₂O₃ ON SUSPENDED MEMS HEATING-PLATE FOR ULTRA-SENSITIVE H₂ GAS SENSING 1489

 Y. Chen¹, P. Xu¹, X. Li¹, Y. Ren², and Y. Deng²
¹Chinese Academy of Sciences, CHINA and ²Fudan University, CHINA

We develop a novel top-down & bottom-up compatible technique for sensing materials self-aligned upload onto the specific area of micro-sensor. Interference signal and noise coming from material disperse can be reduced obviously. With Pd modified mesoporous-In₂O₃ loaded, the sensor shows ultra-high sensitivity to 0.5-100 ppm hydrogen. This easy and repeatable technique offers promise of batch fabrication and application in plenty kinds of chemical sensors.

T3P.052 SIZE-SELECTIVE ELECTROSTATIC SAMPLING AND REMOVAL OF NANOPARTICLES ON SILICON CANTILEVER SENSORS FOR AIR-QUALITY MONITORING 1493

 M. Bertke¹, W. Wu¹, H.S. Wasisto¹, E. Uhde², and E. Peiner¹
¹Braunschweig University of Technology, GERMANY and ²Fraunhofer-WKI, GERMANY

We investigate the size-selective sampling and removal of airborne nanoparticles (NP, < 300 nm) using a silicon resonant micro cantilever mass balance combined with a miniaturized electrostatic precipitator (ESP). This allows to design an overnight-refreshable, pocket-sized, autarkic monitor for NP mass concentration and size. Prototype devices were tested in experiments with widely employed aerosols (C, SiO₂, TiO₂) known to be harmful to the cardiovascular system of exposed workers.

T3P.053 ZERO CONSUMPTION CLARK-TYPE OXYGEN MICROSENSOR FOR CELL CULTURE MONITORING 1497

J. Kieninger, F. Liebisch, A. Weltin, J. Marzioch, and G.A. Urban

University of Freiburg, GERMANY

This paper reports on fabrication and characterization of a true Clark-type microsensor to monitor oxygen locally in cell culture. We were able to implement the Ross principle to achieve zero analyte consumption, as verified by reading the counter electrode potential. Chronoamperometric protocols have been applied for the first time in miniaturized Clark-type arrangements resulting in superior sensor stability. The sensor was applied for oxygen measurements in tumor cell culture.

WEDNESDAY - Chemical Sensors and Microsystems
W3P.041 A PRINTABLE CONDUCTIVE POLYMER CO₂ SENSOR WITH HIGH SELECTIVITY TO HUMIDITY 1501

W.-Y. Chuang, C.-C. Wu, S.-S. Li, and C.-T. Lin

National Taiwan University, TAIWAN

This work utilizes PEDOT:PSS/PANI composite polymer to develop a low-power and low-cost CO₂ sensing material. With proper material composition, the developed CO₂ sensing material overcomes a major problem, selectivity to humidity, of traditional conductive polymer sensors. Based on these experimental results, the developed CO₂ polymer sensor demonstrates a good potential for chemical/environmental applications of Internet-of-Thing technologies.

- W3P.041 A PRINTABLE CONDUCTIVE POLYMER CO₂ SENSOR WITH HIGH SELECTIVITY TO HUMIDITY 1501**
W.-Y. Chuang, C.-C. Wu, S.-S. Li, and C.-T. Lin
National Taiwan University, TAIWAN

This work utilizes PEDOT:PSS/PANI composite polymer to develop a low-power and low-cost CO₂ sensing material. With proper material composition, the developed CO₂ sensing material overcomes a major problem, selectivity to humidity, of traditional conductive polymer sensors. Based on these experimental results, the developed CO₂ polymer sensor demonstrates a good potential for chemical/environmental applications of Internet-of-Thing technologies.

- W3P.042 ATOMIC LAYER DEPOSITED P-TYPE NICKEL OXIDE AND COBALT OXIDE FOR ETHANOL GAS SENSING 1504**
J. Stehle^{1,2}, A.K. Samrao³, U. Krishnamoorthy², and O. Ambacher¹
¹University of Freiburg, GERMANY, ²Robert Bosch LLC, USA, and ³Delphi Labs @ Silicon Valley, USA

We present a study of new materials for ethanol gas sensing with large-scale fabrication techniques. Ultra-thin nickel oxide and cobalt oxide films deposited by atomic layer deposition show promising performance in ethanol sensing. Unlike most semiconducting metal oxides used for gas sensing, nickel and cobalt oxide are p-type materials. P-type metal oxides offer their full sensitivity potential only in thin compact form, where the highly resistive bulk does not dominate the current.

- W3P.043 DESIGN, REALIZATION AND CHARACTERIZATION OF ALL-AROUND SiO₂/Al₂O₃ GATE, SUSPENDED SILICON NANOWIRE CHEMICAL FIELD EFFECT TRANSISTORS 1508**
A. Lale, A. Grappin, D. Bourrier, L. Mazenq, A. Lecestre, J. Launay, and P. Temple-Boyer
Université de Toulouse, FRANCE

We develop a potentiometric sensor platform associated to silicon-nanowire chemical field effect transistors Si-nw-ChemFET. Innovations concern the use of networks of suspended silicon nanowires as conducting channel, the realization by oxidation and atomic-layer deposition of a SiO₂/Al₂O₃ gate insulator all-around the nanowires and to their integration into covered microfluidic channels. The fabrication process and characterizations will be presented, emphasizing reproducibility and reliability.

- W3P.044 EFFECT OF PORE SIZE OF STATIONARY PHASE ON THE SEPARATION PERFORMANCE OF CHIP-BASED GAS CHROMATOGRAPHY COLUMNS 1512**
L. Hou, F. Feng, W. You, P. Xu, F. Luo, B. Tian, H. Zhou, and X. Li
Chinese Academy of Sciences, CHINA

Chip-based semi-packed Gas Chromatography (GC) Columns coated with two kinds of mesoporous silica (MS) stationary phase has been explored and compared. The influence of pore size of the stationary phase on the separation performance has been investigated. As has been demonstrated, full separation of heavy hydrocarbons (C5-C10) can be achieved in both columns. Moreover, compared with stationary phase of smaller pores, that of bigger ones leads to obviously increased retention time of C9 and C10.

- W3P.045 EVALUATION OF TENAX THIN FILMS AS ADSORBENT MATERIAL IN A MICRO-PRECONCENTRATOR AND ITS OPERATION AS A VALVE-LESS MULTIPLE INJECTION SYSTEM IN MICRO-GAS CHROMATOGRAPHY 1516**
I. Azzouz¹, P. Poulichet¹, M. Pirro¹, W. Tan¹, F. Marty¹, M. Capochichi-Gnambodoe¹, E. Nefzaoui¹, A. Boumechhour², W. Cesar³, D. Angelescu⁴, K. Bachari², and T. Bourouina¹
¹Université Paris-Est, FRANCE, ²C.R.A.P.C., ALGERIA, ³Fluigent SA, FRANCE, and ⁴Fluidion SAS, FRANCE

We aim to develop a micro analysis systems for environmental pollutants analysis. We investigate new category of adsorbent in the form of films as an alternative to its solid form (granular). These adsorbent coats MEMS-based chips in order to retain volatil organic compounds (VOCs). The novelty of our work is to investigate the retention of a special group of VOC named BTEX which are very harmful both for human and environment. Very promising results showed a preconcentration factor up to 96.

- W3P.046 WITHDRAWN**

- W3P.047 HIGHLY SENSITIVE MICRO SENSOR WITH NAFION COATED BISMUTH FOR TRACE LEAD DETERMINATION 1524**
L. Wang¹, G. Jing¹, and T. Cui²
¹Tsinghua University, CHINA and ²University of Minnesota, USA

This paper reports a cation-exchanging resin decorated micro bismuth sensor, which makes portable and highly sensitive on-line lead detection possible.

W3P.048 MICRO-PILLAR DENSITY MODULATION IN SEMI-PACKED MEMS COLUMN 1528

R. Chan, A. Lopez, B.P. Regmi, and M. Agah
Virginia Polytechnic Institute and State University, USA

We develop a semi-packed MEMS column utilizing micro-pillar density modulation to improve gas chromatography separation resolution and efficiency at higher inlet pressures for high speed separations.

W3P.049 ROOM-TEMPERATURE CO₂ SENSING BASED ON INTERDIGITATED CAPACITORS AND RESONANT CANTILEVERS 1532

C. Kim, P. Getz, M.G. Kim, and O. Brand
Georgia Institute of Technology, USA

This paper compares a MEMS-based resonant cantilever and an interdigitated capacitor, both coated with an amino-functionalized sensing film, as a carbon dioxide (CO₂) detector. The sensor sensitivities at room temperature to CO₂ are assessed as well as their cross-sensitivities to temperature and humidity. The effectiveness of an uncoated reference cantilever for temperature compensation is demonstrated, reducing the temperature sensitivity of the system by a factor of 300.

W3P.050 SELF-POWERED GAS SENSOR USING THIN-FILM PHOTOVOLTAIC CELL AND MICROSTRUCTURED COLORIMETRIC FILM 1536

K. Kang, K. Na, D. Kwon, J.-Y. Lee, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We developed self-powered gas sensor using microstructured colorimetric film and solar cell, which can be operated without any external power source under ambient sun light. This sensor utilizes the color change of colorimetric film induced by reaction with gas that directly leads to the output change of solar cell. In addition, the sensing performance of gas sensor can be enhanced by coating colorimetric material on the microstructured transparent film with larger surface area.

W3P.051 THIN SILICON LIGHT-ADDRESSABLE POTENTIOMETRIC SENSOR BY DEEP REACTIVE-ION ETCHING 1540

W.-Y. Zeng¹, T.-C. Chen¹, H.-L. Liu¹, Y.-P. Chen¹, and C.-M. Yang^{1,2}
¹Chang Gung University, TAIWAN and ²Chang Gung Memorial Hospital, TAIWAN

To have a high photocurrent and spatial resolution of 2-dimensional chemical image in light-addressable potentiometric sensor, silicon substrate is thinned down to about 100 μm by deep reactive-ion etching. Compare to commercial Si substrate with thickness of 350 μm, photocurrent is increased for 4.5 times and operation frequency is increased to 20 kHz. Higher signal to noise ratio is benefit for high-speed and spatial resolution of 2D chemical image.

MONDAY - Bio-Sensors and Bio-Microsystems

M3P.054 A HIGH THROUGHPUT PHOTSENSITIVE POLYMER CANTILEVER INTEGRATED WITH MICROELECTRODE ARRAY FOR DRUG-INDUCED CARDIAC TOXICITY SCREENING 1543

Y.K. Dai, N.E. Oyunbaatar, E.S. Kim, B.K. Lee, and D.W. Lee
Chonnam National University, KOREA

This paper presents a high throughput photosensitive polymer cantilever device for real time monitor of drug-induced cardiac toxicity screening. The device comprises 3D micro-patterns and 3×3 microelectrode array on its surface. This method used to measure the combined mechanical and electrical performances of cardiomyocytes. The fabricated cantilever can embody the contraction force and impedance simultaneously and identify the relationship between contraction force and cell impedance.

M3P.055 A VACUUM CAPILLARY VISCOMETER THAT MEASURES THE VISCOSITY OF BIOFLUIDS 1547

T.-C. Chou¹, J. Lee², T.K. Hsiai², and Y.-C. Tai¹
¹California Institute of Technology, USA and ²University of California, Los Angeles, USA

We develop and model a new miniaturized vacuum capillary viscometer featuring small sample volume (1-4μL) and fast turnaround time (<30seconds), which allows people for the first time, to perform repeatable blood and plasma viscosity measurements on adult zebrafish.

M3P.056 DEVELOPMENT OF H₂O₂ IMAGE SENSOR FOR GABA AND GLUTAMATE IMAGING 1551

Y. Okumura, S. Mizutani, K. Okumura, T. Iwata, K. Takahashi, and K. Sawada
Toyohashi University of Technology, JAPAN

We have developed 16000 pixels H₂O₂ image sensor with 23.55 μm spatial resolution was constructed Fe²⁺ and Fe³⁺ / enzyme / Au thin film / pH image sensor. H₂O₂ image sensor can read signals of redox reaction, so that it is possible to detect the target without being affected by the buffer solution that is depending on the hydrogen ion activity. From experimental result, it was suggested that the possibility of imaging, utilizing the enzyme reaction system that generates H₂O₂.

M3P.057 ELECTROCHEMICAL MICRODEVICES FOR PROTEINS BASED ON COULOMETRY COUPLED WITH SILVER METALLIZATION 1555

I. Anshori and H. Suzuki
University of Tsukuba, JAPAN

Highly sensitive detection of a protein was conducted using a microfluidic device for coulometry coupled with metallization. On a single electrode, hydrogen peroxide produced from the enzyme-linked immunosorbent assay (ELISA) process was oxidized and silver was deposited simultaneously at the mixed potential. The amount of deposited silver was measured by coulometry. With 120 min incubation for the final enzymatic reaction in the ELISA, the achieved detection limit was 0.4 ng/mL.

M3P.058 HEATING INDUCED SELF-ASSEMBLY DENATURED BOVINE SERUM ALBUMIN FILM ON GRAPHENE TARGETING BIOMOLECULES 1559

L. Zhou^{1,2}, K. Wang^{1,2}, Z.H. Wu^{1,2}, Z.L. Cheng^{1,2}, Y.N. Bai^{1,2}, H.B. Zhou¹, Q.H. Jin¹, H.J. Mao¹, and J.L. Zhao¹
¹Chinese Academy of Sciences, CHINA and ²University of Chinese Academy of Sciences, CHINA

We develop novel graphene biosensor based on self-assembly protein film modified graphene targeting biomolecules. Bovine serum albumin (BSA) molecules in inorganic solution are self-assembled and aggregated on the graphene surface uniformly with the driving of heating for the first time. This self-assembly denatured BSA modified graphene device could detect anti-BSA directly with the high sensitivity of 10pg/ml.

M3P.059 LAB-ON-CHIP STRETCHABLE IMPEDANCE SPECTROSCOPY DEVICE FOR MAMMALIAN CELLS STUDIES 1563

X. Zhang¹, F. Li², K. Lee¹, and I. Voiculescu¹
¹City College of New York, USA and ²New York Institute of Technology, USA

This paper presents the fabrication and testing of a novel Electric Cell-substrate Impedance Spectroscopy (ECIS) biosensor. This is the first time when ECIS electrodes were fabricated on a stretchable substrate and ECIS measurements on mammalian cells exposed to cyclic strain were performed. The stretchable ECIS biosensors simulate *in vitro* the dynamic environment of organism, which enables the investigation on cell behavior that undergoes mechanical stimuli in biological tissue.

M3P.060 MICROFLUIDIC DEVICES FOR ENHANCING *IN-VITRO* FERTILIZATION 1567

Y.-C. Tzeng¹, Y.-J. Chen¹, C. Chuan¹, L.-C. Pan², and F.-G. Tseng¹
¹National Tsing Hua University, TAIWAN and ²Taipei Medical University, TAIWAN

We propose the synergic operation of two devices that consist of a high quality sperm sorter and an oocytes zona-removal as well as incubation device for promoting the successful rate and the efficiency of *In-vitro* fertilization (IVF).

M3P.061 RAPID BACTERIA DETECTION IN WATER BASED ON MICRO/NANO DEVICES 1570

M. Li¹, C. Huang¹, H. Wang², H. Mao¹, L. Li¹, and Y. Zhao¹
¹Chinese Academy of Sciences, CHINA and ²National Health and Family Planning Commission (NHFP), CHINA

We design a micro system to detect bacteria in water including a micro pore arrays MEMS based bacteria filter and a nano forest silver SERS silicon based sensor. The bacteria filter can pre-concentrate and elute the bacteria samples efficiently without culture and proliferation process in tradition bacteria detection methods. The type of the bacteria can be determined by SERS technique without fluorescence labeling and biochemical reaction.

M3P.062 REDOX CYCLING-BASED ELECTROCHEMICAL-ENZYMATIC BIOSENSOR PLATFORM FABRICATED VIA ELECTRODEPOSITION OF GOLD NANOPARTICLES ON CARBON IDA NANO-ELECTRODES 1573

D. Sharma, J. Lee, J. Seo, and H. Shin
Ulsan National Institute of Science and Technology (UNIST), KOREA

We developed a versatile and highly sensitive biosensor platform based on electrochemical-enzymatic redox cycling induced by selective enzyme immobilization on carbon interdigitated array (IDA) nanoelectrodes decorated with gold nanoparticles (AuNPs). The AuNPs integration on the 3D carbon IDA nanoelectrodes facilitates the enhancement of surface reactivity (2.2 times) and surface area, and reduces the inter-electrode gap.

