

2016 IEEE 29th International Conference on Micro Electro Mechanical Systems (MEMS 2016)

**Shanghai, China
24-28 January 2016**

Pages 1-616



**IEEE Catalog Number: CFP16MEM-POD
ISBN: 978-1-5090-0609-0**

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IEEE Catalog Number:	CFP16MEM-POD
ISBN (Print-On-Demand):	978-1-5090-0609-0
ISBN (Online):	978-1-5090-1973-1
ISSN:	1084-6999

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MEMS 2016 Program Schedule

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Sunday, 24 January

17:00 **Registration and Wine & Cheese Welcome Reception**
- 19:00

Monday, 25 January

08:30 **Welcome Address**
Hiroshi Toshiyoshi, *University of Tokyo, JAPAN*
Xiaohong Wang, *Tsinghua University, CHINA*

Invited Plenary Speaker I

08:50 **[QUANTUM ANOMALOUS HALL EFFECT IN MAGNETIC TOPOLOGICAL INSULATORS](#) 1**
Qi-Kun Xue, K. He, and Y. Wang
Tsinghua University, CHINA

Session I - Optics I

09:35 **[A COMPOUND OPTOFLUIDIC LENS FOR SWITCHABLE 2D/3D IMAGING](#) 2**
H. Huang, K. Wei, and Y. Zhao
Ohio State University, USA

We design and develop an adaptive compound optofluidic system for switchable 2D/3D imaging. This system addresses the current challenges that small imaging devices either lack stereoscopic imaging capability or suffer from limited optical resolution.

09:50 **[STANDOFF INFRARED SPECTROSCOPY ON ENERGETIC MATERIALS USING HYDROGEL MICROCANTILEVERS](#) 6**
I. Chae¹, M.F. Khan², J. Song³, J. Lee³, J. Lee³, and T. Thundat²
¹*Pennsylvania State University, USA*, ²*University of Alberta, CANADA*, and
³*Sogang University, SOUTH KOREA*

After we characterize the resonance frequency of fabricated hydrogel microcantilevers upon heating, a pulsed quantum cascade laser reflected off a chemical weapon coated surface is focused onto a hydrogel microcantilever. The absorption by a chemical weapon at specific wavelengths decreases the resonance frequency shift of the hydrogel microcantilever. In summary, we detect 4 different chemical weapons located 4 meter away from hydrogel microcantilevers.

10:05 **[ELASTO-OPTIC MODULATOR INTEGRATED IN HIGH FREQUENCY PIEZOELECTRIC MEMS RESONATOR](#) 9**
S. Ghosh and G. Piazza
Carnegie Mellon University, USA

We demonstrate a novel MEMS-based optical modulator operating on the elasto-optic effect. The device consists of a photonic racetrack embedded into a laterally-vibrating piezoelectric resonator. This constitutes the first demonstration of a MEMS strain-based optomechanical device, which operates on refractive index changes rather than physical displacements. Optical modulation is observed at a resonance frequency of 843 MHz. The device could be used for signal modulation in RF-Photonic systems.

10:20 **Break & Exhibit Inspection**

Session II - Fabrication & Materials I

- 10:50 GRAPHENE WAFER TRANSFER PRINTING FOR 3D SURFACE 13**
Y. Zhang^{1,2}, Y. Gui^{1,2}, F. Meng^{1,2}, L. Li^{1,2}, C. Gao^{1,2}, H. Zhu³, and Y. Hao^{1,2,4}
¹Peking University, CHINA, ²National Key Laboratory of Nano/Micro Fabrication Technology, CHINA, ³Tsinghua University, CHINA, and ⁴Innovation Center for MicroNanoelectronics and Integrated System, CHINA

We develop a novel water transfer printing method which can transfer CVD graphene from copper foil to 3D surface. By using surface tension and vanderwaals force, multilayer graphene sheet can be transferred to various substrates like glass sheet, colophony filament, silicon oxide micro structure, PI film, PMMA tube and optical fibers. As the graphene's shape and position are controllable, this simple room temperature transfer method has potential in flexible MEMS and device on curved surface.

- 11:05 A TRANSFER-FREE WAFER-SCALE CVD GRAPHENE FABRICATION
PROCESS FOR MEMS/NEMS SENSORS 17**
S. Vollebregt¹, B. Alfano^{2,3}, F. Ricciardella⁴, A.J.M. Giesbers⁵, Y. Grachova¹,
H.W. van Zeijl¹, T. Polichetti³, and P.M. Sarro¹
¹Delft University of Technology, THE NETHERLANDS, ²University of Naples, ITALY,
³Ente Nuove Tecnologie, Energia e Ambiente (ENEA) UTTP/MDB, ITALY, ⁴Italian Institute of
Technology, ITALY, and ⁵Philips Innovation Services, THE NETHERLANDS

An innovative transfer-free clean graphene fabrication process was developed. Graphene layers on 4" silicon wafers were deposited by CVD using Mo as catalyst. Removal of the Mo layer after graphene deposition results in a transfer-free and controlled placement of the graphene. Moreover, pre-patterning the Mo layer allows customizable graphene geometries to be directly obtained. This process is extremely suitable for the fabrication of a wide range of MEMS/NEMS sensors, e.g. gas sensors.

- 11:20 HIGH DYNAMIC ABLATION AND INJECTION BY ELECTRIC
CAVITATION FOR WIDE RANGE OF MATERIALS 21**
K. Takahashi¹, Y. Arakawa¹, and Y. Yamanishi^{1,2}
¹Shibaura Institute of Technology, JAPAN and
²Japan Science and Technology Agency (JST), JAPAN

We have successfully carried out local reagent injection and perforation to materials of variety of hardness using bubble cavitation and plasma cavitation. Cavitation and plasma was generated by pulse discharge of microelectrode having special tip structure. Injection to soft material such as animal cell was performed only by cavitation of bubble, and perforation to hard materials such as seeds of plants or metals were achieved by synergistic effect of cavitation of bubble and plasma ablation.

- 11:35 LOW TEMPERATURE DIRECT BONDING OF SINGLE CRYSTAL QUARTZ
SUBSTRATES FOR HIGH PERFORMANCE OPTICAL LOW PASS FILTER
USING AMORPHOUS SiO₂ INTERMEDIATE LAYERS 25**
B. Ma, H. Kuwae, A. Okada, W. Fu, S. Shoji, and J. Mizuno
Waseda University, JAPAN

We proposed a novel single crystal quartz direct bonding method using amorphous SiO₂ layer for optical low pass filter (OLPF) to improve heat resistance compared with conventional OLPFs using UV-curing adhesive. The amorphous layer shows lower activation energy which is appropriate for HF bonding. It realizes high strength than single crystal quartz substrates sample and about nearly 100% transmittance as the same level of UV-curing adhesive sample.