M3P.063 WITHDRAWN

- M3P.064 WIDEFIELD REAL-TIME SINGLE-CELL SECRETION IMAGING WITH OPTICAL WAVEGUIDE TECHNIQUE 1580**
Y. Tanaka¹, N. Suzuki^{1,2}, K. Moro², J. Mizuno³, S. Shoji³, S. Uemura¹, and Y. Shirasaki^{1,2}
¹ Tokyo University, JAPAN, ² Riken IMS, JAPAN, and ³ Waseda University, JAPAN

We developed a novel optical waveguide chip for quick and high definition fluorescence imaging. To allow the high numerical aperture objective lens to approach the evanescent field, we applied cover-glass like quartz slide to our platform. In addition, we made chamber by carbon black PDMS to protect cells against the leaking laser light, which generates active oxygen. Our methodology is useful for real-time imaging of the migrating immune cells' cell-to-cell communication by the cytokine.

TUESDAY - Bio-Sensors and Bio-Microsystems

- T3P.054 A HIGHLY PERFORMED NONENZYMATIC GLUCOSE SENSOR USING SURFACTANT TEMPLATE ASSISTED PLATINUM NANOPARTICLES 1584**
M.F. Hossain, S.C. Barman, and J.Y. Park
Kwangwoon University, KOREA

In this work, a highly performed working electrode, which was decorated with surfactant assisted platinum nanoparticle (PtNP) on rectangular shaped Au thin film electrode for effectively glucose detection. Diblock copolymer surfactant was used to deposit PtNPs on the working and counter electrodes simultaneously. The fabricated biosensor showed good electrocatalytic performance in terms of high sensitivity of 0.32 $\mu\text{A}/\text{mM}$, fast response <5 s, and wide linear range from 0.0625 to 22 mM.

- T3P.055 A NOVEL ON-CHIP ELEMENT TO PROVIDE MAMMALIAN CELL CULTIVATION AND PASSAGING TO LABS-ON-CHIPS 1588**
F. Bunge, S. van den Driesche, and M.J. Vellekoop
University of Bremen, GERMANY

We present the long-term cultivation, passaging, and harvesting of mammalian cells outside of an incubator but inside a microfluidic chip. The presented device includes structures to supply the cells continuously but separately with gases and medium by diffusion through membranes out of agarose hydrogel. The chip is fabricated with standard cleanroom processes out of glass and silicon which enables the future integration of analysis tools towards real Labs-on-Chips applications.

- T3P.056 AN EMBEDDED SINGLE-CELL IMPEDAMETRIC POSITIONING TRACKER IN MICROFLUIDIC DEFORMABILITY ASSAYS 1592**
P. Ghassemi, X. Ren, J.S. Strobl, and M. Agah
Virginia Polytechnic Institute and State University, USA

We report the integration of bioimpedance sensing and cell deformability assays in a unique microfluidic channel for label-free and image-free analysis of single-cell biophysical attributes. The transparent microfluidic chip consists of a constriction channel and an array of embedded ITO electrodes through which cell position can be tracked with high resolution. Information regarding cell transit times and velocities during cell deformation can be readily assessed without using video microscopy.

- T3P.057 WIRELESS NEURAL STIMULATOR BASED ON TWO-PORT SAW DELAY LINE AND AC/DC CONVERTING INTERFACE 1596**
J. Kim, S. Kim, and K. Lee
Ajou University, KOREA

Wireless neural stimulator was developed using SAW delay line, schottky diode and capacitor, sharp metal tip, and antennas. When IDT on SAW delay line receives RF energy from antenna, SAW is generated and propagates toward output IDT. SAW is converted into AC signal at output IDT. By modulating RF power and number of cycles applied to input IDT, the targeted stimulation pulses were obtained at the sharp metal tip. The obtained pulses showed $\sim 0.08\text{mV}$ in amplitude, and 3~10Hz in frequency.

- T3P.058 FPW BIOSENSOR WITH LOW INSERTION LOSS FOR DETECTION OF TETRAHYDROCANNABINOL ANTIGEN 1600**
J.-W. Lan¹, I.-Y. Huang¹, Y.-C. Lin², W.H. Huang¹, C.H. Yeh³, and C.-H. Hsieh¹
¹ National Sun Yat-sen University, TAIWAN, ² National Cheng Kung University, TAIWAN, and ³ National Taiwan University, TAIWAN

We designed focus-type IDTs that can effectively constrain launched wave energy, and adopted a focus-type reflective grating structure to reduce wave propagation loss. The results reveal that the proposed FPW devices have lower insertion loss (38.758 dB). Then, we developed a novel FPW-based biosensor for rapid detection of THC concentration in human urine. This FPW-THC biosensor has low detection limit (40 ng/mL), high sensitivity (126.67 cm^2/g), and high sensing linearity ($R\text{-square}=0.9157$).

T3P.059 HIGHLY PURE PHLOEM-SAP-EXTRACTION SENSOR DEVICE FOR DIRECT COMPONENT ANALYSIS OF NUTRITION IN PLANT SHOOTS 1604

A. Ono, R. Izumi, H. Ishizuka, K. Terao, H. Takao, R. Ichihashi, T. Kobayashi, I. Kataoka, and F. Shimokawa
Kagawa University, JAPAN

This paper describes highly pure phloem-sap-extraction sensor device that mounts phloem position-identification sensor. Convenient methods of artificially extracting highly pure phloem sap for quantitative analysis of plant nutrition have yet to be established. To realize direct analysis of nutrition as well as long-term monitoring of its fluctuation, we propose a novel sensor device that can distinguish phloem and xylem position and extract only pure phloem sap.

T3P.060 LASER MICROMACHINING OF REUSABLE GLASS DEVICES DEDICATED TO THE TARGETED ELECTROPORATION OF CELL ASSEMBLIES 1608

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⁴LightFab GmbH, GERMANY, and ⁵Klearia SAS, FRANCE

We demonstrate that the localized introduction of cell markers by electroporation can be efficiently and safely achieved with reusable microchips complying with industrial micromachining techniques. Thus, relying on contract manufacturing any biologist can now implement this transfection approach at moderate cost. Furthermore, adaptation of the design to specific tissues or to user-inspired ergonomic choices can easily be assisted by numerical simulations.

T3P.061 MOBILE IMMUNOASSAY SYSTEM ON STANDARD CMOS MAGNETIC BEADS SENSOR 1612

T. Ishikawa and S. Tanaka
Tohoku University, JAPAN

A mobile immunoassay system which carries out all its procedure on a CMOS chip is proposed. This method utilizes magnetic beads as its assay marker. The chip is fabricated in a 0.35 μm standard CMOS process. One additional process is etched back of Hall sensor area to enhance its sensitivity and an RF drain current across the sensor lowers the noise floor. Because of reduced fabrication cost, the system enables a regional scale screening and disease control.

T3P.062 REALIZATION OF FILTER-FREE FLUORESCENCE IMAGE SENSOR 1616

K. Tanaka, Y. Kimura, Y.J. Choi, T. Iwata, K. Takahashi, and K. Sawada
Toyohashi University of Technology, JAPAN

We developed a 32×32 filter-free fluorescence image sensor that removed excitation light with utilizing a wavelength-dependent absorption depth of silicon and measuring voltage-controlled photocurrent. This sensor can display each image of excitation light and fluorescence at the same time. We obtained a two-dimensional image of distributed Qdot emission on the image sensor. Proposed sensor can exhibit images of three or more wavelengths at the same time by controlling the photo-gate voltage.

T3P.063 RETROREFLECTION-BASED NONSPECTROSCOPIC OPTICAL IMMUNOSENSING PLATFORM USING RETROREFLECTIVE JANUS PARTICLE 1620

Y.D. Han, K.W. Lee, H.J. Chun, K.R. Kim, and H.C. Yoon
Ajou University, KOREA

We developed a retroreflection-based optical immunosensing system which can be operated under the nonspectroscopic optical transducing equipment such as common white light and digital camera. To utilize the retroreflection as an optical signaling strategy in the immunosensing, the retroreflective Janus microparticle was fabricated as an optical immunosensing probe. By using the developed immunosensing system, an accurate detection of cardiac troponin I was efficiently accomplished.

T3P.064 TOWARD THE ANALYSIS OF MITOCHONDRIA ISOLATED FROM LEUKEMIC CELLS WITH ELECTROCHEMICALLY INSTRUMENTED MICROWELL ARRAYS 1624

G. Lemercier^{1,2}, F. Sekli-Belaïdi¹, V.S. Vajrала³, E. Descamps¹, N. Sojic³, S. Arbault³, J.E. Sarry²,
P. Temple-Boyer¹, and J. Launay¹
¹LAAS-CNRS, FRANCE, ²CRCT - INSERM, FRANCE, and ³ISM - CNRS, FRANCE

This work concerns the development of electrochemical transducers for the monitoring of the metabolic status of isolated mitochondria. Ring nanoelectrodes are integrated into microwell arrays to form addressable sub-picoliter chambers aiming the simultaneous detection of the oxygen consumption and the production of hydrogen peroxide caused by mitochondrial activity.

T3P.065 USING MICROFLUIDIC IMPEDANCE CYTOMETRY TO IDENTIFY THE LIFE STAGES OF C. ELEGANS NEMATODES 1628

W. Chen¹, B. Tian¹, J. Lan², D. Chen², and Z. Zhu¹
¹Southeast University, CHINA and ²Nanjing University, CHINA

This paper presents a microfluidic flow-through system that integrates electrical impedance spectroscopy to identify the life stages of *C. elegans* nematodes. When nematodes in a straight microchannel are passing through a pair of coplanar microelectrodes, electrical impedance signals are recorded via EIS and optical images are taken concurrently. Data analysis shows that impedance amplitudes are linearly correlated to the extracted volume of nematodes.

WEDNESDAY - Bio-Sensors and Bio-Microsystems

W3P.052 A CMOS CAPACITIVE BIOSENSOR ARRAY FOR HIGHLY SENSITIVE DETECTION OF PATHOGENIC AVIAN INFLUENZA DNA 1632

C.-M. Chen and M.S.-C. Lu
 National Tsing Hua University, TAIWAN

This work presents a CMOS capacitive biosensor array for detection of the pathogenic avian influenza virus DNA. Sensing resolution is enhanced by monolithic integration and the use of a thin dielectric layer as the sensing interface. Both planar and interdigitated electrodes are implemented to compare their sensing capabilities. Both designs show highly sensitive detection down to sub-fM concentration, while the interdigitated electrodes show a larger capacitance change between 10 aM to 1 pM.

W3P.053 A MICROFLUIDIC DEVICE TO STUDY EFFECTS OF PHYSICAL STIMULATION AND STEROID TREATMENT ON LUNG EPITHELIAL CELL SURFACTANT PROTEIN EXPRESSION 1636

S.-L. Yeh, T.-R. Lin, C.-C. Peng, W.-H. Liao, and Y.-C. Tung
 Academia Sinica, TAIWAN

This paper reports a microfluidic cell culture device made of polydimethylsiloxane (PDMS) capable of mimicking lung physiological physical stimulation, including cyclic strain and hydrostatic pressure. We demonstrate the promotion of pulmonary surfactant protein C (SPC) expression of lung epithelial cells under physical stimulation, which is comparable to conventional steroid treatment. The results suggest synergic effects of physical stimulation and steroid treatments on SPC expression.

W3P.054 A TIME-RESOLVED FLUORESCENCE IMMUNOSENSING PLATFORM FOR HIGHLY SENSITIVE DETECTION OF CARDIAC TROPONIN I 1640

K.R. Kim¹, H.J. Chun¹, Y.D. Han¹, K.W. Lee¹, D.K. Hong², K.N. Lee², and H.C. Yoon¹
¹Ajou University, KOREA and ²Korea Electronics Technology Institute, KOREA

We presenting a sensitive time-resolved fluorescence (TRF) immunosensing platform for cardiac troponin I (cTnI) quantification. Intensive TRF probes have synthesized as lanthanide-encapsulated nanoparticles to ensure dye stability through cross-linking reaction between dye and silica structure. As a signal transducer, photomultiplier tube-based TRF analyzer was constructed that enables TRF photon counting. Using these, sandwich immunosensing for cTnI was accomplished (ranging 0-20 ng/ml).

W3P.055 ANALYSIS OF THE DIELECTROPHORETIC (DEP) SPECTRA OF BIOLOGICAL CELLS 1644

Z. Çağlayan, K. Sel, Y.D. Yalçın, Ö.Ş. Sukas, and H. Külah
 Middle East Technical University, TURKEY

An approach for analyzing the dielectrophoretic (DEP) spectra of biological cells without ascertaining their membrane and cytoplasmic properties is presented. Combining a strong theory, experimental data and electric field simulations enables determination of the DEP spectrum at a range of frequencies, for the first time in literature. Using the proposed method, DEP spectra of MCF7 breast cancer cells are obtained for 15 different frequencies within 100 kHz-50 MHz.

W3P.056 DNA STRETCHING IN SURFACTANT-STABILIZED MICROCHANNEL 1648

S.-L. Wang and S.-K. Fan
 National Taiwan University, TAIWAN

DNA molecules were transported and stretched through a surfactant-stabilized virtual microchannel between two reservoir droplets driven on a digital microfluidic platform without sophisticated nanostructures or nanomanipulation. We constructed the virtual microchannels with dimensions of length 4 mm, width 2 µm, and height 50 µm using surfactant solutions; the dispersed DNA molecules were manipulated in the microchannel with an adjustable flow field controlled by the terminal reservoir droplets.

W3P.057 FULLY INTEGRATED ELECTRONIC PLATFORM FOR MULTIPLEXED INTERMOLECULAR FORCE SPECTROSCOPY 1652

 S. Challa¹, S. Talebi¹, R.W. Davis¹, M. Javanmard², and S. Emaminejad³
¹Stanford University, USA, ²Rutgers University, USA, and ³University of California, Los Angeles, USA

We developed a handheld, fully integrated and programmable electronic system which interfaces a multiplexed ultradiellectrophoretic force spectroscopy array for probing intermolecular affinities. The platform can be wirelessly programmed to generate electrokinetic force profiles for characterization of molecular interactions. As an example application, we demonstrated the platform's capability in distinguishing between specific and non-specific bindings.

W3P.058 INVESTIGATION OF DISRUPTION OF CELL COLONY FORMATION PROCESS BY ALTERNATING ELECTRIC FIELD 1656

 C.-H. Huang¹ and K.F. Lei^{1,2}
¹Chang Gung University, TAIWAN and ²Chang Gung Memorial Hospital, TAIWAN

Cancer disease is caused by the uncontrolled cell proliferation. Disruption of mitosis by using alternative electric fields was proposed to be a new cancer therapeutic approach. In this work, *in vitro* 3D cell culture device was developed for the investigation of disruption of cell colony formation process under the application of alternative electric fields. Systematic and precise studies of the therapeutic efficacy were conducted in order to understand the therapeutic conditions.

W3P.059 METABOLIC PROFILE ANALYSIS OF A SINGLE CAENORHABDITIS ELEGANS ACROSS THE LIFESPAN WITHIN A MICROFLUIDIC DEVICE 1660

Y.-W. Lin and S.-H. Huang

National Taiwan Ocean University, TAIWAN

A combination of a microfluidic device with a light modulation system was developed to detect the oxygen consumption rate of a single developing *Caenorhabditis elegans* via phase-based phosphorescence lifetime detection. The basal respiration of a single *C. elegans* has been successfully measured from post-embryonic development to aged stages. Sequentially adding inhibitors of bioenergetic pathways allows us to perform respiratory measurements of a single *C. elegans* at key developmental stages.

W3P.060 MULTI-CHANNEL WIRELESS QUARTZ CRYSTAL MICROBALANCE BIOSENSOR FABRICATED WITH POLY(DIMETHYLSILOXANE) 1664

 F. Kato¹, H. Noguchi¹, Y. Kodaka¹, N. Chiku¹, H. Shibata¹, F. Abe¹, and H. Ogi²
¹Nippon Institute of Technology, JAPAN and ²Osaka University, JAPAN

We developed the multi-channel wireless QCM biosensor, which has a thin quartz oscillator supported by micropillars in the microchannel without fixing mechanically; it is fabricated with PDMS using the nanoimprinting process. This biosensor allows the wireless operation and signal detection through the electromagnetic wave via line antennas located outside the sensor chip. This sensor will open up new possibilities for QCM biosensor analysis system by the integration with PDMS micro pump.