- 11:50 HIGH ASPECT-RATIO 3D MICROSTRUCTURES VIA NEAR-FIELD
ELECTROSPINNING FOR ENERGY STORAGE APPLICATIONS 29**
G. Luo^{1,2}, K.S. Teh^{2,3}, X. Zang², D. Wu^{2,4}, Z. Wen¹, and L. Lin²
¹Chongqing University, CHINA, ²University of California, Berkeley, USA,
³San Francisco State University, USA, and ⁴Xiamen University, CHINA

We develop a direct-write, self-aligned 3D electrospinning on paper collector. This process enables design and fabrication of arbitrary, high-aspect-ratio 3D microstructures with controllable manner via consistent fiber-by-fiber stacking. As such, this technique is anticipated to open up a new class of polymer fabrication process to construct 3D microstructures for various applications.

- 12:05 Lunch & Exhibit Inspection**

13:05 Poster/Oral Session I

Poster presentations are listed by topic category with their assigned number starting on page 16.

15:05 Break & Exhibit Inspection

Session III - PowerMEMS

15:35 **LOW-FREQUENCY AND ULTRA-WIDEBAND MEMS ELECTROSTATIC VIBRATION ENERGY HARVESTER POWERING AN AUTONOMOUS WIRELESS TEMPERATURE SENSOR NODE** 33

Y. Lu¹, F. Cottone^{1,2}, S. Boisseau³, F. Marty¹, D. Galayko⁴, and P. Basset¹

¹Université Paris-Est, FRANCE, ²University of Perugia, ITALY,

³CEA-LETI, FRANCE, and ⁴UPMC-Sorbonne Université, FRANCE

We report for the first time a 1-cm× ultra-wideband MEMS electrostatic vibration energy harvester (e-VEH) that combines a frequency-up conversion system with a vertical electret layer obtained by corona discharge. At 2.0 g RMS, the device could harvest more than 1 μW from 59 to 148 Hz, and more than 0.5 μW from 14 to 152 Hz. Thanks to this new device, we demonstrate the self-starting of an energy autonomous temperature sensor node with a data transmission beyond a distance of 10 m at 868 MHz.

15:50 **LIQUID-CRYSTAL-ENHANCED ELECTROSTATIC VIBRATION GENERATOR** 37

K. Kittipaisalsilpa, T. Kato, and Y. Suzuki

University of Tokyo, JAPAN

We propose a liquid-crystal-enhanced electrostatic/electret vibration generator, which can generate two-orders-of-magnitude higher power than conventional generators with an air-filled gap. By using nematic liquid crystals, 440 μW output power from 10 Hz and 1 mmp-p vibration has been demonstrated. It is also shown that the enhancement of the power output is deteriorated at higher temperature than the phase transition temperature, showing that the anisotropy permittivity plays the dominant role.

16:05 **HYBRID ENERGY HARVESTER BASED ON PIEZOELECTRIC AND TRIBOELECTRIC EFFECTS** 41

J. Park and K.-S. Yun

Sogang University, SOUTH KOREA

We develop an energy harvesting device which uses triboelectric and piezoelectric effect at the same time to harvest the mechanical energy. The vertical force is converted into lateral force through the hinge structure to maximize the stress applied on woven piezoelectric structures. Also the nano-structured metal and PDMS film was formed to enhance the triboelectric effect during the operation. The output voltage can be simultaneously obtained from the triboelectric and piezoelectric effects.

16:20 **A FLEXIBLE, FOLDABLE, TUBULAR μDMFC FOR POWERING WRIST BANDS** 43

Z. Wu¹, X. Wang^{1,2}, X. Kuang¹, and L. Liu¹

¹Tsinghua University, CHINA and ²Chinese Academy of Sciences

This paper reports a flexible tubular passive μDMFC for powering wrist bands at the first time. The tubular μDMFC, featured by flexible electrodes and foldable whole structure, shows excellent power density and long-term performance compared to batteries. It is believed that this μDMFC is applicable to serve as the power unit for wrist bands (typically 1-20mW) or even other wearable devices.

Session IV - Resonators I

16:35 **OVERCOMING STICTION FORCES WITH RESONANT OVER-TRAVEL STOPS** 47

V.A. Hong, D.B. Heinz, D.L. Christensen, D.D. Shin, Y. Chen, C.H. Ahn, Y. Yang,

E.J. Ng, I.B. Flader, and T.W. Kenny

Stanford University, USA

This work reports over-travel stops actively driven into resonance to help overcome stiction forces between contacting silicon surfaces. We show that effective adhesion forces are decreased by over 60% compared to cases with static bump stops. Furthermore, by monitoring shift in resonant frequency during contact, we present a novel way to precisely determine adhesion forces, even within fully encapsulated devices, where other measurement methods are unavailable.

**16:50 SOFT-IMPACTING MICROMECHANICAL RESOSWITCH
ZERO-QUIESCENT POWER AM RECEIVER 51**

R. Liu, J.N. Nilchi, W.-C. Li, and C.T.-C. Nguyen
University of California, Berkeley, USA

A micromechanical resonant switch-based envelope detector employing a soft-impact cantilever output electrode to affect a linear input amplitude-to-output level gain has successfully received, filtered, amplified, and demodulated an input AM signal over a 63-kHz carrier, effectively demonstrating a zero-quiescent power AM receiver.

**17:05 A MULTIMODE SINGLE-CHIP SCANNING PROBE MICROSCOPE FOR
SIMULTANEOUS TOPOGRAPHICAL AND THERMAL METROLOGY
AT THE NANOMETER SCALE 55**

N. Sarkar^{1,2}, G. Lee^{1,2}, D. Strathearn^{1,2}, M. Olfat^{1,2}, and R.R. Mansour^{1,2}
¹*University of Waterloo, CANADA and* ²*ICSPI Corp., CANADA*

This paper reports the first single-chip scanning probe microscope that simultaneously performs atomic force microscopy and scanning thermal microscopy without requiring any off-chip scanning or sensing hardware. A thermal-piezoresistive resonant sensor holds the tip-sample interaction force constant, while a bolometer-style probe measures local heat transfer effects. The instrument obtains local thermal measurements of powered electrothermal MEMS devices and can pattern heat-sensitive media.

**17:20 ALL-ELECTRICAL READOUT OF ATOMICALLY THIN MoS₂
NANOELECTROMECHANICAL RESONATORS IN THE VHF BAND 59**

R. Yang, Z. Wang, and P.X.-L. Feng
Case Western Reserve University, USA

We demonstrate the first single-, bi-, and tri-layer molybdenum disulfide (MoS₂) nanoelectromechanical resonators with all-electrical signal transduction. These atomically thin MoS₂ membranes, suspended on circular microtrenches, form vibrating-channel transistors (VCTs). The devices are measured using down-mixing techniques with frequency modulation (FM), showing resonance in the very high frequency (VHF) band, Q up to 300, plus clear tunability of resonance by varying gate voltage.

**17:35 HIGH PERFORMANCE POLYSILICON NEMS FABRICATED
AT LOW TEMPERATURE WITH UV LASER ANNEALING 63**

I. Ouerghi¹, M. Sansa¹, L. Duraffourg¹, K. Benedetto¹, P. Besombes¹, K. Huet²,
F. Mazzamuto², I. Toque-Tresonne², C. Ladner¹, S. Kerdiles¹, W. Ludurczak¹, and T. Ernst¹
¹*CEA-LETI, FRANCE and* ²*SCREEN-LASSE, FRANCE*

We present for the first time poly-Silicon nanowire based NEMS resonators fabricated at very low temperature (300°C max) and recrystallized with a 308nm excimer laser for low cost co-integrated mass sensors on CMOS. Poly-Si NEMS performances have been compared to crystalline silicon NEMS and most important resonator's figure of merit have been extracted. Within an excellent fabrication yield, the stability measurements of poly-Si NEMS lead to a mass resolution detection down to hundred zg.

17:50 Adjourn for the Day

Tuesday, 26 January

Invited Plenary Speaker II

- 08:30 BRINGING A MEMS STARTUP TO SUCCESS FROM LAB TO MARKET, WITH A FABLESS BUSINESS MODEL 67**
Nicolas Abelé, F. Khechana, L. Kilcher, and M. Boella
Lemoptix SA, SWITZERLAND

Session V - Actuators

- 09:15 A LARGE RANGE MICRO-XZ-STAGE WITH MONOLITHIC INTEGRATION OF ELECTROTHERMAL BIMORPH ACTUATORS AND ELECTROSTATIC COMB DRIVES 71**
X. Zhang, L. Zhou, and H. Xie
University of Florida, USA

This paper reports a micro-XZ-stage achieved by monolithic integration of large-vertical-displacement electrothermal bimorph actuators and large-lateral-displacement electrostatic comb drives for the first time. The integration is enabled by a unique release process that can simultaneously achieve high-aspect-ratio silicon comb drives and complete silicon removal underneath bimorphs. The fabricated device achieved over 40µm in-plane and 100µm out-of-plane quasi-static displacements.

- 09:30 A PIVOT-HINGED, MULTILAYER SU-8 MICRO MOTION AMPLIFIER ASSEMBLED BY A SELF-ALIGNED APPROACH 75**
X. Xie and C. Livermore
Northeastern University, USA

We demonstrate the design, fabrication and characterization of an out-of-plane micro tactile actuator that employs pivot hinges fabricated by a multilayer self-aligned approach to deliver high force and large displacement. A piezoelectric extensional actuator vibrates in plane, and a micro motion amplifier converts the in-plane vibrations to larger out-of-plane vibrations. The system uses a pivot-hinged structure to apply a combination of shear and indentation forces to the users' fingertips.

- 09:45 INTEGRATED SMA-BASED NEMS ACTUATOR FOR OPTICAL SWITCHING 79**
F. Lambrecht¹, I. Aseguinolaza², V. Chernenko^{2,3}, and M. Kohl¹
¹Karlsruhe Institute of Technology (KIT), GERMANY, ²University of the Basque Country, SPAIN, and ³Ikerbasque, Basque Foundation of Science, SPAIN

We develop and demonstrate a integrated NEMS actuator based on a shape memory alloy (SMA)-silicon-bimorph cantilever for control of optical transmission in a tapered silicon waveguide. A new process flow is resented with critical dimensions of 50 nm and footprint in the order of 1 µm². In-situ measurements reveal out-of-plane actuator deflections of 100 nm at about 140 µW. For decreasing gap size between actuator and waveguide to 50 nm, optical transmission is reduced by about 8 dB.

- 10:00 SMART SELF-CLEANING COVER GLASS FOR AUTOMOTIVE MINIATURE CAMERAS 83**
K.Y. Lee¹, J. Hong², D.S. Jang¹, S.J. Hong¹, S.J. Le², and S.K. Chung¹
¹Myongji University, SOUTH KOREA and ²Pohang University of Science and Technology (POSTECH), SOUTH KOREA

This paper firstly presents a smart self-cleaning cover glass based on electrowetting-on-dielectric (EWOD) actuation for miniature cameras. It can remove water droplets in a wide range of sizes to allow the camera's lens to get clean at any time. The proposed cover glass offers a simple design structure to be easily installed on any device but provides a fast and energy efficient droplet cleaning operation.

- 10:15 Break & Exhibit Inspection**

Session VI - Resonators II

- 10:45** **A HIGH-SENSITIVE RESONANT ELECTROMETER BASED ON MODE LOCALIZATION OF THE WEAKLY COUPLED RESONATORS** 87
H. Zhang, W. Yuan, J. Huang, B. Li, and H. Chang
Northwestern Polytechnical University, CHINA

We reported a high-sensitive MEMS electrometer based on mode localization of two weakly coupled resonators (WCRs). The sensitivity based on the amplitude ratio is 663751ppm with a charge input of 144fC, which is ~2341 times higher than that of the frequency (283ppm). A mechanically coupled 2DoF WCRs with ultra-low coupling factor (0.000976) is developed, and four tune electrodes are added to set the appropriate initial working conditions by compensating the stiffness disorder of the WCRs.

- 11:00** **OVENIZED DUAL-MODE CLOCK (ODMC) BASED ON HIGHLY DOPED SINGLE CRYSTAL SILICON RESONATORS** 91
Y. Chen, E.J. Ng, D.D. Shin, C.H. Ahn, Y. Yang, I.B. Flader, V.A. Hong, and T.W. Kenny
Stanford University, USA

This work demonstrates the ovenization of a fully-encapsulated dual-mode silicon MEMS resonator. We maintain a localized, elevated operating temperature by utilizing the TCF difference between two modes excited on the same resonant body as a thermometer, and a micro-oven integrated in the encapsulation layer. Preliminary results of real-time compensation demonstrate a stability of ± 250 ppb of the Lamé-mode frequency over -20~80°C.

- 11:15** **AMPLITUDE MOTION STABILIZATION IN DRIVE RESONATORS LIMITED BY AN AUTOMATIC FEATHER CONTACT MECHANISM** 95
F. Giacci, A. Bianchi, S. Dellea, A.F. Longoni, and G. Langfelder
Politecnico di Milano, ITALY

The work introduces amplitude control in MEMS resonators based on a first mechanical collision of anti-phase driven frames, and on a consecutive self-adaptation of the frames motion, that at every cycle skim over one another. This feather contact (FC) method is applied on a gyroscope with a 3.2 μ m FC amplitude. Results show motion amplitude immunity to equivalent resistance variations superior to any amplitude-gain-control circuit. The rate sensitivity in the FC regime is similarly stable.

- 11:30** **LOW POWER DAMPING CONTROL OF A RESONANT SENSOR USING BACK ACTION IN SILICON NANOWIRES** 99
G. Lehee^{1,2}, F. Souchon^{3,4}, J.-C. Riou¹, A. Bosseboeuf², and G. Jourdan^{3,4}
¹*SAGEM Defense Security, FRANCE*, ²*Université Paris-Sud, FRANCE*,
³*University Grenoble Alpes, FRANCE*, and ⁴*CEA-LETI, FRANCE*

We report the damping control of a MEMS resonator, vibrating at several kilohertz, using P-doped silicon nanowires, due to thermal piezoresistive back action induced by current biasing. Quality Factor can be finely controlled for current as low as a few tens μ A, which leads to very low power consumption at constant voltage generator circuitry. The proposed mechanism allows bandwidth tuning and temperature compensation of the quality factor.