W3P.061 REASSEMBLING SMARTPHONE WITH LIQUID CRYSTAL DISPLAY PANEL INTO A NEW OPTICAL TRANSDUCER FOR POINT-OF-CARE SENSING APPLICATION 1668

H.J. Chun, Y.D. Han, K.R. Kim, K.W. Lee, and H.C. Yoon

Ajou University, KOREA

We developed a smartphone-based optical biosensing system based on the light assimilation phenomena. To achieve this, we prepared the signal guide that contains multiple polygonal figure composed of special light ratio. When the color-generated biosensing channel was located on the signal guide, the number of observed polygons was changed due to absorption of specific light in the polygons. Using this system, the concentration of biomarkers for diabetes and osteoarthritis could be quantified.

W3P.062 SIMULTANEOUS OPTICAL AND ELECTRICAL MONITORING OF CELLS ON A TRANSPARENT THIN FILM TRANSISTOR ARRAY 1672

G.A. Cathcart, A. Tixier-Mita, F. Shaik, S. Ihida, and H. Toshiyoshi

University of Tokyo, JAPAN

We report the label-free monitoring of dying yeast cells using impedance measurements across a Thin Film Transistor (TFT) gated electrode array verified with simultaneous optical measurements. The electrically measured living cell count matches the fluorescent measurements with high consistency independent of cell concentration. This is a crucial step towards high resolution long term cell culture monitoring in a manner that does not interfere with conventional optical measurements.

- W3P.063** **TRANSPARENT CELL-CAPTURING CHIP LAMINATED BY FILM PHOTORESIST WITH SUCTION HOLES AND CHANNELS AND ITS APPLICATION TO TRANSEPIHELIAL ELECTRIC RESISTANCE MEASUREMENT** 1676
 T. Matsuyoshi, T. Fujita, and S. Konishi
Ritsumeikan University, JAPAN

This paper presents a transparent cell-capturing chip that is usable for both upright and inverted microscopes. Our study aims to align a needle electrode probe into cellular aggregate for transepithelial electrical resistance (TER) measurement. A transparent chip enables the alignment of the needle electrode probe with the targeted object by using both the top and the bottom views. It is formed by using a film photoresist laminated over fluidic surface structures on a transparent substrate.

- W3P.064** **MICRODEVICE ARRAYS FOR IDENTIFYING 3D MECHANICAL STIMULATION CONDITIONS IN TISSUE ENGINEERING** 1680
 H. Liu, J. Usprech, C. Simmons, and Y. Sun
University of Toronto, CANADA

We demonstrate, for the first time, the use of deformable membrane device arrays in identifying beneficial 3D mechanical stimulation conditions for engineered cell-hydrogel constructs. We show that medium levels of dynamic tensile strain and duty cycles best promote spreading and collagen expression by human mesenchymal stromal cells (hMSCs) embedded in hydrogels.

MONDAY - Medical Microsystems

- M3P.065** **A MINIMALLY INVASIVE *IN VIVO* ELECTROPORATION METHOD UTILIZING FLEXILE ELECTRODE AND MICRONEEDLE ROLLER** 1684
 D. Huang, D.Y. Zhao, J.H. Li, L.L. Du, Z.W. Wei, Z.C. Liang, and Z.H. Li
Peking University, CHINA

We develop a minimally invasive *in vivo* electroporation method utilizing parylene-based flexile electrode and microneedle array. Benefiting from more uniform electric field under skin, good biocompatibility, and lower applied voltage, the transfection rate is higher and the electroporated skin is less likely to be harmed compared to the commercial device. Furthermore, the low cost and convenient operation offer vast potential for clinical application.

- M3P.066** **FLEXIBLE INTEGRATED CHEMICAL AND PHYSICAL SENSORS TOWARD A WEARABLE HEALTHCARE PATCH** 1688
 S. Nakata, T. Arie, S. Akita, and K. Takei
Osaka Prefecture University, JAPAN

We developed a wearable flexible chemical pH sensor consisted of ISFET integrated with a printed flexible temperature sensor by developing material systems and optimizing the fabrication process as the first proof-of-concept. A major role of flexible ISFET is to measure pH value of sweat by putting it on a skin. The integrated temperature sensor is used to monitor skin temperature and to compensate pH value measured by ISFET because the characteristics of ISFET is changed by temperature.

- M3P.067** **INTEGRATION OF FLOW SENSOR AND OPTICAL FIBERSCOPE FOR *IN-SITU* BREATHING AND SURFACE IMAGE EVALUATIONS IN SMALL AIRWAY** 1692
 C. Okihara¹, Y. Hasegawa¹, M. Matsushima², T. Kawabe², and M. Shikida¹
¹Hiroshima City University, JAPAN and ²Nagoya University, JAPAN

We challenged to integrate a flow sensor onto an optical fiberscope for *in-situ* breathing and surface image evaluations in small airway. This time, we newly developed the simple fabrication process, and successfully produced a miniaturized tube type flow sensor with an outer diameter of less than 1.8 mm. Two sensor characteristics were experimentally evaluated, and confirmed that the developed sensor system can be applied in breathing and image evaluations in the small airway.

- M3P.068** **PASSIVE PUMP BASED ON CAPILLARY FORCE GENERATED BY GAPS BETWEEN MICROBEADS FOR BLOOD COLLECTION VIA MICRONEEDLE** 1696
 M. Suzuki, T. Takahashi, and S. Aoyagi
Kansai University, JAPAN

We propose a new passive pump for high-speed blood collection via ultra-narrow microneedle based on capillary force, in which the hydrophilized microbeads (30 μm in diameter) are three dimensionally integrated. The gaps between microbeads act as capillary pumps. Merits are 1) blood is automatically sucked up when the needle reaches to blood vessel, 2) it is much smaller than conventional syringe pumps. A developed pump successfully sucked up human blood via a microneedle (inner dia.: 30 μm).

TUESDAY - Medical Microsystems

- T3P.066 A FLEXIBLE PH SENSING SMART BANDAGE WITH WIRELESS CMOS READOUT FOR CHRONIC WOUND MONITORING 1700**
M. Punjiya, H. Rezaei, M.A. Zeesham, and S. Sonkusale
Tufts University, USA

We report a two dimensional pH mapping bandage constructed with pH sensing threads for chronic wound monitoring. The bandage is integrated with custom CMOS readout electronics for wireless monitoring and data transmission and is capable of continuously monitoring wound pH in space and time. The bandage has a pH sensitivity of 54 mV/pH and response time of less than 2 minutes.

- T3P.067 COMPACT INTRACEREBRAL PROBE WITH YELLOW PHOSPHOR-BASED LIGHT CONVERSION FOR OPTOGENETIC CONTROL 1703**
S. Ayub, C. Gossler, F. Engesser, O. Paul, and P. Ruther
University of Freiburg, GERMANY

This paper reports on the use of phosphor particles to alter the emission spectrum of blue light-emitting diodes (LED) integrated in MEMS-based neural probes. Light emission is confined to spots as small as 50 μm in diameter by implementing apertures in the probe stiffening structure made of silicon (Si). The rear stray light emission through the semi-transparent polyimide (PI) is effectively blocked by a shielding layer.

- T3P.068 HIGH MAGNETIC FIELD fMRI COMPLIANT CARBON NANOFIBER NEURAL PROBES 1707**
S.-P. Fang¹, L. Colon-Perez¹, J. Zhou², T.B. DeMarse², M. Febo¹, P.R. Carney², and Y.-K. Yoon¹
¹University of Florida, USA and ²University of North Carolina, Chapel Hill, USA

In this work, a high magnetic field functional magnetic resonance imaging (fMRI) compliant carbon nanofiber (CNF) based neural probe has been demonstrated. The CNF probe has high spatial resolution electrode patterns for precise extracellular deep brain stimulation (DBS) and detection. The probe offers a unique feature of *in-situ* DBS during fMRI imaging. 4.7T fMRI has been performed on the CNF neural probes implanted in a rat's brain ex-vivo and no image distortion has been observed.

- T3P.069 MICRO CHECK VALVE INTEGRATED MAGNETICALLY ACTUATED MICROPUMP FOR IMPLANTABLE DRUG DELIVERY 1711**
C. Wang, J.-S. Kim, and J. Park
Sogang University, KOREA

We proposed an intraocular implantable magnetically actuated micropump for drug delivery. Magnetic nanoparticle-PDMS composite membrane assembly can be actuated in magnetic field for drug release. It is composed of thin elastic PDMS membrane and thick magnetic nanoparticle-PDMS composite to obtain maximum deflection within confined room. Micro check valve composed of two PDMS layers is integrated to realize on-demand drug delivery and effectively prevent drug diffusion without magnetic field.

- T3P.070 SEMI-IMPLANTABLE POLYIMIDE/PTFE NEEDLE-SHAPED BIOSENSOR FOR CONTINUOUS GLUCOSE MONITORING 1714**
H.S. Yoon, S.K. Jeong, X. Xuan, and J.Y. Park
Kwangwoon University, KOREA

Semi-implantable and miniaturized needle-shaped biosensor was newly developed for painless and continuous glucose monitoring. Three electrodes were fabricated on polyimide using electroplating and wrapped on a medical PTFE catheter by using silicone adhesive. The sensor was improved in stability and reliability because the catheter was used as supporting structure of flexible sensor. The sensor could also be delivered to subcutaneous tissue by using guide needle without surgery.

WEDNESDAY - Medical Microsystems

- W3P.065 A MICROFLUIDIC DEVICE WITH AUTOMATIC EMBRYOS TRAPPING AND CO-CULTURE WITH HUMAN STROMAL CELLS 1718**
T.-W. Lo¹, Y.-J. Sung¹, S.S. Bhosale¹, Y.-W. Wang², H.-Y. Huang², and C.-H. Liu¹
¹National Tsing Hua University, TAIWAN and ²Chang Gung Memorial Hospital, TAIWAN

In order to overcome the limitations of the traditional IVF culture method, this microfluidic chip is designed to integrate multiple functions to achieve the purpose of the embryos culturing *in vitro*. The chip combines the mechanism of dynamic flow resistance to trap and locate the embryos, and co-culture with the stromal cells secreting the growth factors to give a better environment for embryos. Finally, the research succeeded in giving birth to the mice.

W3P.066 **IN VIVO NEURONAL RECORDINGS USING THREE-DIMENSIONAL MICRONEEDLE-ELECTRODE ASSEMBLED ON FLEXIBLE SUBSTRATE** 1722

S. Yamagiwa, H. Sawahata, R. Numano, M. Ishida, K. Koida, and T. Kawano
Toyoashi University of Technology, JAPAN

This paper reports a < 10- μ m-diameter three-dimensional needle-electrode assembled on a 10- μ m-thick 1 \times 2 mm² flexible film. Herein, we develop a fabrication process, in which a vapor-liquid-solid (VLS) grown Si-microneedle is assembled on a Si film which is released from the substrate with a flexible film of parylene. The fabricated device shows the neuronal recording capability, as demonstrated in the *in vivo* recording of action potentials (spikes) from a mouse's cortex.

W3P.067 **NOVEL METHOD OF FABRICATING SELF-DISSOLVABLE AND FREELY FLOATING NEURAL ARRAY** 1726

M. Leber¹, R. Bhandari², F. Solzbacher¹, and S. Negi^{1,2}
¹University of Utah, USA and ²Blackrock Microsystems, USA

We developed, fabricated, and tested a self-dissolvable implantable freely floating neural electrode array. This technology allows the fabrication of up to 10 \times 10 electrodes that can freely float in the brain independent to each other. The array base is held together by biocompatible dissolvable polyethylene glycol, which dissolves in the brain fluid after implantation. The device can move with the micromotion of the brain, mitigating foreign body response and increasing the device lifetime.

W3P.068 **VAGUS NERVE STIMULATION (VNS) FOR HEART RATE CONTROL USING NOVEL NEURAL INTERFACES** 1730

S. Lee¹, W.Y.X. Peh¹, N.V. Thakor^{1,2}, S.-C. Yen¹, and C. Lee¹
¹National University of Singapore, SINGAPORE and ²Johns Hopkins University, USA

This paper demonstrates a novel neural interface for neuromodulation of vagus nerves. This novel design allows easy and reliable implantation on small nerves, so that it provides reliable interface to modulate neural signals. Vagus nerve stimulation in rats is conducted using this neural interface to control heart rate. The heart rate is temporarily decreased while the stimulation and is recovered normal condition after the stimulation within certain ranges of parameters.

MONDAY - Microfluidics

M3P.069 **DEVELOPMENT OF A FLUIDIC CELL TO IMAGE PRECIPITATION REACTIONS BY X-RAY MICROSCOPY** 1734

C. Gosse¹, J. Frederick², C. Blot², S. Lefrançois³, S. Swaraj³, S. Stanesco³, R. Belkhou³,
P. Guenoun², and C. Chevallard²
¹LPN, CNRS, FRANCE, ²CEA Saclay, FRANCE, and ³Soleil synchrotron, FRANCE

We introduce a simple microreactor dedicated to image, at the nanoscale, the kinetics of reactions taking place at the liquid/solid interface. The conception principles are applicable to X-ray microscopy. An assembly procedure could be devised that necessitates no sophisticated microfabrication, despite the necessity for the chamber to be vacuum-tight, to have a well-controlled thickness in the micron range, and to precisely regulate the hydrodynamic flow carrying the reagents.

M3P.070 **A SELF-ASSEMBLED GRAPHENE-BASED MICRO FLOW METER BY STREAMING POTENTIAL EFFECT** 1738

S. Sando and T. Cui
University of Minnesota, USA

This study proposes a new micro flow meter based on self-assembled graphene, demonstrating label-free detection of flow velocity, as it directly senses dragged ion accumulation on the graphene surface by water flow, known as streaming potential effect.

M3P.071 **FACILE ASSEMBLING METHOD FOR COSCINODISCUS SP. DIATOM FRUSTULE MONOLAYERS TOWARDS CONTROLLED ORIENTATIONS** 1742

A. Li¹, M. Moges², J. Morales³, A. Saccoccio⁴, S. Anderson⁵, and X. Zhang¹
¹Boston University, USA, ²Georgia Institute of Technology, USA, ³Interamerican University, PUERTO RICO,
⁴Randolph Community Middle School, USA, and ⁵Boston University Medical Center, USA

Diatom frustules have been used in many studies due to their excellent material properties. This study reports a novel method that assembles Coscinodiscus sp. diatom frustules into monolayers. Near-uniformly oriented monolayer regions were achieved with this method. Initial simulations were conducted to explain the observed phenomenon. The method introduced herein could potentially broaden diatom frustules' applications in engineering and enable studies on their collective properties.

M3P.072 **MICROFLUIDIC CHIP OF IMMUNOASSAY SYSTEM FOR KIDNEY STUDIES** 1746

B.-J. Zhang¹, C.-W. Huang¹, K.-W. Chang¹, C.-W. Yang², C.-C. Hung²,
Y.-C. Ko², L.-F. Chou², G. Pendharkar¹, and C.-H. Liu¹
¹National Tsing Hua University, TAIWAN and ²Chang Gung Memorial Hospital, TAIWAN

In this research, we have demonstrated a microfluidic chip integrated the dielectrophoresis (DEP) force to manipulate and pattern the cell in the different culture chamber for Kidney studies. Dwarf structures were used to separate monocytic cell and kidney cell enabling us to observe the cell-cell interaction after added stimulus to the microchannels.

M3P.073 PRESSURE-DRIVEN SEPARATION OF DNA BY USING SELF-ENCLOSED INTEGRATED GLASS NANOCAPILLARY 1750

L. Duan and L. Yobas
Hong Kong University of Science and Technology, HONG KONG

A silicon chip featuring 5cm long self-enclosed integrated glass microcapillaries for hydrodynamic chromatography (HDC) is demonstrated for the first time. The integrated microcapillary provides exceptional performance, including fast separation (3 min) and high plate number (162 000 plates/m). These advantages are ascribed to the cylindrical lumen as oppose to the rectangular profile which exhibits stronger axial dispersion and smooth surface imparted by thermal reflow.