- 11:45** **OFF-RESONANCE OPERATION OF A MEMS LORENTZ FORCE MAGNETOMETER WITH IMPROVED THERMAL STABILITY OF THE SCALE FACTOR** 103
S. Sonmezoglu and D.A. Horsley
University of California, Davis, USA

We report a new method for improving thermal stability of the scale factor in resonator-based micromachined Lorentz force magnetometers. This method significantly reduces the effect of the resonator's temperature coefficient of frequency (TCF) on the output by using two nominally-identical magnetometers, improving the sensor's temperature coefficient from 12177 ppm/°C to 508 ppm/°C in a temperature range of 10-60°C.

- 12:00** **MEMS 2017 Announcement**

- 12:15** **Lunch & Exhibit Inspection**

- 13:15** **Poster/Oral Session II**

Poster presentations are listed by topic category with their assigned number starting on page 16.

Session VII - Acoustics

15:45 **MONOLITHIC 591×438 DPI ULTRASONIC FINGERPRINT SENSOR** 107

X. Jiang¹, H.-Y. Tang¹, Y. Lu², X. Li¹, J.M. Tsai³, E.J. Ng³, M.J. Daneman³,
M. Lim³, F. Assaderaghi³, B.E. Boser¹, and D.A. Horsley²

¹University of California, Berkeley, USA, ²University of California, Davis, USA, and
³Invensense Inc., USA

Achieving 591×438 dpi piezoelectric micromachined ultrasonic transducer (PMUT) arrays requires a dramatic reduction in the PMUT size to < 50µm, risking acoustic output and fill-factor. This paper presents a systematic design study of individual and array parameters, leading to a 51.7% fill factor, 110×56 PMUT array composed of 30×43µm rectangular PMUTs demonstrating 2 µV/Pa sensitivity, 19 kPa pressure output, 75µm lateral resolution, and 150µm axial resolution in a 4.6 mm × 3.2 mm image.

16:00 **ARRAYING SH0 LITHIUM NIOBATE LATERALLY VIBRATING RESONATORS FOR MITIGATION OF HIGHER ORDER SPURIOUS MODES** 111

Y.-H. Song and S. Gong

University of Illinois, Urbana-Champaign, USA

This paper studies the origin and mitigation of higher-order spurious modes in shear horizontal (SH0) mode Lithium Nio-bate (LN) laterally vibrating resonators (LVRs). By simply using an array of single resonators with only two electrodes, an unprecedented spectral range (230 % centered about the resonance) of spurious-free response and a high figure of merit (FoM) of 154 have been achieved concurrently, thus further advancing LN LVR technology toward the wireless market-place.

16:15 **MONOLITHIC MEMS-CMOS ULTRASONIC RANGEFINDER BASED ON DUAL-ELECTRODE PMUTS** 115

O. Rozen¹, S.T. Block¹, X. Mo¹, W. Bland¹, P. Hurst¹, J.M. Tsai², M. Daneman²,
R. Amirtharajah¹, and D.A. Horsley¹

¹University of California, Davis, USA and ²InvenSense Inc., USA

A monolithic MEMS-CMOS rangefinder using piezoelectric micromachined ultrasonic transducers (PMUT) is presented. A dual-electrode PMUT design is used where the center electrode is driven externally to transmit an ultrasound pulse and the outer ring electrode is used to sense the returning echoes. The devices were fabricated by wafer-scale eutectic bonding of a CMOS signal processing ASIC to the PMUT. The ASIC provides each PMUT with a dedicated receiver, resulting in low parasitics and noise.

16:30 **ERADICATION OF ASYMMETRIC SPURIOUS MODES IN ALN MEMS RESONATORS USING MODE CONVERSION** 119

A. Gao, Y. Yang, and S. Gong

University of Illinois, Urbana-Champaign, USA

We report on a spurious mode suppression technique that converts the asymmetrical (A0) mode to the intended symmetrical (S0) mode vibrations by installing a notch in the resonator body for lamb wave AlN MEMS resonators. The technique has been experimentally validated to simultaneously eradicate the A0 spurious mode and enhance the S0 mode electromechanical coupling (kt²) for the monolithically integrated resonators over a wide frequency range (100–600 MHz).

16:45 **FREQUENCY-TUNABLE CURRENT-ASSISTED AlGaIn/GaN ACOUSTIC RESONATORS** 123

A. Ansari and M. Rais-Zadeh

University of Michigan, USA

This work reports on frequency tunable AlGaIn/GaN acoustic resonators that utilize piezo-resistive readout based on forward-biased Schottky electrodes, and integrated AlGaIn/GaN HEMTs. Wide-range frequency tuning is achieved by flowing DC current through the contacts, causing large elastic modulus change due to Joule heating. Such devices can be used as in-situ temperature sensors where the resonance frequency shift is an indicator of the temperature rise in the suspended HEMT channel.

17:00 **SILICON ACOUSTIC WAVEGUIDE BASED ON LOCALLY RESONANT PHONONIC CRYSTAL** 127

D. Feng^{1,2}, W.L. Jiang^{1,2}, D.H. Xu¹, B. Xiong¹, and Y.L. Wang¹

¹Chinese Academy of Sciences, CHINA and

²University of the Chinese Academy of Sciences, CHINA

This paper demonstrates a silicon acoustic waveguide with locally resonant phononic crystal. The experiment result vividly shows the response of the acoustic waveguide under different frequency excitation, which shows that the locally resonant phononic crystal could effectively control the propagation of elastic waves in the waveguide with frequency in the bandgap range.

17:15	CFRP MONITORING METHOD WITH PIEZORESISTIVE BEAMS	131
	N. Matsuda, N. Minh Dung, T. Takahata, K. Matsumoto, and I. Shimoyama <i>University of Tokyo, JAPAN</i>	

In this study we present an approach for carbon fiber reinforced polymer (CFRP) monitoring, using miniature embedded piezoresistive sensors. The sensor includes several piezoresistive beams that enable it to measure both 3D stresses and Acoustic Emissions (AE). The sensor is tiny such that we can embed it within a 1.6 mm-thick CFRP sheet without any damages. Experiment demonstrates that 3-D stresses and AE could be measured at the same time using our proposed method.

Session VIII - Microfluidics I

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	P. Kundu, S.-Y. Liu, F.-R. Chen, and F.-G. Tseng <i>National Tsing Hua University, TAIWAN</i>	

For the first time, using wet cell in a liquid environmental transmission electron microscopy (LETEM), we have successfully generated highly stable oxygen nanobubbles with diameter 5~7 nm by decomposition of 0.02% H₂O₂ on Pt/CNT nanocomposite. The nucleation, growth and stability of those nanobubbles have been characterized. Along with this, we also have studied the variation of the internal pressure with average radius of stable nanobubbles with respect to time

17:45	ELECTRIC INSTABILITY OF CASSIE DROPLETS ON SUPER-LYOPHOBIC PILLAR SURFACE: PULL-IN VERSUS ELECTROWETTING	137
	Y.-C. Chen, K. Morimoto, and Y. Suzuki <i>University of Tokyo, JAPAN</i>	

We present for the first time the modeling and experimental efforts to investigate the electric instability modes of the Cassie droplets on super-lyophobic surface. The shape of the liquid-air interface on overhanging pillar structure has been directly captured with laser displacement meter. We show a geometry-dependent boundary curve identifying the two competing modes, i.e. pull-in and electrowetting-dominated collapsing modes, which has been verified through experiments.

18:00	ALL-ROUND MICRO SHEATH FLOW FORMATION TO REALIZE COMPLEX CROSS SECTIONS BY SIMPLY STACKED PDMS STRUCTURES	141
	D.H. Yoon, L. Ariyoshi, D. Tanaka, T. Sekiguchi, and S. Shoji <i>Waseda University, JAPAN</i>	

This research proposed a sheath flow formation method for complex 3D structure such as multi-core and multi-sheath using multi-stacked PDMS units. Cross sectional shape of the flow and the number of sheath layer were defined simply by combination of different PDMS units. The stacked PDMS units allowed independent fluid injection of different layers and the short sheath area realized low diffusion between each layer.

18:15 Adjourn for the Day

Wednesday, 27 January

Invited Plenary Speaker III

- 08:30** **PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS
IN CONSUMER ELECTRONICS: THE NEXT LITTLE THING?** 145
David A. Horsley^{1,2}, R.J. Przybyla¹, M.H. Kline¹, S.E. Shelton¹, A. Guedes¹,
O. Izyumin¹, and B.E. Boser³
¹Chirp Microsystems, USA, ²University of California, Davis, USA, and
³University of California, Berkeley, USA

Session IX - Medical Microsystems

- 09:15** **AN ORIGAMI-INSPIRED ULTRASTRETCHABLE
BIOPROBE FILM DEVICE** 149
Y. Morikawa, S. Yamagiwa, H. Sawahata, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

We report an ultrastretchable and flexible bioprobe film device, which enables to follow spherical-shaped deformable biological tissue. As the film material, we use biocompatible parylene-film, which shows the stretchability of 1,100% by embedding slits, so called 'Amanogawa' design in Origami (or Kirigami). In addition, we demonstrate in vivo electrocardiogram (ECoG) recordings from mouse cortex, indicating the recording capability of the electrodes while the film stretches.

- 09:30** **A MICROFABRICATED NEURAL PROBE WITH POROUS-SI-PARYLENE
HYBRID STRUCTURE TO ENABLE A RELIABLE
BRAIN-MACHINE INTERFACE** 153
T. Sun¹, S. Merugu¹, W.M. Tsang^{1,2}, W.-T. Park^{1,3}, N. Xue¹, W.-T. Park^{1,3},
Y. Liu¹, B. Han¹, G. Dawe⁴, and A.Y. Gu¹
¹Agency for Science, Technology and Research (A*STAR), SINGAPORE, ²Hong Kong Applied
Science and Technology Research Institute (ASTRI), HONG KONG, ³Seoul National University of
Science and Technology, SOUTH KOREA, and ⁴National University of Singapore, SINGAPORE

We develop a multifunctional porous silicon-parylene neural probe using a CMOS compatible fabrication process. The biodegradable PSi shank serves as a mechanical stiffener for insertion process then dissolves to leave only the polymeric structure to reduce stiffness mismatch, thus attenuates tissue responses. Moreover, the porous structure of PSi can serve as drug reservoir. The healing of the insertion trauma can be enhanced by continuously releasing pre-loaded drugs during PSi degradation.

- 09:45** **STIFFNESS-INDEX MAP BASED ON SINGLE CELL-SPHEROID
ANALYSIS USING ROBOT INTEGRATED MICROFLUIDIC CHIP** 157
K. Ito¹, S. Sakuma¹, M. Kimura², T. Takebe², M. Kaneko³, and F. Arai¹
¹Nagoya University, JAPAN, ²Yokohama City University, JAPAN, and ³Osaka University, JAPAN

We present a method which can evaluate stiffness of cell-spheroids. To obtain the stiffness-index map which shows the relationship between the size and stiffness of cell-spheroids, we applied a robot integrated microfluidic chip (robochip). The robochip has a microchannel and a pair of on-chip probes which contains a force sensor. The stiffness-index of the single spheroid is evaluated from the reactive force. The results shows that the index increased along the culture days.

- 10:00** **A STEERABLE SMART CATHETER TIP REALIZED BY
FLEXIBLE HYDROGEL ACTUATOR** 161
M. Selvaraj and K. Takahata
University of British Columbia, CANADA

This paper reports a smart catheter tip realized by integrating a thermoresponsive hydrogel on a flexible strip of MEMS heater. Activation of the heater stimulates the hydrogel to actuate the flexible tip, providing controlled steerability for a wide range of navigation angles. The prototypes fabricated using low-cost flex-circuit technology are demonstrated to show good temporal response with significantly larger bending angles of up to 130 degrees compared with other reported active catheters.

- 10:15** **Break & Exhibit Inspection**

Session X - Pressure Sensors I

- 10:45 MEASUREMENT OF JUMPING FORCE OF A FRUIT FLY USING A MESA STRUCTURED FORCE PLATE 165**
R. Furuya, H. Takahashi, N. Thanh Vinh, T. Yano, K. Ito, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on a mesa structured force plate for measurement of jumping force of a fruit fly. Using the fabricated force plate, the jumping force was measured when a fruit fly took off from the plate surface. The maximum value of the jumping force is approximately 7 times larger than the weight of the fruit fly. Additionally, the result shows that the legs generated a half of total impulse which supports jumping motion.

- 11:00 TUNNELING PIEZORESISTIVE TACTILE SENSING ARRAY FOR CONTINUOUS BLOOD PRESSURE MONITORING 169**
C.-M. Chang, F.-W. Lee, Y.-H. Lin, and Y.-J. Yang
National Taiwan University, TAIWAN

This work presents a highly sensitive tunneling piezoresistive tactile sensing array for continuous blood pressure monitoring. The polymer-based sensing device was patterned with microdome structures by using membrane filter substrates. Based on the tonometric method, blood pressure can be estimated from the measured pulse pressure signals. The sensing array is arranged in 8×1 linear configuration with tiny gaps between sensing elements, which substantially enhances the acquisition of signals.

- 11:15 ULTRA-SENSITIVE TRANSPARENT AND STRETCHABLE PRESSURE SENSOR WITH SINGLE ELECTRODE 173**
J. Zhang, M. Shi, H. Chen, M. Han, Y. Song, X. Cheng, and H. Zhang
Peking University, CHINA

This paper reports a novel pressure sensor with single electrode PDMS-PEDOT-Parylene 3-layers structure, which is not only super thin, but also transparent and stretchable, therefore, it could work as part of electronic skins or wearable devices. Based on the sensitive deformation of the microstructure when external pressure applied, it reaches the high sensitivity of 14.15 /kPa and excellent linearity in the low pressure regime, and distinguishes a pressure about 0.212 Pa for the first time.