M3P.074 TESLA INSPIRED PUMP AND MICROFLUIDIC GRADIENT REALIZED WITH LITHOGRAPHY BASED ADDITIVE MANUFACTURING 1754

M.-B. Habhab and J.F. Lo
University of Michigan, Dearborn, USA

The Tesla turbine was demonstrated by Nicholas Tesla in 1913. Scaling the Tesla turbines down to the microfluidic regime would leverage laminar flows to produce smooth continuous pumping. Achieved here is a microscale Tesla pump fabricated using a Digital Light Processing (DLP) based 3D printer capable of flow rates up to 12.6 mL/min at 1200 rpm, unloaded. The μ Tesla pump is used to drive a Tesla valve inspired mixer network, demonstrating an all-Tesla microfluidic system.

TUESDAY - Microfluidics
T3P.071 A MASS MANUFACTURABLE THERMOPLASTIC BASED MICROFLUIDIC DROPLET GENERATOR USING RAPID INJECTION MOLDING AND SOLVENT BONDING METHOD 1758

S. Ghosh¹, G.K. Kurup², M.S. Lee², A.P. Lee², and C.H. Ahn¹
¹University of Cincinnati, USA and ²University of California, Irvine, USA

We designed, fabricated and characterized a mass manufacturable thermoplastic based microfluidic droplet generator using rapid injection molding and solvent bonding method. Thermoplastic chips with feature size as low as 20 μ m is efficiently fabricated to successfully generate stable monodisperse droplets. The COC chips developed in this work can pave a new way towards manufacturable high throughput droplet generators for single cell analysis.

T3P.072 ADJUSTABLE GAIN FOR STEERING BETWEEN HIGH-SPEED AND HIGH-RESOLUTION CELL MANIPULATION 1762

C.-H.D. Tsai and M. Kaneko
Osaka University, JAPAN

We develop a novel method for adjusting the gain of cell manipulation. The gain is defined as the ratio between the flow pushed by an actuator and the corresponding displacement of a target cell. The gain is controllable by adjusting the offset pressure in the channel. According to the experimental results, the gain is about proportional to the pressure within the range from 100 kPa to 200 kPa. The method can be employed for steering between high-speed and high-resolution cell manipulation.

T3P.073 FINGER-POWERED, 3D PRINTED MICROFLUIDIC PUMPS 1766

E.C. Sweet, R.R. Mehta, R. Lin, and L. Lin
University of California, Berkeley, USA

Here, we demonstrate for the first time an entirely 3D printed, human powered microfluidic pump that can produce fluidic flows of 157 μ L/min from prototype devices without using electricity. The fully 3D printed fluidic actuator utilizes seamless 3D design integration and fabrication with discrete fluidic diodes and capacitors. Applications to fluidic controls, chemical analyses and bio-assays are a few potential microfluidic uses; we also demonstrate the application of a pulsatile mixer.

T3P.074 MICROFLUIDIC PAPER-BASED SAMPLE PRECONCENTRATOR BY ION CONCENTRATION POLARIZATION 1770

S.I. Han, Y.K. Yoo, J.W. Lee, D. Lee, C. Kim, K. Lee, and J.H. Lee
Kwangwoon University, KOREA

We have developed a reservoir type paper-based sample preconcentrator in using the human serum by ion concentration polarization. To concentrate in serum, we used to double-patterned Nafion membrane. In conclusion, we obtained a concentration ratio of 5-fold in human serum. The outcomes have important implications for sample preconcentration without dilution of the body fluid.

T3P.075 SELF-CLEANING SURFACES USING ANISOTROPIC RATCHET CONVEYORS 1773

D. Sun and K.F. Böhringer
University of Washington, USA

We develop an active self-cleaning surface where an optically flat and transparent anisotropic ratchet conveyor (ARC) guides a water droplet under orthogonal vibrations. ARC surfaces can work with a wide frequency bandwidth at 20~500 Hz as well as with surface inclination angles up to 15°. The self-cleaning surface has potential applications on solar panel cover glass to remove dust accumulation and improve efficiency.

- T3P.076 THE DEFORMABLE VALVE PUMP (DVP) 1777**
A. Shabanian, F. Goldschmidtboeing, H.G. Bettaswamy Gowda, C.C. Dhananjaya, and P. Woias
University of Freiburg, GERMANY

We present a Valve-Pump which utilizes a novel concept for a reciprocating micropump, employing our high stroke buckling piezo-membrane-actuator. The pumping concept of the device which results in several orders of magnitude higher energy efficiency compared to other micropumps is explained. Fabrication methods are described and at the end valving performance of the device at 70 kPa of back pressure, as well as its outstanding pumping functionality with a flowrate of 25 ml/min are demonstrated.

WEDNESDAY - Microfluidics

- W3P.069 A MICROFLUIDIC 16x6-CELL-TRAP ARRAY FOR COMPARATIVE CELL CULTURING 1781**
Z. Zhu¹, P. Chen¹, R. Peng², K. Zheng³, Y. Fan³, A. Hierlemann², and Q.-A. Huang¹
¹*Southeast University, CHINA*, ²*ETH Zürich, SWITZERLAND*, and ³*Nanjing Forestry University, CHINA*

We presents a microfluidic chip with an array of 96 cell traps (16 rows × 6 columns) for trapping and comparative culturing of single cells. Cells can be delivered to each column of the array through a laminar focused flow and are reliably captured at the traps through hydrodynamic forces. Immobilized cells can then be cultured while being exposed to different media and compounds. It allows for executing comparative experiments under continuous monitoring of the dynamic cellular development.

- W3P.070 DIGITAL HYDRAULIC DRIVE FOR MICROFLUID LARGE-SCALE INTEGRATION SYSTEM BASED ON SHAPE MEMORY ALLOY ACTUATORS 1785**
C. Tsai¹, X. Wu¹, S. Zimmermann¹, R. Zengerle^{1,2}, and P. Koltay^{1,3}
¹*Freiburg University, GERMANY*, ²*Hahn-Schickard Freiburg, GERMANY*, and ³*BioFluidix GmbH, GERMANY*

We present a small size and low power Digital Hydraulic Drive (DHD) intended for use in miniaturized and portable control systems for microfluidic large-scale integration (mLSI) chips. The main components of a DHD are a pneumatic cylinder and a shape memory alloy (SMA) actuator. The DHD is not only able to provide digital hydraulic pulses, but can maintain a steady state up to 24 hours. A single DHD enables to control 256 valves in parallel.

- W3P.071 IN-LINE TRAPPING AND ROTATION OF BIO-PARTICLES VIA 3-D MICRO-VORTICES GENERATED BY LOCALIZED ULTRAHIGH FREQUENCY ACOUSTIC RESONATORS 1789**
M. He, W. Cui, H. Zhang, Y. Yang, W. Pang, H. Qu, and X. Duan
Tianjin University, CHINA

We developed a minimized bio-particles manipulation tool utilizing localized ultrahigh frequency acoustic resonators which can induce 3-D micro-vortices, by which particles with diameter from 50 nm to tens of micrometers can be effectively trapped and precisely rotated. A finite elements simulation was conducted to explain the principle of micro/nanoparticles trapping and rotation.

- W3P.072 NUCLEIC ACID PURIFICATION ON A LAB-ON-A-DISC WITH TIME-CONTROLLED INCUBATION 1793**
D.J. Kinahan, L.A. Julius, M. Tutty, F. Mangwanya, R. Mishra, D. King, and J. Ducreé
Dublin City University, IRELAND

We present an integrated Lab-on-a-Disc (LoaD) cartridge, which is applied to the purification of nucleic acid using the silica bead based method. We utilize 'event-triggered' dissolvable film (DF) valving to control DNA binding, sample washes and DNA elution.

- W3P.073 SPATIALLY ENCODED PICOLITER DROPLET GROUPS FOR HIGH-THROUGHPUT COMBINATORIAL ANALYSIS 1797**
P. Zhang, A. Kaushik, K. Hsieh, and T.-H. Wang
Johns Hopkins University, USA

We present a novel nanoliter-picoliter (nL-pL) device for high-throughput combinatorial analysis that can generate spatially encoded groups of thousands of picoliter droplets from different nanoliter plugs. These plugs can be uniquely assembled in an automated manner prior to small droplet generation. We demonstrate the ability of our nL-pL device to generate distinct picoliter droplet groups with high stability and uniformity.

- W3P.074 WITHDRAWN**

MONDAY - Energy and Power MEMS

- M3P.075 A DOUBLE HUMAN SKIN CONTACT BASED SANDWICH STRUCTURED TRIBOELECTRIC MICRO-GENERATOR 1804**
M.S. Rasel and J.Y. Park
Kwangwoon University, KOREA

This paper reports a wristband coupled sandwiched triboelectric microgenerator (S-TEMG) for harvesting human double skins contacts by increasing the effective contact surface area between skin and Polydimethylsiloxane (PDMS). Two microstructured PDMS films have been attached back to back which have been microfabricated using sandpaper template. Owing to the structure, the as-fabricated prototype produces voltage up to 150 V and 100 μ W peak power by mild fingers pressing on the device.

- M3P.076 COMBINING NEURAL ELECTRODES AND TRIBOELECTRIC NANOGENERATORS (TENGs) TO ENABLE
A SELF-SUSTAINABLE PLATFORM FOR NEUROMODULATION 1808**
S. Lee¹, H. Wang¹, Q. Shi¹, J. Wang¹, T. He¹, H. Wu¹, N.V. Thakor^{1,2}, S.-C. Yen¹, and C. Lee¹
¹National University of Singapore, SINGAPORE and ²Johns Hopkins University, USA

This paper reports direct stimulation of sciatic nerve in rats using a self-sustainable platform combined neural interfaces and triboelectric nanogenerators for neuromodulation. The stacked TENGs generate enough charge by hand tapping to selectively stimulate the sciatic nerve with neural sling interface for different activation patterns of muscles. This result indicates that this technology could be the way of realizing a self-sustainable platform for neuromodulation in the future.

- M3P.077 ELECTROPOLYMERIZED THIOPHENE-BASED DEVICES FOR PHOTOCATALYTIC HYDROGEN GAS HARVESTING 1812**
E. Kao, Q. Liang, G. Rez-Kallah Bertholet, J. Lu, and L. Lin
University of California, Berkeley, USA

We present thiophene-based devices made by spin-coating and electropolymerization for possible usages in solar-powered, photocatalytic hydrogen gas (H₂) harvesting. Two innovative claims include: (1) first demonstration of electropolymerized photoelectrochemical (EP-PEC) devices for water splitting, and (2) drastically improved performance of EP-PEC devices over spin-coated PEC H₂ harvesters, achieving >0.5V improvement in onset voltage.

- M3P.078 FULLY CASTED STRETCHABLE TRIBOELECTRIC DEVICE FOR ENERGY HARVESTING
AND SENSING MADE OF ELASTOMERIC MATERIALS 1816**
R.I. Haque, G. Ferracci, P.-A. Farine, and D. Briand
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

Wearable soft triboelectric devices, fabricated using film casting and stencil printing techniques, are reported. The process is scalable. The devices have simple designs: utilize sliding and vertical contact separation mode mechanisms. Elastomeric materials, such as, polydimethylsiloxane (PDMS), polyurethane (PU) as dielectrics and carbon-based elastomeric materials as electrodes have been used. Both generators are capable of harvesting energy at 1 Hz and can be used for body movement sensing.

- M3P.079 MEMBRANELESS MICROFLUIDIC REDOX BATTERY FOR WEARABLE ELECTRONICS APPLICATIONS 1820**
I. Karakurt¹, J. Elwood¹, X. Li^{1,2}, L. Beker¹, E. Sweet¹, W. Cai^{1,3}, and L. Lin¹
¹University of California, Berkeley, USA, ²Southeast University, CHINA, and
³South China University of Technology, CHINA

A Flexible microfluidic redox battery (MRB) that utilizes a membraneless design that can power wearable electronics is demonstrated. This device relies on laminar flow principles to separate two electrolytes into a side-by-side flow eliminating the need for expensive proton exchange membranes. Using the non-toxic 2,6-DHAQ and ferrocyanide redox pair this MRB can be integrated into wearable electronics as a power source.

- M3P.080 REVERSE ELECTRODIALYSIS BASED NANOFLUIDIC POWER GENERATOR WITH MULTIPLE CELLS 1824**
C. Wang¹, E. Choi², and J. Park¹
¹Sogang University, KOREA and ²Chonnam National University, KOREA

We propose nanofluidic power generator inspired by electrical eel to harness ion concentration gradient by reverse electrodialysis. Cation-exchange and anion-exchange nanochannel networks membrane constructed by self-assembled nanoparticles with hydroxyl and amine groups, respectively, enable high ionic current for efficient power generation. The system performance is investigated by changing the number of serially stackable cells and intermembrane distance between cells.

- M3P.081 SILICON GRASS BASED NANO FUNCTIONAL ELECTRODES FOR MEMS SUPERCAPACITORS OF IMPROVED ENERGY DENSITY** 1828
P. Lu¹, K. Du¹, P. Ohlckers¹, E. Halvorsen¹, L. Müller², S. Leopold², M. Hoffmann², K. Grigoras³, J. Ahopelto³, M. Prunnila³, and X. Chen¹
¹University College of Southeast Norway, NORWAY, ²Technische Universität Ilmenau, GERMANY, and ³VTT Technical Research Centre of Finland Ltd, FINLAND

We develop a high energy density MEMS supercapacitor by combining advanced atomic layer deposition (ALD) and cyclic deep reactive ion etch (C-DRIE) in MEMS technology. The electrodes were structured with C-DRIE organized silicon grass (Si-g) as the scaffold for conformal coating with ALD nano layer TiN as the current collector, and electrochemical loading pseudo-capacitive material as active material. As obtained Si-g/TiN/MnOx on-chip electrode results in largely improved energy density.

TUESDAY - Energy and Power MEMS

- T3P.077 A LOW FREQUENCY VIBRATION DRIVEN, MINIATURIZED AND HYBRIDIZED ELECTROMAGNETIC AND TRIBOELECTRIC ENERGY HARVESTER USING DUAL HALBACH ARRAY** 1832
M. Salauddin and J.Y. Park
Kwangwoon University, KOREA

We have proposed and experimentally validated a highly miniaturized and hybridized electromagnetic (EM) and triboelectric (TE) energy harvester for scavenging low frequency vibration using dual Halbach array. The fabricated hybrid energy harvester delivered an output power of 2.1mW, corresponding to a volume power density of 68W/m³ under a loading resistance of 112Ω at 10Hz resonant frequency and 0.5g acceleration.

- T3P.078 DISCREPANCY BETWEEN GALLOPING THEORY AND EXPERIMENT ON A MEMS PIEZOELECTRIC WIND ENERGY HARVESTER** 1836
X. He, Z. Shang, and S. Jiang
Chongqing University, CHINA

We fabricated and tested a galloping-based MEMS piezoelectric wind energy harvester. Experimental results show that the nonstreamlined shape of MEMS devices causes the behavior to obviously deviate from the classical galloping theory. This deviation may come from the loads of vortex shedding and/or turbulence. The interaction of galloping and vortex-induced vibration may be used to enhance the electrical output and the galloping theory needs to expand to include these loads.

- T3P.079 ENHANCED PERFORMANCE OF ELECTROSTATIC ENERGY HARVESTER WITH INTEGRATED OPPOSITE-CHARGED ELECTRETS** 1840
K. Tao¹, H.L. Chang¹, J. Wu², L.H. Tang³, A.G.P. Kottapalli², L. Hu², S.W. Lye², and J.M. Miao²
¹Northwestern Polytechnical University, CHINA, ²Nanyang Technical University, SINGAPORE, and ³University of Auckland, NEW ZEALAND

We have developed an electrostatic vibration energy harvester with opposite-charged electrets. It has the advantages of inducing maximum charge at the lowest and highest position of the movable mass. The enhancement mechanism is further studied by equivalent model simulations, which demonstrate good agreement with experimental results.

- T3P.080 HIGHLY EFFICIENT SUPERHYDROPHOBIC SURFACE-BASED TRIBOELECTRICNANOGENERATOR FOR ROTATIONAL MACHINERIES** 1844
C.-R. Yu, M.-J. Jung, Y.-I. Song, J.-H. Park, and D.-W. Lee
Chonnam National University, KOREA

We report super-hydrophobic surface-based triboelectric nanogenerators (TEGs) which can be employed to harvest mechanical energy from rotational machineries to power battery-less sensor nodes. The proposed TEGs consist of a coaxial cylindrical structure connected with a motor and two Al electrode covered by super-hydrophobic PDMS films which are demonstrated with Self-cleaning effect. We believe that the proposed TENG has a great potential to realize battery-less sensor systems.