- 11:30 PRESSURE DISTRIBUTION ON THE CONTACT AREA DURING THE IMPACT OF A DROPLET ON A TEXTURED SURFACE 177**
N. Thanh-Vinh, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We directly measure the pressure distribution on the contact area during the impact of a droplet on a micropillar array. We show that immediately after the droplet hits the surface, the pressure becomes maximum in the center of the contact area and this maximum pressure value is more than twice larger than the dynamic pressure. We demonstrate that the critical value of pressure which causes the Cassie-Wenzel transition agrees well with the maximum capillary pressure of the micropillar array.

- 11:45 IEEE Daniel E. Noble Award for Emerging Technologies Recipient**
Mark G. Allen, Ph.D.
University of Pennsylvania, USA

- 12:00 IEEE Electron Devices Society Robert Bosch Micro and Nano Electro Mechanical Systems Award Recipient**
Henry Baltes, Ph.D.
ETH Zürich, SWITZERLAND

- 12:15 Lunch & Exhibit Inspection**

- 13:00 Poster/Oral Session III**
Poster presentations are listed by topic category with their assigned number starting on page 16.

- 15:00 Break & Exhibit Inspection**

Session XIa - Microfluidics II

- 15:30 IN-LINE DNA PRECONCENTRATION, SIZE SEPARATION, AND SINGLE MOLECULE DETECTION WITHOUT APPLIED ELECTRIC FIELDS 181**
S.M. Friedrich¹, J.M. Burke², K.J. Liu², and T.-H. Wang¹
¹*Johns Hopkins University, USA and* ²*Circulomics, Inc., USA*

We report an in-line microfluidic preconcentration method that does not require electrodes or an externally applied electric field. We demonstrate that this method, that we call Flow Enhanced Diffusiophoretic Concentration (FEDC), is stable for long time spans and can achieve concentration factors exceeding 3 orders of magnitude. We then couple FEDC with Single Molecule Free Solution Hydrodynamic Separation to achieve in-line, electric field free DNA concentration with size-based separation.

- 15:45 NANO-PYRAMID ARRAYS FOR NANO-PARTICLE TRAPPING 185**
X. Sun, H.-W. Veltkamp, E.J.W. Berenschot, H.J.G.E. Gardeniers, and N.R. Tas
MESA+, University of Twente, THE NETHERLANDS

In this paper, sub-micrometer and relatively open pyramidal cages composed of silicon nitride nanowires were fabricated by corner lithography. The cages are placed in an array on a perforated membrane. To check the particle trapping ability of the cages, aqueous gold nanoparticle suspensions with mean diameter of 150nm were filtered by the device. Gold nanoparticle trapping and electron microscope imaging was demonstrated.

- 16:00 LOW-COST TEMPERATURE-COMPENSATED THERMORESISTIVE MICRO CALORIMETRIC FLOW SENSOR BY USING 0.35 μ m CMOS MEMS TECHNOLOGY 189**
W. Xu¹, B. Gao^{1,2}, S. Ma^{1,2}, A. Zhang², Y. Chiu³, and Y.-K. Lee¹
¹*Hong Kong University of Science and Technology, HONG KONG,*
²*Xi'an Jiaotong University, CHINA, and* ³*National Chiao Tung University, TAIWAN*

We report a low-cost Temperature-Compensated Thermoresistive Micro Calorimetric Flow (T2MCF) Sensor by using 0.35 μ m CMOS MEMS technology. The fabricated sensor can achieve a normalized sensitivity of 230 mV/(m/s)/mW with respect to the input heating power, two orders of magnitude better than the previous thermal flow sensors, and excellent low-drift output with maximum normalized variation of 0.5%, compared to the counterpart (49%).

- 16:15 TOWARDS NANOGRAM PER SECOND CORIOLIS MASS FLOW SENSING 193**
J. Groenesteijn¹, R.G.P. Sanders¹, R.J. Wiegerink¹, and J.C. Lötters^{1,2}
¹*MESA+, University of Twente, THE NETHERLANDS and*
²*Bronkhorst High-Tech BV, THE NETHERLANDS*

We have designed, fabricated and tested a micromachined Coriolis flow sensor which can measure up to 50 μ g/s at a maximum pressure drop of 1bar with a zero stability of 14ng/s, an improvement by a factor 40 compared to current state of the art Coriolis flow sensors. With this resolution the sensor can replace thermal flow sensors in many applications, giving the benefit of medium independent mass flow measurement and in addition a measure for the density of the medium.

Session XIb - Fabrication & Materials II

- 15:30 NON-SPHERICAL LIPOSOME FORMATION USING 3D-LASER-PRINTED MICRO-CUBE STRUCTURES 197**
K. Inoue^{1,3}, K. Kamiya^{1,4}, T. Osaki^{1,2}, N. Miki^{1,3}, and S. Takeuchi^{1,2}
¹*Kanagawa Academy of Science and Technology, JAPAN,*
²*University of Tokyo, JAPAN,*
³*Keio University, JAPAN, and*
⁴*Japan Science and Technology Agency (JST), JAPAN*

We developed a construction of non-spherical liposomes by encapsulating 3-D microstructures which emulates cytoskeleton proteins into biological cells. First, we fabricated micro-cubic frames with 3D-laser-printed photoresists. Next, we formed lipid bilayer membrane (BLM) on the faces of these microstructures in a microfluidic channel. We confirmed BLM formation by reconstituting membrane protein α HL. We successfully formed non-sphere liposomes with artificial cytoskeleton.

- 15:45 VIBRATION-TRIGGERED SELF-ASSEMBLY OF CAGED DROPLETS TO CONSTRUCT A DROPLET INTERFACE BILAYER NETWORK 200**
H. Yasuga¹, T. Osaki¹, K. Kamiya¹, R. Kawano¹, N. Miki^{1,2}, and S. Takeuchi¹
¹University of Tokyo, JAPAN, ²Keio University, JAPAN, and
³Tokyo University of Agriculture and Technology, JAPAN

We propose a novel self-assembly method of a droplet interface bilayer (DIB) network accomplished by combining three factors: mechanically supported droplets of Droplet-box (DB), multi-geometric DB tessellation, and vibration-triggered alignment. In this work, geometries of the DB were square, hexagon and octagon and tessellation of them generated designed DIB network patterns. Vibration triggered sliding of DBs and secured the complete contact for DIB formation by capillary force.

- 16:00 PATTERNED SOFT-MICROPOLYHEDRA BY SELF-FOLDING AND MOLDING 203**
S. Pandey, C. Yoon, Z. Zhang, H.R. Kwag, J. Hong, and D.H. Gracias
Johns Hopkins University, USA

It is extremely challenging to mass-produce polymeric microstructures with patterns in all three dimensions. We describe a strategy to create metal inverse molds using self-folding and utilize them to mold polyhedra with a range of polymers and even cell-laden hydrogels. We highlight applications of these polyhedra in drug delivery, self-assembly and tissue engineering.