- T3P.081 mm-SCALE AND MEMS PIEZOELECTRIC ENERGY HARVESTERS POWERING ON-CHIP CMOS TEMPERATURE SENSING FOR IoT APPLICATIONS** 1848
S. Fan^{1,2}, X.-Q. Zheng¹, R. Wei¹, J.S. Pulskamp³, R. Rudy³, R.G. Polcawich³, and P.X.-L. Feng¹
¹Case Western Reserve University, USA, ²Xi'an Jiaotong University, CHINA, and ³US Army Research Laboratory, USA

We report on the design and demonstration of a self-powering sensor microsystem that exploits vibrational energy harvesting to fully power an integrated, ultra-low-power, CMOS temperature sensor. This system features a novel circuit interface, capable of handling input power down to sub-μW level, enabled by an application-specific integrated circuit (ASIC) that performs energy conversion for mm-scale and MEMS piezoelectric harvesters.

- T3P.082 RF POWERING OF MICRO COILS ARRAY FOR WIRELESS SPHERICAL PARTICLE-BASED NEURAL PROBES 1851**
W. Luo, R. Likhite, C. Mastrangelo, and D. Young
University of Utah, USA

We present a RF powering system that can wirelessly transfer power to an array of 10 x 10 1.5mm-diameter micro coils positioned at 2cm away from a powering coil. Under 10W external RF power, the micro coils can receive 4.6mW and 0.5mW at the center and edge of the array, respectively, enabling spherical particle-based neural recording applications.

- T3P.083 WIND-POWERED TRIBOELECTRIC ENERGY HARVESTER USING CURVED FLAPPING FILM ARRAY 1855**
D.-S. Kwon and J. Kim
Yonsei University, KOREA

We developed a wind-powered triboelectric harvester using flapping film. The flapping film was fabricated by plastic deformation of polymer film. The plastically deformed film forms a curved shape and makes variable gap between the flap and the substrate. When the wind blows, the harvester generates energy through the changes in contact area according to deformation and vibration of the flap. Through this mechanism, it can harvest energy from the winds which are various in directions and speeds.

WEDNESDAY - Energy and Power MEMS

- W3P.075 CELL-FREE ARTIFICIAL PHOTOSYNTHESIS SYSTEM 1859**
X. Ren^{1,2}, P. Ghassemi², W. Yuan³, J. Zhou¹, P. Chong⁴, and M. Noh¹
¹Drexel University, USA, ²Virginia Polytechnic Institute and State University, USA,
³North Carolina State University, USA, and ⁴Temple University School of Medicine, USA

We developed a cell-free artificial platform conducting both light and dark reactions. To the best of our knowledge, such a device had not been reported so far. This device was able to harvest light energy and transform the energy to organic compounds, mimicking a plant leaf. We integrated the "artificial leaves" on a PCB demonstration board to create a compact energy harvesting system with a promising efficiency.

- W3P.076 ELECTROMAGNETIC ENERGY HARVESTING FROM SWING-ARM MOTION USING ROTATIONAL ECCENTRIC MASS STRUCTURE 1863**
M.A. Halim¹, R. Rantz¹, Q. Zhang², L. Gu², K. Yang², and S. Roundy¹
¹University of Utah, USA and ²Analog Devices Inc., USA

We present an EMEH using rotational eccentric mass that generates power from swing-arm motion. It consists of two aligned eccentric rotors containing multiple N52 magnet pole-pairs with back iron shields that increase magnetic flux densities by 63%. The stator is an array of copper coils. Voltage induces due to magnetic flux change while the rotor rotates due to swing-arm motion. A prototype harvester generates maximum 55 μ W power at ± 25 degree amplitude and 0.8 sec period (1.25 Hz).

- W3P.077 FACILE BATCH MODE PROCESS FOR HIGH CAPACITY RECHARGEABLE NICKEL-ZINC MICROBATTERIES 1867**
N. Vellaluru, Y.B. Gianchandani, and T. Li
University of Michigan, USA

We report an easy and reliable approach, facilitated by unconventional structural materials and fabrication options, for batch fabrication of secondary Ni-Zn microbatteries. Ni and Zn foils are patterned by micro electrodischarge machining; the cathode and electrolyte are integrated using a self-aligned damascene method. The batteries have a footprint <5mm² and capacity >63 μ Ah, providing sufficient energy for many mm-scale autonomous microsystems for implantable and environmental applications.

- W3P.078 MANUFACTURING TECHNOLOGY OF ALL-SOLID-STATE THIN-FILM BATTERY FOR STAND-ALONE MEMS/SENSOR APPLICATION 1871**
A. Suzuki, S. Sasaki, T. Murayama, I. Kimura, Y. Morikawa, T. Jimbo, and K. Suu
ULVAC, Inc., JAPAN

All-solid-state thin-film batteries have come to be recognized as one of the key enabling technologies for stand-alone MEMS/sensor devices which are essential for internet of things (IoT) solution. We have developed reliable hardware and processes for the mass-production using vacuum technology. Our manufacturing process, battery performance and recent development will be introduced.

- W3P.079 MULTI-STEPPED SPIRAL TRENCH WITH SMOOTHENED SCALLOP TO DEPOSIT SUPERCONDUCTING MATERIAL FOR ENERGY STORAGE 1875**
C.-W. Hsu¹, S. Kumagai¹, Y. Suzuki², T. Hioki², T. Motohiro², and M. Sasaki¹
¹Toyota Technological Institute, JAPAN and ²Nagoya University, JAPAN

A 3-stepped spiral trench (full length: 45m) over the 3-inch wafer is fabricated to realize the coil of the superconducting magnetic energy storage (SMES). The fabrication based on 3-times patterning can reduce the disconnection risk caused by the unavoidable defects during the processing. The recipe of the plasma Si etching is tuned to decrease the scallop. The smooth sidewall improves the material quality deposited later. The fabricated coil shows the improved superconducting current density.

W3P.080 SCANDIUM ALUMINUM NITRIDE VIBRATION ENERGY HARVESTER WITH A STRESS COMPENSATION 1879

R. Takei¹, N. Makimoto¹, T. Tabaru¹, M. Akiyama¹, T. Itoh², and T. Kobayashi¹

¹National Institute of Advanced Industrial Science and Technology (AIST), and

²JAPAN and University of Tokyo, JAPAN

This paper reports a ScAlN vibration energy harvester (VEH). A ScAlN thin film has a large piezoelectric effect, which is much attractive to MEMS cantilever VEHs. However, a ScAlN thin film has a violent compressive stress of around 1 GPa, resulting in a decrease in an efficiency of energy harvesting. In this paper, we introduced an AlN stress compensation layer, resulting in an increase by 66% in generated electrical power compared with a power generated by a VEH without the compensation.

MONDAY - RF MEMS, Resonators, and Oscillators

M3P.082 WITHDRAWN

M3P.083 NONLINEAR BEHAVIOR OF THE CAPACITIVELY COUPLED NEMS RESONATOR OPERATING CLOSE TO THE NONLINEAR REGIME CANCELLATION 1887

G. Sobreviela¹, G. Vidal-Alvarez¹, M. Riverola¹, A. Uranga¹, F. Torres¹, E. Marigó², M. Soundara-Pandian², and N. Barniol¹

¹Universitat Autònoma de Barcelona, SPAIN and ²Silterra Malaysia Sdn. Bhd., MALAYSIA

We present the characterization of a NEMS-on-CMOS resonator that shows the appearance of both, the mechanical and the electrical nonlinear regime. From the open loop characterization we demonstrate that there is an optimum biasing point where the power handling of the NEMS can be maximized. At the same time, a study of the frequency-amplitude evolution has shown that it is possible to obtain an operation point where the resonance frequency does not depend of the amplitude fluctuations.

M3P.084 GERMANIUM ALUMINUM NITRIDE THIN FILMS FOR PIEZO-MEMS DEVICES 1891

T. Mizuno¹, K. Umeda¹, Y. Aida¹, A. Honda¹, M. Akiyama², T. Nagase², and M. Kobayashi¹

¹Murata Manufacturing Co., Ltd., JAPAN and

²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

We present the polarity control method for the piezoelectric AlN thin films, which is achieved by germanium doping. The germanium doping at appropriate concentration could invert the polarity of sputtered AlN thin films without degrading piezoelectric property. Additionally, the bulk acoustic wave resonator with the stack of both N-polarity(GeAlN) and Al-polarity(pure AlN) layer is demonstrated as an application of this technique.

M3P.085 MICRO SHELL RESONATOR WITH T-SHAPE MASSES FABRICATED BY MICRO BLOW-TORCHING USING WHIRLING PLATFORM 1895

W. Li, Z. Hou, K. Lu, Y. Shi, D. Xiao, Y. Wu, and X. Wu

National University of Defense Technology, CHINA

This paper reports a novel fused silica (FS) micro shell resonator (MSR) with eight circular-distributed T-shape masses. The resonator has a higher electrostatic transduction efficient than conventional resonator using out-of-plane electrodes. A new fabrication process is presented for making FS MSR through the improved micro blow-torching with whirling platform, which results in a good structural symmetry and surface quality.

M3P.086 WITHDRAWN



Source: Kaohsiung City Government Photographer: Chung-Hui Pao

TUESDAY - RF MEMS, Resonators, and Oscillators

- T3P.084** **A MONOLITHIC TUNABLE OUT-OF-PLANE INDUCTOR BASED ON NITI TWO-WAY SHAPE-MEMORY-ALLOY** 1903
 O.F. Hikmat, F.A. Mohd Ghazali, A. AbuZaiter, and M.S. Mohamed Ali
Universiti Teknologi Malaysia, MALAYSIA

This paper reports a novel tunable technique for an out-of-plane micro inductor using NiTi shape-memory-alloy (SMA) with two-way shape-memory-effect. The SMA coil is monolithically fabricated and is trained to have two memorized out-of-plane states: martensite (cold state) and austenite (hot state). The coil can provide large displacement between these states to create a fairly linear inductance tuning. A total inductance range of 15.6% and a maximum quality factor of ~16 has been achieved.

- T3P.085** **EFFECTIVE QUALITY FACTOR AND TEMPERATURE DEPENDENCE OF SELF-OSCILLATIONS IN A THERMAL-PIEZORESISTIVELY PUMPED RESONATOR** 1907
 J.M.L. Miller, D.B. Heinz, I.B. Flader, Y. Chen, D.D. Shin, and T.W. Kenny
Stanford University, USA

We measure the influence of ambient temperature (-40°C to 80°C) on the threshold current for self-sustained oscillations in a thermal-piezoresistively pumped, capacitively-sensed resonator. We observe the generation of harmonics during self-oscillation with amplitudes that decrease but effective quality factors that increase with each successive mode. We demonstrate that the threshold current decreases with decreasing ambient temperature.

- T3P.086** **WITHDRAWN**

- T3P.087** **NON-CONTACT DETECTING SOLUTION IONIC STRENGTH IN MICROFLUIDIC CHANNEL UTILIZING GHZ COMPLEMENTARY SPLIT-RING RESONATOR (CSRR)** 1915
 C.-H. Li¹, K.-W. Chen², C.-M. Hsu², C.-L. Yang², K.-C. Hsieh¹, and C.-H. Lin¹
¹National Sun Yat-sen University, TAIWAN and ²National Cheng Kung University, TAIWAN

We presents a novel microchip integrated with a complementary split-ring resonator (CSRR) and a microfluidic channel for non-contact detecting the ionic strength of solutions. The microchip is capable of detecting NaCl solutions of the concentration with a sensitivity of 1.5 dB/Molar in high concentration range. And it is also capable of distinguishing solutions but different ionic charges. The chip has shown its potentials for remote monitoring the solution properties with a microchip device.

- T3P.088** **WITHDRAWN**

WEDNESDAY - RF MEMS, Resonators, and Oscillators

- W3P.081** **WITHDRAWN**

- W3P.082** **ABOVE-IC 300 MHZ AIN SAW OSCILLATOR** 1927
 A. Uranga¹, G. Sobreviela¹, E. Marigó², M. Soundara-Pandian², and N. Barniol¹
¹Universitat Autònoma de Barcelona, SPAIN and ²Silterra Malaysia Sdn. Bhd., MALAYSIA

This paper reports on the fabrication of an AIN SAW resonator above a commercial CMOS technology using the SiTerra MEMS on CMOS process platform and its electrical characterization. As a proof of concept, a low noise CMOS sustaining amplifier followed by a very high frequency buffer has been designed to implement a fully integrated oscillator.



Source: Kaohsiung City Government Photographer: Chung-Hui Pao

- W3P.083 FREQUENCY STABILITY OF MICROMECHANICAL BEAM OSCILLATOR UNDER SUBHARMONIC SYNCHRONIZATION** 1931
D. Pu¹, R. Huan¹, and X. Wei²
¹Zhejiang University, CHINA and ²Xi'an Jiaotong University, CHINA

We investigate enhanced short term frequency stability of the sub-synchronized piezoresistive oscillator for the first time. Frequency stability is found steady in sub-synchronization region and can be further improved in short terms with larger perturbation.

- W3P.084 LOW IMPEDANCE ARRAYS OF COUPLED CROSS-SECTIONAL LAMÉ MODE RESONATORS WITH HIGH FIGURE OF MERIT IN EXCESS OF 100** 1935
C. Cassella, G. Chen, T. Wu, Z. Qian, and M. Rinaldi
Northeastern University, USA

We report on novel high electromechanical coupling coefficient (k^2) and large input capacitance (c_0) Cross-Sectional Lamé mode resonators (CLMRs). We show that, by coupling multiple 3-fingers CLMRs, it is possible to simultaneously achieve high Figure of Merit (FoM, namely the product between quality factor, Q, and k^2) and large CO-values.

- W3P.085 NONRECIPROCAL ACOUSTOELECTRIC INTERACTION OF SURFACE WAVES AND FLUORINE PLASMA-TREATED AlGaIn/GaN 2DEG** 1939
S. Ghosh¹, T. Hancock¹, M. Storey², L. Parameswaran¹, M. Geis¹, R. Ralston¹, and D. Weinstein²
¹Massachusetts Institute of Technology, USA and ²Purdue University, USA

This work demonstrates acoustoelectric (AE) effects in an AlGaIn/GaN 2DEG, where a fluorine based plasma has been used to tune the carrier concentration. Incorporation of fluorine ions in the AlGaIn barrier is shown to reduce sheet carrier density in the 2D layer, which is required to prevent screening of piezoelectric fields. The monolithic gain devices exhibit nonreciprocal insertion losses under applied DC bias for surface acoustic wave (SAW) modes in GaN on sapphire at 728 MHz and 1.48 GHz.

- W3P.086 ULTRA COMPACT CMOS-MEMS OSCILLATOR BASED ON A RELIABLE METAL-VIA MEMS RESONATORS WITH NOISE-MATCHED HIGH-GAIN TRANSIMPEDANCE CMOS AMPLIFIER** 1943
G. Sobreviela, M. Riverola, F. Torres, A. Uranga, and N. Barniol
Universitat Autònoma de Barcelona, SPAIN

In this paper we present a high transimpedance, low-noise and noise-matched pre-amplifier for integrated CMOS-MEMS devices sensing. The thermomechanical noise of a MEMS resonator has been characterized under atmospheric conditions in order to prove the low input noise of the designed transimpedance preamplifier. Results of the CMOS-MEMS system in a Pierce oscillator configuration demonstrates the lowest floor noise reported until now in a capacitively coupled CMOS-MEMS oscillator.

MONDAY - Optical MEMS

- M3P.087 A 2-AXIS MEMS SCANNING MICROMIRROR WITH 45 DEG AUTO-POSITIONING MECHANISM FOR ENDOMICROSCOPIC PROBE** 1947
Q.A. Tanguy¹, S. Bargiel¹, C. Duan², W. Wang^{2,3}, P. Struk¹, H. Xie², P. Lutz¹, and C. Gorecki¹
¹University of Bourgogne Franche-Comté, FRANCE, ²University of Florida, USA, and ³Shanghai Jiao Tong University, CHINA

In this work, a 2D MEMS electrothermal microscanner has been developed; it includes a brand novel mechanical stopper system used for an auto positioning at 45° of the mirror plate. In order to retrieve a high quality OCT image once integrated onto the Mirau endomicroscopic probe, the distal micromirror was designed to achieve higher performances than the former generations and eliminate significantly the axis cross-coupling. The mirror plate of 850 µm in diameter reaches mechanical angles up to 22° for only 7: 2V and we observe three resonant modes for the outer frame free bending at 455 Hz, the tilt mode at 730 Hz and the piston mode at 1:085 kHz.