- 16:15 MICROFLUIDIC FABRICATION OF HYDROGEL-FIBER-BASED 3D CONSTRUCTS UTILIZING LIQUID ROPE-COIL EFFECT 207**
M. Nie¹ and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

We report a series of microfluidic fabrication techniques based on liquid rope-coil effect. Ca-alginate micro fiber (diameter ~70 μm) based sub-millimeter (such as springs, grooved tubes) or macro (such as hollow coils, super-coils) 3D constructs can be fabricated using different experimental setups. Due to its compatibility with cell encapsulation methods, this technique provides an option for rapid generation of macro/sub-macro constructs for bottom-up tissue engineering applications.

Session XIIa - Pressure Sensors II

- 16:30 ACHIEVING CLINICALLY VIABLE 12-CM READOUT DISTANCE FROM MICROMACHINED IMPLANTABLE INTRAOCULAR PRESSURE SENSOR USING A STANDARD CLINICAL SLIT LAMP 210**
J.O. Lee¹, H. Park¹, O. Chen¹, A. Balakrishna¹, J. Du², D.W. Sretavan², and H. Choo¹
¹California Institute of Technology, USA and
²University of California, San Francisco, USA

We have demonstrated the remote optical readout of intraocular pressure (IOP) at an unprecedented distance of 12 cm. Our redesigned micromachined IOP sensor was implanted in an ex-vivo rabbit eye, and we used the Zeiss SL-30 slit lamp, a standard ophthalmic scope widely used by clinicians, as a readout system. This substantial improvement, a significant increase in readout distance accomplished using a widely used ophthalmic clinical scope, makes our IOP system a more clinically viable choice.

- 16:45 A NOVEL TUB (THIN-FILM UNDER BULK) PROCESS FOR HIGH-PERFORMANCE PRESSURE SENSORS OF SUB-KPA MEASURE-RANGE 214**
H. Zou^{1,2}, J. Wang¹, and X. Li^{1,2}
¹Chinese Academy of Sciences, CHINA and
²University of the Chinese Academy of Sciences, CHINA

For the first time, the paper reports a process to develop surface-micromachined poly-Si thin-film under bulk-micromachined single-crystalline Si structure to form a TUB (thin-film under bulk) configuration for volume fabricating complex-structured MEMS devices in single-wafer, e.g. ultra-low measure-range differential-pressure sensors.

- 17:00 WIRELESS MAGNETOSTRICTIVE TYPE INDUCTIVE SENSING CMOS-MEMS PRESSURE SENSORS 218**
H.-C. Chang, S.-C. Liao, C.-L. Cheng, J.-H. Wen, H.-S. Hsieh, C.-H. Lai, and W. Fang
National Tsing Hua University, TAIWAN

This study demonstrates wireless magnetostrictive type inductive sensing CMOS-MEMS pressure sensors. Features of this study are: (1) Highly sensitive pressure sensors are realized based on inverse-magnetostrictive sensing principle via CoFeB films; (2) Metal and dielectric layers of CMOS process are employed to form the magnetic coil and pressure diaphragm; (3) Wireless sensing is available by external reading coil. Experiments show sensors with gauge factor ranging 480~1100 are achieved.

- 17:15 A NOVEL PRESSURE SENSOR WITH BUILT-IN OVERPRESSURE PROTECTION UTILIZING THREE-DIMENTIONAL ETCHING AND WAFER-LEVEL STACKING TECHNOLOGY 222**
 T. Tokuda, Y. Seto, and M. Yoneda
Azbil Corporation, JAPAN

We develop a multivariable piezoresistive pressure sensor equipped with a novel structure, utilizing grayscale method, wafer-level Surface Activated Bonding, and a combination technique of Bosch and Non-Bosch process. It enables the sensor to have an effective resistance against overpressures that are 600 times higher than those within the normal range of operation, and take highly accurate measurements of differential pressure and static pressure with one chip.

Session XIIb - Optics II

- 16:30 METAL-DIELECTRIC-METAL PLASMONIC NANOHELMS AS BROAD-COLOR-GAMUT TUNABLE PIXELS FOR VIVID DISPLAY 226**
 J.R. Fan and W.G. Wu
Peking University, CHINA

We report a Au film-coupled-nanohelms structures. They are actually metal-dielectric-metal resonators that can be tailored to excite surface plasmon hybridization and thus map white light to splendid colors. Moreover, the plasmon resonance properties of the helm nanoantennas are significantly dependent upon incident angle of light, also resulting in a broad color tuning. The unique optical functionality of proposed metamaterial structure could be used to engineer vivid color pixel application.

- 16:45 DYNAMIC METASURFACE FOR BROADBAND ELECTROMAGNETIC MODULATOR IN REFLECTION 230**
 P.C. Wu¹, H. Cai², Y.D. Gu², W.M. Zhu¹, W. Zhang¹, Z.C. Yang³, Y.F. Jin³,
 Y.L. Hao³, D.-L. Kwong², D.P. Tsai⁴, and A.-Q. Liu¹
¹Nanyang Technological University, SINGAPORE, ²Agency for Science, Technology and Research (A*STAR), SINGAPORE, ³Peking University, CHINA,
⁴Academia Sinica, TAIWAN, and ⁵National Taiwan University, TAIWAN

This paper presents a first experimental demonstration on Galinstan-based microfluidic metasurface which can be individually controlled for electromagnetic modulator. By combining the microfluidic system with metasurface, both the polarization state and intensity of reflected light can be actively modulated in a wide range of frequency. Such proposed dynamic metasurface is a good candidate for many practical applications such as tunable imaging system and optical components.

- 17:00 FRACTAL ENGINEERED VOIDS FOR NON-RESONANT NANO-PLASMONIC DETECTION OF WEAK MOLECULAR FINGERPRINT AT MID IR 234**
 D. Hasan, J. Wang, and C. Lee
National University of Singapore, SINGAPORE

An approach of using engineered voids towards non resonant, nanoplasmonic, universal detection of weak molecular finger prints at mid IR for biomedical and forensic applications is demonstrated

- 17:15 NANO-OPTOMECHANICAL DISK RESONATORS OPERATING IN LIQUIDS FOR SENSING APPLICATIONS 238**
 E. Gil-Santos¹, C. Baker¹, D.T. Nguyen¹, W. Hease¹, C. Gomez², A. Lemaître²,
 S. Ducci¹, G. Leo¹, and I. Favero¹
¹Université Paris Diderot, FRANCE and ²CNRS, FRANCE

We demonstrate the potential of miniature optomechanical disk resonators operating in liquids as ultrafast and ultrasensitive nanodensimeter, nanoviscosimeter and mass sensors. We develop and validate new numerical and analytical models that describe the fluid-structure interaction of these GHz devices. We also measure the thermomechanical noise spectrum stability of a disk vibrating in water at 1.3 GHz, and estimate the limits of detection in terms of mass deposition, density and viscosity.