- M3P.088 A POLARIZATION AND ANGLE INSENSITIVE TERAHERTZ LENS BASED ON CASCADED COMPLEMENTARY METASURFACES** 1951
D. Jia, W. Ma, Y. Wen, and X. Yu
Peking University, CHINA

In this paper, a three-layer cascaded complementary metasurfaces for complete terahertz (THz) phase control was designed at 3.11 THz and a transmissive lens was fabricated and experimentally demonstrated with a focal length of 23 mm and a full width at half maximum (FWHM) of 1.1 mm at the focal plane. Simulations and calculations reveal that the lens is insensitive to incident angle and polarization direction, which is favorable to the development of compact THz imaging and spectroscopy systems.

- M3P.089 AN ELECTROWETTING DRIVEN LIQUID TUNABLE OPTICAL PHASE SHIFTER 1955**
A. Ousati Ashtiani and H. Jiang
University of Wisconsin, USA

We report an electrowetting-based liquid tunable optical phase shifter. In this device, two immiscible liquid layers are placed adjacently with a planar boundary in between. By modifying the thickness of these layers, an optical path difference is induced, which results in a tunable phase shifter. A multi-layer SU8 structure is used to realize the device. A phase shift of 171° was observed by applying a 100 V AC signal to the electrowetting actuator embedded in the device.

- M3P.090 FABRICATION AND CHARACTERIZATION OF MEMS AIRGAP-BASED OPTICAL FILTERS FOR THE UV SPECTRAL RANGE 1959**
M. Ghaderi and R.F. Woffenbuttel
Delft University of Technology, NETHERLANDS

We have designed and fabricated MEMS airgap-based optical filters for the ultraviolet spectral range. Optical design, process condition, and material choice have been optimized to obtain large-area and optically flat filters. Several distributed Bragg reflectors with a high fill-factor were fabricated in a standard Si technology. The optical characterization of filters with only a few number of layers demonstrated a peak reflectance of up to 80% over a bandwidth of 175 nm in the UV spectrum.

- M3P.091 MONOLITHIC SILICON-ON-NOTHING PHOTONIC CRYSTAL PRESSURE SENSOR 1963**
Y.-P. Wong, J. Bregman, and O. Solgaard
Stanford University, USA

We present a single-mask process that combines isotropic and anisotropic etching with selective removal of passivation layers followed by hydrogen annealing to yield monolithic crystalline silicon devices. The process is demonstrated by creating pressure sensors that combine photonic crystal mirrors pressure-sensing diaphragm with silicon-on-nothing reference cavities in monolithic form. Sensors were tested with fiber-optic readout and showed high sensitivity and good stability.

- M3P.092 RELIABLE CARBON NANOTUBE BASED MICRO WIRE FOR MICRO FOCUS FIELD EMISSION X-RAY SOURCE BY MICROMACHINING 1967**
B. Sun, Y. Wang, M. Deng, and G. Ding
Shanghai Jiao Tong University, CHINA

We report on a flexible Ni micro wire with CNTs inserted in its surface for X-ray sources. Thanks to the effective direct contact and the strong interactions between CNTs and the substrate, the micro wire can bear complex curving with preservation of the field emission properties, which is beneficial for geometric optimization.

TUESDAY - Optical MEMS

- T3P.089 A HIGH-Q THREE-DIMENSIONAL TERAHERTZ METAMATERIAL PERFECT ABSORBER 1971**
X. Zhao¹, M. Wu¹, J. Zhang², J. Schalch², K. Cremin², R.D. Averitt², and X. Zhang¹
¹Boston University, USA and ²University of California, San Diego, USA

This paper reports a novel three-dimensional metamaterial perfect absorber (MPA) that is insensitive to the polarization and incident angle of the terahertz (THz) radiation. The unique 3D unit-cell structure leads to a near-unit absorption at 1.6 THz with a high-quality factor, enabling its potential chemical sensing applications.

- T3P.090 AG/AU NANOCOMPOSITES ON CELLULOSE FIBER MATRICES AS PLASMONIC SUBSTRATE FOR BIOSENSING 1975**
M. Park and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper reports Ag/Au nanocomposites on cellulose fiber matrices as plasmonic substrate for biosensing such as metal-enhanced fluorescence (MEF), and surface-enhanced Raman scattering (SERS). Ag/Au nanocomposites were fabricated by using concurrent deposition of Ag and Au under composition regulation. This novel plasmonic paper substrate enables about 2-fold enhancement of fluorescence signals, chromatographic MEF, and additional enhancement in SERS signals for detection of DNA base molecule.

- T3P.091 DEVELOPMENT OF ACOUSTIC-OPTIC (AO) SLM APPLICABLE TO 3D HOLOGRAPHIC DISPLAY 1979**
G. Ryu, Y. Lee, and K. Lee
Ajou University, KOREA

We demonstrate the possibility and validity of development of acousto-optic (AO) spatial light modulator (SLM), which extends to holographic display system. To deflect light beam freely, Bragg diffraction between surface acoustic wave (SAW) and light wave is used. This research shows diffraction angle and amount of diffracted light varied to applied conditions of SAW, proposing novel design and fabrication for several light beam with lens array to make focus on screen.

- T3P.092 FABRICATION OF AN ELECTROWETTING MICROLENS ARRAY ON A FLEXIBLE SUBSTRATE 1983**
 K.L. Van Grinsven, A.O. Ashtiani, and H. Jiang
University of Wisconsin, USA

We describe the fabrication of a flexible electrowetting microlens array. The microlenses are composed of two immiscible liquids on a flexible substrate. The electrode design utilized for electrowetting allow for the independent tuning of the individual microlenses, while the flexible substrate provides the ability to increase the field of view. We report our fabrication method and demonstrate actuation of the lens for a tunable microlens array made exclusively of flexible materials.

- T3P.093 NONLINEARITY COMPENSATION OF MICRO-MIRROR HARD-SPRING BY ELECTROSTATIC COMBS 1987**
 T. Izawa, T. Sasaki, and K. Hane
Tohoku University, JAPAN

Torsion bar of micro-mirror scanner often shows hard-spring effect, which bends the oscillation curve and causes instability such as hysteresis. In this report, we propose a method to compensate equivalently the hard-spring nonlinearity of micro-mirror scanner using electrostatic combs. A 0.02% bend of oscillation curve of micro-mirror scanner was compensated by an applied comb voltage of 12V and the oscillation curve became symmetrical at the peak frequency.

- T3P.094 ROUGHENED CYLINDRICAL GOLD LAYER WITH CURVE GRAPHENE COATING FOR ENHANCED SENSITIVITY OF FIBER SPR SENSOR 1991**
 B. Lu, X. Lai, P. Zhang, H. Wu, H. Yu, and D. Li
Tianjin University, CHINA

A fiber surface plasmon resonance sensor with roughened gold film and curve graphene coating for glucose monitoring with enhanced sensitivity is proposed. This is the first attempt to employ ultrasonic cavitation to roughen the gold layer on micron-scale cylindrical surface. A liquid transfer method is also first employed to curve CVD graphene film to coat the roughened gold layer through Van der Waals force for promoting the electron mobility.

WEDNESDAY - Optical MEMS

- W3P.087 A MEMS ARRAY-TYPE MIRAU INTERFEROMETER FOR SWEEPED-SOURCE OCT IMAGING WITH APPLICATIONS IN DERMATOLOGY 1995**
 C. Gorecki, S. Bargiel, N. Passilly, O. Gaiffe, L. Froehly, J. Lullin, and S. Perrin
Université de Bourgogne, FRANCE

This papers reports on the technology and experimental validation of a miniaturized active array-type Mirau interferometer applied for OCT (optical coherence topography) imaging of skin lesions. This is the word-first achievement in the field of fully integrated OCT microsystems.

- W3P.088 AN AIR-SPACER TERAHERTZ METAMATERIAL PERFECT ABSORBER FOR SENSING AND DETECTION APPLICATIONS 1999**
 G. Duan¹, J. Schalch², X. Zhao¹, J. Zhang², R.D. Averitt², and X. Zhang¹
¹Boston University, USA and ²University of California, San Diego, USA

We designed, fabricated, and characterized a metamaterial perfect absorber at terahertz (THz) frequency range by utilizing air as the dielectric material. There was a three times improvement of the quality factor. Also high sensitivity can be achieved compared with traditional metamaterials absorbers. Moreover, the absence of the dielectric materials offered the special opportunity to using liquid or gas as the dielectric layer for sensing and detection purposes.

- W3P.089 DIELECTRIC MICROSPHERE-BASED OPTICAL SYSTEM FOR SUPER-RESOLUTION MICROSCOPY 2003**
 G. Huszka, H. Yang, and M.A.M. Gijs
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We present a dielectric microsphere-based super-resolution scanning optical microscope. We fixed a microsphere on a frame that was attached to a microscope objective and performed an automatic step-by-step scanning and imaging of the sample. Later, a single wide-field super-resolution image was synthesized. Furthermore, we propose an array fabrication process for placing multiple microspheres in the optical path of the microscope objective, thereby parallelizing the imaging process.

- W3P.090 FEW-LAYER MoS₂-DEPOSITED FLEXIBLE SIDE-POLISHED FIBER BRAGG GRATING BENDING SENSOR FOR PULSE DETECTION 2007**
 C. Li¹, X. Peng¹, C. Wang², S. Cao³, and H. Zhang¹
¹Beihang University, CHINA, ²Wuhan University, CHINA, and ³Shenzhen University, CHINA

We present a flexible side-polished FBG-based bending sensor involving the deposition of MoS₂ onto the FBG fiber core. The MoS₂ overlay enables the sensor a higher sensitivity to bending strain because of refractive index changes in the overlay in relation with evanescent field interaction with fiber gratings. The extracted subtle wrist pulse signal validates the great potential of MoS₂-based side-polished fibers as wearable sensors for human activity detection.

W3P.091 REAL-TIME MULTI-SPECTRAL T-RAY IMAGING USING A HYBRID METAMATERIAL FOCAL PLANE ARRAY 2011

Z. Zhou^{1,2}, H. Li^{1,2}, T. Zhou¹, J. Cao^{1,2}, and H. Tao^{1,2,3}

¹Chinese Academy of Sciences, CHINA, ²University of Chinese Academy of Sciences, CHINA, and ³University of Texas, USA

We have designed, fabricated, and characterized a real-time multi-spectral T-ray imager based on a hybrid metamaterial focal plane array (FPA). The heart of the imager is a multi-spectral terahertz metamaterial detector operating at 2.5 THz, 3.4 THz and 4.3 THz, respectively. The prototype FPA consists of 4×4 image pixels, which can be easily scaled up for a larger array.

MONDAY - Actuators

M3P.093 A NOVEL INERTIAL MICROSWITCH WITH SYNCHRONOUS FOLLOW-UP COMPLIANT ELECTRODES FOR EXTENDING OUTPUT SWITCH-ON PULSE WIDTH 2015

Q. Xu¹, Z.Q. Yang¹, Y.N. Sun¹, J.B. Luo¹, H.F. Li¹, G.F. Ding¹, X.L. Zhao¹, J.Y. Yao¹, and J. Wang²

¹Shanghai Jiao Tong University, CHINA and ²University of South Florida, USA

A novel inertial microswitch with synchronous follow-up compliant electrodes for extending switch-on pulse width is proposed. The flexible movable electrode and stationary electrode can keep a continuous duration contact by double-stair and spring-shape structures. The comparison test results show that there is no contact bouncing behavior under $\sim 466g$ half sine-wave shock acceleration and the output switch-on pulse width can reach $390\mu s$, which is longer than that in the traditional design.

M3P.094 BULK-UNIMORPH PZT ACTUATOR FOR LARGE PISTON MOTIONS WITH 2-AXIS SMALL ANGLE ADJUSTMENTS 2019

I. Grinberg, N. Maccabi, and D. Elata

Technion - Israel Institute of Technology, ISRAEL

We present a piezoelectric actuator for large piston motion that enables small angle adjustments in two axes. The actuator is made from a single thick layer of PZT, and is constructed from spiral arms that support a central rigid stage. Interdigitated electrodes induce torsion in the spiral arms. We demonstrate that this torsion dominates the piston-motion of the actuator, and that the effect of bending moments is small by comparison.

M3P.095 LOW-VOLTAGE MICROFLUIDIC ACTUATOR DRIVEN BY TENSION MODIFICATION 2023

N. Hasan, F. Khan, S.S. Pandey, A. Banerjee, H. Kim, and C.H. Mastrangelo

University of Utah, USA

We report the fabrication and testing of a new type of microfluidic actuator driven by electrically-induced changes in the tension of a thin elastic diaphragm. The actuator is simple consisting of a pressurized fluid cavity bounded by a pre-tensed PDMS diaphragm with embedded thin shape memory coil. When the SMA wire is electrically heated it reduces the membrane tension causing large deflections at the membrane center. We observed deflections of $600\mu m$ on 36 mm diameter membranes at $3.2V$.

M3P.096 THE MICRORAILGUN: A NEW CLASS OF HIGH VELOCITY MICROACTUATOR 2027

S.S. Pandey, A. Banerjee, M. Karkhanis, and C.H. Mastrangelo

University of Utah, USA

μ -railguns generate forces proportional to the square of current producing very high forces and velocities when driven by ultrafast capacitor discharges. μ -railguns were fabricated on an SOI wafer with $15\mu m$ thick device layer. A test set-up was built for high speed capacitive discharge and stroboscopic imaging of device under actuation. Initial results demonstrate μ -railguns with actuation velocity of 49 m/s at 1 MHz , nearly 2 times higher than possible with PZT piezoelectrics.

M3P.097 TACTILE DISPLAY MEMS DEVICE WITH SU8 MICRO-PIN AND SPRING ON SMA FILM ACTUATOR ARRAY 2031

T. Mineta¹, H. Yanatori¹, K. Hiyoshi¹, K. Tsuji¹, Y. Ono², and K. Abe²

¹Yamagata University, JAPAN and ²Tokai Rika CO. LTD., JAPAN

We have newly developed a 5×5 arrayed tactile display device which consisted of SMA thick film planar actuator array with photo-lithographed SU8 bias springs, micro-pins (1 mm pitch), and cap layers. The device was able to provide mechanical sensation to human finger skin by vibration at driving frequency of 30 Hz .

TUESDAY - Actuators

T3P.095 A PURE-TWISTING PIEZOELECTRIC ACTUATOR FOR TILTING MICROMIRROR APPLICATIONS 2035

I. Grinberg, N. Maccabi, and D. Elata

Technion - Israel Institute of Technology, ISRAEL

We present a piezoelectric beam actuator that responds in pure twisting deformation. The actuator is made from a single thick layer of PZT, with interdigitated electrodes on its top and bottom surfaces. The interdigitated electrodes are oriented at 45 degrees on the top surface, and at -45 degrees on the bottom surface. When the electrodes are subjected to voltages with the same polarity as used during poling, a pure twisting torque is induced.

- T3P.096 COUPLED PIEZOELECTRIC NONLINEAR TRANSDUCTION ARRAY FOR TURBULENCE MANIPULATION 2039**
M.B. Mansoor¹, N. Reuther², S. Koeble¹, T.W. Wong¹, P. Woias¹, and F. Goldschmidtboeing¹
¹University of Freiburg, GERMANY and ²Bundeswehr University Munich, GERMANY

This paper reports on a piezoelectric MEMS transducer designed to influence the outer turbulent boundary layer. A systematic parametric analysis has helped to optimize the peak-to-peak amplitude from 200 μm to 500 μm near the frequency range of 1200 Hz. Four such resonant oscillators are cascaded in a row to form a modular array capable of creating transverse surface waves. Particle Image Velocimetry measurements have shown promising results for drag reduction.

- T3P.097 MEMS SWITCH WITH PROLONGED LIFETIME UNDER HOT SWITCHING CONDITIONS BASED ON GOLD AS CONTACT MATERIAL 2043**
T. Lisec, F. Stoppel, D. Kaden, F. Heinrich, A. Neumann, and B. Wagner
Fraunhofer Institute for Silicon Technology (ISIT), GERMANY

The reliability of a surface-micromachined ohmic switch, featuring bi-directional actuation with high forces, a very low contact resistance and good heat dissipation, is described. It is shown, that bi-directional actuation stabilizes the switch behavior despite process induced variations and enables hot switching with Au as contact material even in ambient air. With a load of 10 mA at 10 VDC at least 200 million cycles are possible. 80 million cycles could be demonstrated at 50 mA and 10 VDC.

- T3P.098 NOVEL MEMBRANE-LESS TWO-WAY MEMS LOUDSPEAKER BASED ON PIEZOELECTRIC DUAL-CONCENTRIC ACTUATORS 2047**
F. Stoppel, C. Eisermann, S. Gu-Stoppel, D. Kaden, T. Giese, and B. Wagner
Fraunhofer Institute for Silicon Technology (ISIT), GERMANY

In this paper a novel type of piezoelectric MEMS loudspeaker is presented. The device concept is based on concentrically cascaded PZT actuators making it the first two-way MEMS speaker reported. As a further novelty the device is designed to operate without a closed membrane offering significant improvements with respect to acoustic performance, energy efficiency and manufacturability. Extensive FEA studies have revealed a very high SPL of more than 85 dB at 500 Hz for a device $10 \times 10 \text{ mm}^2$ in size. At higher frequencies even larger SPL values are achieved enabling a flat frequency response with 95 dB for frequencies above 800 Hz. Based on the concept speaker prototypes have been fabricated using MEMS technology and are currently being characterized.

- T3P.099 ULTRA-THIN POLYMER LOUDSPEAKER BASED ON ELECTRO ACTIVE POLYMER ACTUATION 2051**
F. Casset^{1,2}, P. Poncet^{1,2}, A. Latour^{2,3}, B. Laroche⁴, S. Bouchet⁴, and S. Fanget^{1,2}
¹Université de Grenoble Alpes, FRANCE, ²CEA, LETI, FRANCE, ³CEA-LITEN, FRANCE, and ⁴FOCAL, FRANCE

We develop an ultra-thin polymer loudspeaker based on a piezoelectric Electro-Active Polymer actuator. Electromechanical and acoustic characterizations were performed on this device and have proven its functionality. Satisfying audible sounds and music can be played using our polymer loudspeaker demonstrator.

WEDNESDAY - Actuators

- W3P.092 A LOW-COST REUSABLE MICRO-NEWTON SCALE MICRO-THRUSTER 2055**
J. Law¹, W. Sun², Z. Wu³, H.-Y. Chan¹, Y. Zhou³, and W.J. Li¹
¹City University of Hong Kong, HONG KONG, ²Shenzhen Academy of Robotics, CHINA, and ³Harbin Institute of Technology, CHINA

We develop and test a low-cost reusable micro-thruster that can produce intermittent streams of water sprays based on bubble-jet effect using batch-fabricated micro-heaters. The propulsion performance of the micro-thruster has been studied by measuring its average weight loss during each spray and the speed profile of the ejected droplets. The propulsion performance has been also measured using a simple pendulum model. The estimated thrust is in micro-Newton range per spray.

- W3P.093 BIOINSPIRED MICROACTUATORS FOR ZERO-POWER HEAT FLUX REGULATION 2059**
M. Thielen, E. Sanusoglu, F. Furer, N. Ehrenberg, and C. Hierold
ETH Zürich, SWITZERLAND

We report on a bioinspired and zero-power approach to regulate the heat flux through a heat sink using temperature sensitive microactuators. For the first time we replicate the mammal piloerection mechanism for thermoregulation with bimorph microhairs fabricated from polyimide and PVDF-TRFE copolymer. The actuators feature a very high temperature sensitivity ($SD=0.03 \text{ 1/K}$) that is unprecedented in literature and enables a number of other microactuator applications.

- W3P.094 FULL INTEGRATION OF A DIELECTRIC ELASTOMER ACTUATOR WITH A FLEXIBLE 1 kV THIN-FILM TRANSISTOR 2063**
A. Marette, C. de Saint-Aubin, S. Rosset, D. Briand, and H. Shea
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We present the first integration of flexible 1 kV TFTs with Dielectric Elastomer Actuators (DEA), providing a key building block for smart compliant machines. DEAs are flexible actuators with impressive performance, whose use has been limited by the need for one external HV switch per DEA. Here we show that with a 30V gate signal, the on-device compliant HVTFT switches more than 1 kV across the DEA, allowing matrices of DEAs to be controlled using only low voltage control signals.

- W3P.095 MICROORGANISMS DRIVEN MICRO ACTUATION MECHANISMS FOR THE KINETIC ENERGY HARVESTING 2067**
T. Hatsuzawa, Y. Yanagida, and T. Nisisako
Tokyo Institute of Technology, JAPAN

Three types of micro actuation mechanisms for the kinetic energy harvesting by microorganisms were fabricated by optical lithography and 3D printing. First, a reciprocating micro-float was driven by *Artemia*, with a driving speed of 0.3mm/s. Also, a rotary micro-ratchets was also driven by *Artemia* larva, with a rotation speed of 0.35 rpm. Then, Micro-ratchets are driven by *Volvox*, and achieved rotation speed of 3.5rpm.

- W3P.096 RESEALABLE, ULTRA-LOW LEAK MICRO VALVE USING LIQUID SURFACE TENSION SEALING FOR VACUUM APPLICATIONS 2071**
C. Yang, X. Xie, S. Liu, and C. Livermore
Northeastern University, USA

We present the design, fabrication, and successful demonstration of a micro valve that uses the surface tension of molten solder to make a reversible, ultra low-leak seal. The valve comprises a silicon chip with a solder-ringed flow orifice and integrated heater, and a piezoelectric translational actuator with a solder-ringed sealing plate. The closing and opening of the valve under electrical actuation are demonstrated. The open-state flow rate greatly exceeds the closed-state leak rate.

- W3P.097 UNTETHERED FLIGHT OF A TINY BALLOON VIA SELF-SUSTAINED ELECTROSTATIC ACTUATORS 2075**
M. Qi^{1,2}, Y. Yang³, X. Yan^{1,4}, Z. Liu¹, X. Zhang^{1,4}, and L.W. Lin²
¹Beihang University, CHINA, ²University of California, Berkeley, USA,
³Shanghai Electro-Mechanical Engineering Institute, Shanghai, CHINA, and
⁴Peking University, CHINA

We present electrostatic flapping actuators with self-sustained oscillations powered by on-board capacitors for the untethered flight control of a palm-sized balloon. With a length of 13mm and weight of only 3mg, the actuator generates lift force of 1mg with a stroke frequency of 50Hz under applied DC voltage. The actuator produces a wing rotation angles up to $\pm 45^\circ$, and successfully realizes untethered flapping on the plastic balloon for 27 seconds for lateral movements of 295 mm in the sky.

MONDAY - Theory, Design and Test Methodology

- M3P.098 A HIGH-RESOLUTION NON-CONTACT THICKNESS TEST METHOD OF ULTRA-THIN SILICON DIAPHRAGM 2079**
T. Guan, F. Yang, W. Wang, B. Jiang, P. Liu, L. Zhang, R. Li, Z. Fan, L. Cheng, W. Wang, Q. Zhao, and D. Zhang
Peking University, CHINA

This paper reported a high-resolution non-contact thickness test method of ultra-thin silicon diaphragm fabricated by KOH cavity erosion. Employing the deformation mechanism for multi-layer materials, a film thickness and film deformation curvature radius (Curve) relationship model is established and optimized. For the first time, the test sensitivity increases when film thickness decreases, so the novel method is especially suitable for ultra-thin film measurement.

- M3P.099 EFFICIENT REDUCED ORDER MODELING OF FLUID SOLID INTERACTIONS FOR STRUCTURAL COMPLEX PERFORATED MEMS 2083**
H. Schmidt, A. Sorger, and J.E. Mehner
Chemnitz University of Technology, GERMANY

A ROM approach is presented, which allows the efficient implementation of physics-based damping in mechanical models of structurally complex, perforated MEMS. The system model is created by a Craig-Bampton component mode synthesis. System modes are selectively mapped to component level, serving as deflection profiles in lumped flow resistance network simulations. The system model is adapted by the acquired modal damping coefficients, allowing a close approximation of the dynamic behavior.

- M3P.100 RECONFIGURABLE AIN RESONATOR FILTER DESIGN BASED ON EXTENDED STATISTICAL ELEMENT SELECTION** 2087
 J. Xu¹, S. Merugu², N. Singh², G. Piazza¹, L. Pileggi¹, and G.K. Fedder¹
¹Carnegie Mellon University, USA and ²Institute of Microelectronics, SINGAPORE

We develop a reconfigurable design of aluminum nitride (AlN) MEMS resonator filter with GHz level center frequency to reduce center frequency (f_0) error due to systematical process variations. To improve f_0 yield, an Extended Statistical Element Selection (ESES) approach is implemented to optimize yield while minimize area consumption.

- M3P.101 MODELING OF A VISCOMETRIC MEMS AFFINITY GLUCOSE SENSOR** 2091
 J. Shang, H. Sun, and Q. Lin
 Columbia University, USA

We present simulation and experimental verification to understand the interactions between structural vibrations and highly confined flow in a MEMS glucose sensor. Coupled structural vibration and fluid flow is a challenging problem of great practical relevance to MEMS sensors and actuators. We address this problem with a MEMS viscometric glucose sensor as a demonstrative example using theory of squeeze-film damping and vibrations of pre-stressed diaphragms.

TUESDAY - Theory, Design and Test Methodology

- T3P.100 A NOVEL SQUEEZED-FILM DAMPING MODEL FOR MEMS COMB STRUCTURES** 2095
 A. Sinding¹, A. Parent¹, I.E. Ocak², W.U. Syed³, A.N. Chatterjee⁴, C. Welham¹, S. Liu⁵,
 J. Yan⁵, S. Breit⁵, H.-K. Chang², I.M. Elfadel³, and Z. Sbiaa⁴
¹Coventor, SARL, FRANCE, ²Agency for Science, Technology and Research (A*STAR), SINGAPORE,
³Masdar Institute of Science and Technology, UAE, ⁴GLOBALFOUNDRIES, SINGAPORE, and ⁵Coventor, Inc, USA

We describe the implementation of a novel model for simulating comb squeezed-film damping. The model is computationally efficient and optionally includes substrate surfaces. Damping coefficients are within 1% of values obtained from standard numerical simulation. One application is to predict the Q factors of resonant MEMS, where high values are preferred. The model is validated to experimental Q factors of a magnetometer, predicted values are within 10% of measurement from 0.01MPa to 100Pa.

- T3P.101 IONIC JET FLOW IN A CIRCULATORY MINIATURIZED SYSTEM** 2099
 L.B. Dang¹, T.X. Dinh², T.T. Bui³, T.C. Duc³, H.T. Phan⁴, and V.T. Dau⁵
¹Hanoi University of Science and Technology, VIETNAM, ²Ritsumeikan University, JAPAN,
³Vietnam National University, VIETNAM, ⁴Hanoi University of Industry, VIETNAM, and
⁵Sumitomo Chemical. Ltd, JAPAN

This paper reports a novel device for generating circulatory jet flow using bipolar discharge configuration. This arrangement allows to generate simultaneously ionic wind with opposite charge, thus the ion flow is self-neutralized while keeping the momentum in desired direction. Experiment and simulation has shown that the air flow is successfully circulated in the confined device with peak velocity of 2 m/s while consuming only 33 mW.

- T3P.102 TEMPERATURE CHARACTERIZATIONS ON GRAPHENE-BASED GAS SENSORS** 2103
 T. Hayasaka¹, Y. Kubota^{1,2}, Y. Liu¹, and L. Lin¹
¹University of California, Berkeley, USA and ²Toyohashi University of Technology, JAPAN

The source-drain resistance of graphene field effect transistor (FET)-based gas sensor was characterized while controlling the temperature of the device and the relative humidity (R.H.) level inside the chamber. By means of the precisely controlled measurement system, the combining effects of temperature, R.H. level, and gate voltage were revealed. The results presented in this paper can be directly applied to the calibration of graphene FET-based gas sensors operated in ambient air.

WEDNESDAY - Theory, Design and Test Methodology

- W3P.098 DESIGN METHOD FOR RAPID CUSTOMIZATION OF MEMS SENSORS** 2107
 T. Kawamura, K. Watanabe, Y. Kamada, A. Isobe, H. Hasegawa, N. Sugii,
 D. Ryuzaki, H. Kurata, and S. Nishimura
 Hitachi, Ltd., JAPAN

This paper reports a novel method that reduces time for design customization of MEMS sensors by a six-fold. A design database that contains a variety of structural and characteristics parameter sets is built beforehand. Once specifications are given, the database is analyzed to present a candidate structure and a guideline for a refinement. Number of recalculations is dramatically reduced with this method.

- W3P.099 HOW ACCURATE IS THE FABRY-PEROT APPROXIMATION IN HIGH-FINESSE LINEAR VARIABLE OPTICAL FILTERS FOR GAS ABSORPTION SPECTROSCOPY? 2111**
 N.P. Ayerden and R.F. Wolffenbuttel
Delft University of Technology, NETHERLANDS

The gas-filled linear variable optical filter (LVOF) improves the level of integration of a microspectrometer by using the resonator cavity of a wideband interference filter also as the gas cell. The demanding operating conditions render the conventional approximation of the tapered resonator into an array of Fabry-Perot filters invalid. In this paper, a novel design method using the Fizeau interferometer approach is described and demonstrated with measurements.

- W3P.100 THE EFFECT OF THE ELECTRODE RESISTANCE ON THE PERFORMANCE OF CODE-MULTIPLEXED RESISTIVE PULSE SENSING 2115**
 R. Liu, N. Wang, C.-H. Chu, and A.F. Sarioglu
Georgia Institute of Technology, USA

We analyze the scaling of the Microfluidic CODES technology that can be used to code-multiplex a large number of electrical sensors on a microfluidic device. We model the effect of the electrode trace resistance on the sensor performance and optimize the device layout to improve the decoding of sensor signals. Our results can also be adapted in designing sensor architectures that utilize the resistive pulse sensing to obtain the spatio-temporal information of particles on a microfluidic chip.

MONDAY - Late News

- M3P.102 A 1200-ATMOSPHERE BULK-TYPE ALL-SILICON PRESSURE SENSOR 2119**
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Distinct from conventional diaphragm-type pressure sensors, a bulk-type all-silicon pressure sensor is developed in which external hydrostatic pressure acting on the sensor is converted to biaxial compression inside a vacuum-sealed cavity and measured using piezoresistors optimally oriented for the anisotropic piezoresistance. Containing no fragile microstructures, the sensor is robust and intrinsically capable of a pressure rating much beyond the 1200-atmosphere limit imposed by the test setup.

- M3P.103 A MICROELECTROMECHANICAL ALN RESOSWITCH FOR RF RECEIVER APPLICATION 2123**
 T. Wu, G. Chen, Z. Qian, W. Zhu, M. Rinaldi, and N. McGruer
Northeastern University, USA

We report an AlN-based resonant switch (resoswitch) based on a novel design and fabrication process. A folded beam structure compensates for stress-gradient-induced bending in the sputtered AlN material. A 21.14 kHz resoswitch with a Q greater than 2000 and an actuation gap of 1.3 μm is turned on by a 0.5dBm, 800MHz RF signal modulated at the resonant frequency of the switch. The switch is intended for monolithic integration with AlN RF components to build zero-power RF receivers.

- M3P.104 A WAFER LEVEL PROCESS FOR BULK TUNGSTEN INTEGRATION IN MEMS VIBRATION ENERGY HARVESTERS AND INERTIAL SENSORS 2127**
 A. Dompierre and L.G. Fr  chette
Universit   de Sherbrooke, CANADA

We present a new fabrication process for wafer-level integration of high density proof masses on silicon. Made from thick tungsten substrates, the masses are patterned in a 2-step wet chemical milling approach and integrated by wafer bonding on silicon cantilevers. Out of plane resonators are fabricated and characterized to showcase the process potential to fabricate highly sensitive inertial MEMS sensors and energy harvesters for low frequency ambient vibrations applications.

- M3P.105 AN OUT-OF-PLANE "HINGE-SHAPED" NANO-GAP ACCELEROMETER WITH HIGH SENSITIVITY AND WIDE BANDWIDTH 2131**
 Y. Jeong, A. Daruwalla, H. Wen, and F. Ayazi
Georgia Institute of Technology, USA

This paper presents the design, fabrication, and characterization of a novel "hinge-shaped" out-of-plane accelerometer utilizing nano-meter sensing gap electrodes. The increased electromechanical coupling provided by the narrow gap allows the design of micro-g accelerometer with high resonant frequency (>10 kHz), which extends the operational bandwidth compared to conventional devices. Novel microstructure also increases immunity against the stiction without compromising device sensitivity.

- M3P:106 BROADBAND FREQUENCY VISCOSITY MEASUREMENT USING LOW TCF SHEAR MODE RESONATORS CONSISTING OF C-AXIS TILTED SCALIN THIN FILM ON THICK AT-CUT QUARTZ PLATE** 2135
 Y. Yamakawa¹, K. Sano¹, R. Karasawa¹, and T. Yanagitani^{1,2}
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We report a new type HBAR sensor which makes it possible to operate in the wide frequency range unlike other TSM viscosity sensors. The HBAR consists of the c-axis tilted ScAlN film grown on an AT-cut quartz crystal plate. Frequency shifts were measured for various concentration of glycerine solutions. As a result, the tendency of the resonant frequency decreasing caused by liquid viscosity increasing was observed.

- M3P:107 CONFOCAL LASER DISPLACEMENT SENSOR USING MEMS VARIFOCAL MIRROR** 2139
 K. Nakazawa¹, T. Sasaki¹, H. Furuta², J. Kamiya², H. Sasaki², T. Kamiya², and K. Hane¹
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A confocal laser displacement sensor using a micro-machined electrostatically actuated varifocal mirror is reported. The focal length modulation is a key function for the sensor. The measurement speed and range depend on the mechanism. In this study, we propose to use the micro-machined varifocal mirror for the mechanism of the focal length modulation in the confocal displacement sensor. The measurement range at 7 kHz is 310 μm . The linearity in the full scale range is from -1.5% to 0.85%.

- M3P:108 DEVELOPMENT OF ULTRA-THIN MEMS MICRO MIRROR DEVICE** 2143
 T. Takeshita, T. Yamashita, N. Makimoto, and T. Kobayashi
 National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

We have developed the ultra-thin MEMS mirror device. The thickness of the device is 5.31 μm . The device was fabricated using SOI wafer on which Pt/SRO/PZT/SRO/Pt/Ti/SiO₂ were deposited. The mirror device was bonded on a flexible substrate using conventional MEMS, bonding, and printing technology. The mirror device was rotated 3.58 deg. when applied voltage was 1 Vpp at resonant frequency of 10400 Hz on the flexible substrate.

- M3P:109 FOCUSED SOURCE FORMATION USING A MICRO DISC-LIKE PATCH ANTENNA ARRAY FOR THz CMOS TRANSCIVER APPLICATIONS** 2147
 Y.-X. Lu¹, M.-T. Hsu¹, Y.T. Cheng¹, C.-H. Li², and C.-N. Kuo¹
¹National Chiao Tung University, TAIWAN and ²National Central University, TAIWAN

The paper presents a scheme to generate a focused THz source using a disc-like antenna array for THz CMOS-based transceiver application. The disk-like antenna array is fabricated by pressing a steel ball onto a flexible flat antenna array placed on a hollow silicon mold to form a hemispherical shell disk. In comparison with the flat antenna array, about 1-2 dB higher receiving power measured experimentally has validated the source focusing capability of the disk via the scheme.

- M3P:110 LIVING SINGLE CELL SAMPLING INTERFACE: CELL RELEASE AND VIABILITY TEST** 2151
 K. Mawatari, L. Lin, and T. Kitamori
 University of Tokyo, JAPAN

Single cell analytical technology is becoming important in general biology and medicine. For this, fundamental technologies are required in sampling, chemical processing, and detection. In this presentation, we demonstrate living single cell sampling utilizing micro/nanofluidic technologies. Sampling of 39 fL was demonstrated and the cell kept the viability after sampling.

- M3P:111 MEMS-BASED SAMPLE CARRIERS FOR SIMULTANEOUS HEATING AND BIASING EXPERIMENTS: A PLATFORM FOR IN-SITU TEM ANALYSIS** 2155
 H.H. Perez Garza¹, Y. Pivak¹, L. Molina Luna², J.T. van Omme¹, R.G. Spruit^{1,3}, M. Sholkina¹, M. Pen¹, and Q. Xu¹
¹DENSolutions, NETHERLANDS, ²Technische Universitat Darmstadt, GERMANY, and ³Technische Universiteit Delft, NETHERLANDS

We present the development of a MEMS-based sample carrier to be used for *in-situ* Transmission Electron Microscope. Such device allows simultaneous heating and biasing experiments, by enabling temperatures up to 800°C, applied voltages up to 100V and electric fields as high as 200kV/cm. This is an ideal tool for failure analysis of semiconductors, current-voltage characterization at high temperatures and studies of structure responses to electric fields.

- M3P:112 SILICON BASED MID-INFRARED PHOTODETECTORS USING PLASMONIC GOLD NANO-ANTENNA STRUCTURES** 2159
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We developed a mid-infrared photodetector using nano-antennas on an n-typed Si wafer. The gold nano-antennas absorbed the infrared light effectively. The absorbed photon energy was transduced to photocurrent by a Schottky barrier formed at the interface between the Cr and n-typed Si. Mid-infrared light, λ over 3.2 μm , was detected due to absorption enhancement of mid-infrared light and significantly lowered Schottky barrier as small as 0.32 eV by the reverse bias.

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- T3P.103 A FLEXIBLE MICROCANTILEVER APTASENSOR FOR TRACE LEVEL DETECTION OF RICIN 2163**
Y. Tian, R. Zhao, and X. Yu
Peking University, CHINA

This work introduces a flexible piezoresistive microcantilever by using polyimide (PI) and silicon oxide (SiO₂) as the insulation layers of titanium (Ti) strain resistors. The microcantilever is elaborately devised including the strain and piezoresistive characteristics of Ti and the film formation and patterned process of the PI. An aptasensor is developed through functionalizing the microcantilevers, which is able to detect ricin of 10 ng/mL concentration with good specificity.

- T3P.104 A THREE-PORTS STRUCTURE FOR ELECTROSTATIC ENERGY-HARVESTER TO LOWER CONSTRAINT FORCE AND TO ENHANCE FAST STORAGE 2167**
H. Honma¹, H. Mitsuya², G. Hashiguchi³, H. Fujita¹, and H. Toshiyoshi¹
¹University of Tokyo, JAPAN, ²Saginomiya Seisakusho, JAPAN, and ³Shizuoka University, JAPAN

In this paper, we discuss on a new method to increase the output current of energy-harvesting device by using a symmetric three-ports electrostatic comb-drive mechanism that enables fast charging of battery. A symmetric electrodes layout is used to reduce the binding electrostatic force, thereby allowing a formation of a high electret potential without electrostatic collapse.

- T3P.105 A TRANSPARENT CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER (CMUT) ARRAY FOR FINGER HOVER-SENSING DIAL PADS 2171**
D.-C. Pang and Y.-H. Chiang
National Kaohsiung University of Applied Sciences, TAIWAN

The purpose of this research was to develop a finger hover-sensing dial pad using a 3×4 transparent capacitive micromachined ultrasonic transducer (CMUT) array with 12 different resonant frequencies. The CMUT array with 12 different membrane diameters generated ultrasounds ranging from 0.83MHz to 1.63MHz. Use of the hover-sensing controls does not obstruct the user's view by the fingers as occurs with touch screens, making this technology valuable in wrist-type wearable electronics applications.

- T3P.106 ADJUSTMENT OF SURFACE CONDITION FOR SELF-GENERATION OF DROPLET ARRAY USING OIL-WATER REPLACEMENT 2175**
H. Yasuga and N. Miki
Keio University, JAPAN

2D droplet arrays are powerful tools for high throughput and low-cost processes in the field of biology or medicine. Here, we developed a self-generation method of nanoliter-scale droplet array without precise liquid control such as precise pipetting or pumping. As a material, a photoresist off-stoichiometry thiol-ene was applied, of which surface energy can be tuned by polymer chain grafting. We experimentally found the surface conditions to self-generate an array of nanoliter-scale droplets.

- T3P.107 AN INTEGRATED OPTOELECTRONIC POSITION SENSOR FOR MEMS SCANNING MIRRORS 2179**
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¹Xiamen University, CHINA, ²University of Florida, USA, and ³Shanghai Jiao Tong University, CHINA

We develop an integrated optoelectronic position sensor that can measure the linear displacement and tilting angle of 2-axis electrothermally-actuated MEMS scanning mirrors. Experimental results show that this integrated optoelectronic position sensor has a linear response when the distance between the MEMS mirror and the integrated sensor is from 4.0 mm to 4.9 mm and the tilting angle of the mirror plate scans from -1.5° to +1.5°.

- T3P.108 EDGE-ANCHORED MODE-MATCHED MICROMACHINED GYROSCOPIC DISK RESONATOR 2183**
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This paper reports on a vacuum packaged circular disk gyroscopic resonator with T-shape anchors fabricated in a (100) single crystalline silicon substrate. This device topology simplifies the fabrication process as compared to previous approaches to realize center-anchored disk gyroscopes. Mode-matching of the trigonal modes of the disk is realized with open-loop characterization results demonstrating a over 1.5e6 Quality factor with an initial modal frequency split of 4.81ppm.

T3P.109 LONG-TERM VIBRATION CHARACTERISTICS OF MEMS INERTIAL SENSORS BY MULTI-LAYER METAL TECHNOLOGY 2187

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This paper present the long-term vibration characteristics of MEMS inertial sensors developed by multi-layer metal technology based on gold electroplating. We employ a cyclic input acceleration with the amplitude of 1G. The experimental results show that the inertial sensors have a mechanical tolerance to the vibration up to 107 cycles. Moreover, the cantilever tests suggest that the structure stability of multi-layer metal devices could be higher when the structure thickness becomes thicker.

T3P.110 MEMBRANE CHIPS LITHOGRAPHY FOR MICROFLUIDIC HYDROGEL-BASED MICROSTRUCTURES 2191

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¹National Tsing Hua University, TAIWAN and ²National Changhua University of Education, TAIWAN

We demonstrate a Membrane Chips Lithography to form photopolymerized hydrogel-based microarchitectures that use PDMS-based microstructures and oxygen inhibition layers. Base on the thin PDMS-based membrane, membrane chip have these advantages about less UV light intensity attenuation and low refractive exposure error. The special oxygen inhibition layers between different kind of hydrogel microstructures exposed by the UV light and PDMS walls could be applied to the biotechnology.

T3P.111 MICROFLUIDIC PRINT-TO-SYNTHESIS ENABLED COMBINATORIAL PEPTIDE MICROARRAY FOR CANCER TARGETING 2195

J. Li, R.P. Carney, R. Liu, J. Fan, S. Zhao, K.S. Lam, and T. Pan

University of California, Davis, USA

We develop a microfluidic print-to-synthesis platform for synthesizing combinatorial peptide on PEG microdisc array. The platform shows distinct features including free of contamination, multiplexibility, low cost, and high throughput. Using the platform, a tetrapeptide library was constructed and screened for ligands targeting $\alpha 4 \beta 1$ integrin overexpressed on tumor cell membranes. Results demonstrate the feasibility of the platform and identify positive sequences that bind to tumor cells.

T3P.112 PHOTONIC LAB-ON-A-CHIP DEVICE WITH UV LIGHT RESPONSIVE SMART SURFACES 2199

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¹Paul Scherrer Institute, SWITZERLAND and ²Monash University, AUSTRALIA

The combination of an optofluidic component and a polymeric substrate with a smart surface is presented. Before activation, visible light propagating through the optofluidic device is unaffected. When the device is exposed to UV light, an enzymatic reaction that changes light absorption in the system is enabled. The integration of the optofluidic component and the smart surface into a photonic LoC, its behavior and performance and the reversible nature of the UV activation are demonstrated.

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W3P.101 A BONE-ON-A-CHIP MICRODEVICE FOR LONG-TERM SPONTANEOUS 3D BONE TISSUE FORMATION AND CANCER BONE METASTASIS 2203

S. Hao, G. Cheng, Y. Wan, Y. Xia, D.M. Sosnoski, A.M. Mastro, and S.-Y. Zheng

Pennsylvania State University, USA

We report a bone-on-a-chip microdevice that can spontaneously form of a 3D, mineralized, collagenous bone tissue from an inoculum of isolated osteoblastic cell line without any artificial scaffold materials.

W3P.102 ALUMINUM NITRIDE PIEZOELECTRIC MICROPHONES AS ZERO-POWER PASSIVE ACOUSTIC FILTERS 2207

R.W. Reger¹, P.J. Clews¹, G.M. Bryan^{1,2}, C.A. Keane^{1,3}, M.D. Henry¹, and B.A. Griffin¹

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This work describes the development and characterization of piezoelectric MEMS microphones based on aluminum nitride (AlN) for near-zero power wakeup applications. The microphones operate as passive acoustic filters by placing their resonant response within bandwidths of interest. Devices are demonstrated with operational frequencies ranging from 430 Hz to greater than 10 kHz with quality factors as large as 3,000 and open-circuit voltages exceeding 600 mV/Pa.

W3P.103 DIODE-BASED CMOS MEMS THERMAL FLOW SENSORS 2211

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We report on the intrinsic advantages of thermoelectronic flow sensors. We numerically and experimentally show that thermoelectronic flow sensors (i.e. thermal flow sensors employing p-n junction based devices as temperature sensors) benefit from the possibility of having the temperature sensor located in the hottest area of the heating element for enhanced convective effects and thus improved sensor sensitivity. A multidirectional thermoelectronic flow sensor is also reported.

W3P:104 ELECTROSPUN NANOFABRIC BASED ALL-FABRIC IONTRONIC PRESSURE SENSOR 2215

R. Li, Y. Si, Z. Zhu, Y. Guo, Y. Zhang, N. Pan, G. Sun, and T. Pan
University of California, Davis, USA

A flexible supercapacitive sensing modality to all-fabric materials is introduced for wearable pressure and force sensing using an elastic ionic-electronic interface. Utilizing electrospun iontronic nanofabric as the sensing element, the all-fabric supercapacitive iontronic device offers an unprecedented sensitivity (114 nF/kPa), 2.4 Pa pressure resolution, and milliseconds response time, achieving high levels of noise immunity and signal stability for wearable applications.

W3P:105 ENERGY HARVESTER MADE OF TAIWAN LOCAL NEPHILA PILIPES SPIDER SILK 2220

C.-T. Pan, C.-K. Yen, M.-C. Hsieh, S.-W. Zeng, S.-W. Kuo, Y.-L. Shiue, and C.-H. Chien
National Sun Yat-Sen University, TAIWAN

Spider silk produced stronger and stabler piezoelectric property through the polarization technology. Moreover, the electrical testing shows the output voltage of polarized silk was higher than non-polarized silks. Thus, spider silk show great potential in energy harvester due to its piezoelectricity.

W3P:106 PICO-THERMOGRAVIMETRIC MATERIAL PROPERTIES ANALYSIS USING DIAMOND CANTILEVER BEAM 2223

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This paper presents a novel technique for picothermo gravimetric analysis of material properties using diamond cantilever beam. The thermal decomposition of calcium carbonate (CaCO₃) was examined. The cantilever beam with CaCO₃ attached was introduced in a thermal chamber and the temperature was raised to 600 centigrade. The resonant frequency measurements provided evidence that the thermal conversion started at 500 centigrade. Variations of the analyzed material picomass were also observed.

W3P:107 STRETCHABLE SENSOR ARRAY FOR RESPIRATORY MONITORING 2227

E. Koch and A. Dietzel

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We present a novel stretchable sensor array to be used for triggering artificial respiration of premature infants by measuring thorax deformations. A polyimide based flexible sensor becomes stretchable by fs-laser structuring and embedding in PDMS, providing skin-like properties. Sensor signals are used to determine trigger points for respiration and to facilitate surface reconstruction which in future could turn the sensor into an extended diagnostic tool during artificial respiration.

W3P:108 WAFER LEVEL FABRICATION METHOD OF HEMISPHERICAL REFLECTOR COUPLED MICRO-LED ARRAY STIMULATOR FOR OPTOGENETICS 2231

W. Khan and W. Li

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We report a monolithic wafer-level fabrication method for a hemispherical reflector coupled light emitting diode (LED) array using isotropic etching of silicon. Our stimulators provide higher intensity for effective opsin expressions in optogenetics experiments. It was found that the light intensity increases by a minimum of 49% and a maximum of 65% when coupling a reflector with the μ -LEDs.

W3P:109 ELECTROSTATIC MICROSHUTTER ARRAYS 2235

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⁵Catholic University of America, USA, and ⁶SGT Inc., USA

Based on the Microshutter technology developed at NASA Goddard Space Flight Center for the James Webb Space Telescope (JWST), Next Generation Microshutter Array has been developed to be used as multi-object selectors for future telescopes in space applications. Microshutter arrays function as transmission devices. The programmable microshutters open and close making the device perform as a multi object selector that can be used on space telescopes.