17:30 Adjourn for the Day

**19:00 Conference Banquet
 - 22:00**

Thursday, 28 January

Invited Plenary Speaker IV

- 08:30 VISION FOR COMMERCIALIZATION OF MEMS -
A VIEW FROM THE INDUSTRY 242**
Susumu Kaminaga
SPP Technologies Co., Ltd. JAPAN

Session XIII - Inertial Sensors

- 09:15 A SIX-AXIS MICRO PLATFORM FOR IN SITU CALIBRATION
OF MEMS INERTIAL SENSORS 243**
E.E. Aktakka and K. Najafi
University of Michigan, USA

This paper reports an advanced multi-axis micro actuation and sensing platform for in situ self-calibration of generic MEMS inertial sensors. Compared to previously reported platforms, the device provides the best performance at smallest footprint, with six-axis actuation at low power consumption, closed-loop capacitive sensing of applied stimulus, integrated interconnects to an inertial sensor load, and increased shock protection. The entire platform is confined to 9×9 mm².

- 09:30 A MEMS BASED ELECTROCHEMICAL SEISMOMETER
WITH A NOVEL INTEGRATED SENSING UNIT 247**
Z. Sun, D. Chen, J. Chen, T. Deng, G. Li, and J. Wang,
Chinese Academy of Sciences, CHINA

This study developed an integrated fabrication process to fabricate the sensing unit of the electrochemical seismometer on a single silicon wafer to improve the consistency of devices, where the fabrication efficiency of the flow channels and the effective area of electrodes are significantly increased. The maximum 3 dB working bandwidth and the sensitivity of the proposed devices were both better than those of the commercial electrochemical seismometer CME6011.

- 09:45 ULTRA-LOW POWER SELF-COMPUTING BINARY OUTPUT
DIGITAL MEMS ACCELEROMETER 251**
V. Kumar¹, X. Guo¹, R. Jafari², and S. Pourkamali¹
¹University of Texas, Dallas, USA and ²Texas A&M, USA

This work presents the concept and preliminary results for electromechanically self-computing digital MEMS accelerometers with binary output. Such devices require only bias voltages and zero static power for operation without the need for any readout circuitry. The structure comprises of acceleration switches which are coupled to each other via electrostatic actuators and an applied acceleration on the switches generates a binary output. In this work, a 2-bit accelerometer is demonstrated.

- 10:00 RELIABILITY OF GYROSCOPES BASED ON PIEZORESISTIVE
NANO-GAUGES AGAINST SHOCK AND FREE-DROP TESTS 255**
S. Della¹, F. Giacci¹, P. Rey², A. Capodici³, and G. Langfelder¹
¹Politecnico di Milano, ITALY, ²CEA-LETI, FRANCE, and ³ST Microelectronics, ITALY

Piezoresistive sensing through Si gauges of sub-micrometric cross-section represents an alternative to capacitive sensing in MEMS sensors. This work gives reliability data against mechanical shocks and drops for such type of technology. The characterization campaign includes shock tests up to 3500 g and free-drop tests, for 20 gyroscopes based on nano-gauge readout. The results indicate 100% survivability rate to shocks. The rate sensitivity changes after 10 free drops are lower than 0.8%.

- 10:15 Break & Exhibit Inspection**

Session XIV - Cell Cultures

- 10:45** **STRETCHABLE CULTURE DEVICE OF SKIN-EQUIVALENT WITH IMPROVED EPIDERMIS THICKNESS** 259
N. Mori¹, Y. Morimoto^{1,2}, and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

We report a device for culturing skin-equivalent with vascular channels under dynamic stretching. The culture device is composed of a frame made of silicone rubber and resin connections. Owing to the flexibility of silicone rubber, we can apply forces to skin-equivalent in various directions. Moreover, we applied a 1-axial cyclic force to the skin-equivalent during perfusion culture. As a result, we observed a thicker epidermis of the stretched skin-equivalent than that of not-stretched one.

- 11:00** **ANISOTROPIC SPHERICAL COLLAGEN MICROPARTICLES FOR CONFINED 3D CELL CULTURE SYSTEM WITH SPATIALLY DESIGNED MICROENVIRONMENT** 263
S. Yoshida¹, M. Takinoue², and H. Onoe¹
¹Keio University, JAPAN and ²Tokyo Institute of Technology, JAPAN

This study describes anisotropic spherical collagen hydrogel microparticles for confined 3D cell culture system. We fabricated uniform-sized collagen microparticles by ejecting micro-droplets containing collagen pre-gel solution and sodium alginate into calcium chloride solution under high gravity. Using our collagen microparticles, we successfully demonstrated in encapsulating differently labeled cells in each hemisphere and in culturing the cells inside the microparticles.

- 11:15** **A MICROFABRICATED PLATFORM WITH ON-CHIP STRAIN SENSING AND HYDROGEL ARRAYS FOR 3D MECHANICAL STIMULATION OF CELLS** 267
H. Liu, C.A. Simmons, and Y. Sun
University of Toronto, CANADA

Current high-throughput biomaterial screening approaches fail to consider the effects of dynamic mechanical stimulation, despite its importance in regenerative medicine. We report a deformable membrane array enabling both 3D dynamic stretch and real-time stiffness sensing of cell-hydrogel constructs. Human mesenchymal stromal cells embedded in hydrogels and subjected to dynamic mechanical stimulation undergo myofibroblast differentiation and synthesize collagen, leading to gel stiffening.

- 11:30** **QUANTIFICATION OF CONTRACTILE PROPERTY FOR FUNCTIONAL DRUG TESTING WITH HUMAN IPS-DERIVED CARDIOMYOCYTES** 271
Y. Morimoto^{1,2}, S. Mori^{1,2}, F. Sakai^{1,2}, and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

We propose a drug testing system for quantifying contractile properties of human iPS-derived cardiomyocyte tissues. As a result of drug tests using our system, we achieved detection of changes of their contractile properties in accordance with physiological reactions occurring in humans. Thus, we believe that the system will be a useful tool in first-in-human pharmacokinetic studies for drug development.

11:45 **Award Ceremony and Final Remarks**

12:00 **Conference Adjourns**

POSTER/ORAL PRESENTATIONS

M – Monday (13:05 - 15:05) T – Tuesday (13:15 - 15:15)

W – Wednesday (13:00 - 15:00)

Bio and Medical MEMS Biochemical Sensors

- M-001 3D HUMIDITY IMAGER IN MICRO ENVIRONMENT BASED ON DNA CONDUCTIVITY AND RIGIDITY MEASURED BY SILICON NANO TWEEZERS 275**
G. Perret^{1,3}, N. Lafitte¹, M.C. Tarhan¹, L. Jalabert¹, M. Kumemura¹, T. Lacornerie²,
E. Lartigau², F. Cleri³, H. Fujita¹, and D. Collard¹
¹University of Tokyo, JAPAN, ²University of Lille 2, FRANCE, and
³University of Lille1, FRANCE

Novel approach to scan with a high resolution the relative humidity around water in microsized environment. The humidity sensor is composed of a MEMS device, the Silicon Nano Tweezers and a DNA bundle. The measurement principle is based on the relation between the electro-mechanical properties (conductance and stiffness) of DNA bundle and the relative humidity. The system is developed to obtain precisely and automatically the opening center of a microfluidic cavity for self alignment purpose.

- T-002 A HIGHLY SENSITIVE AND SELECTIVE ENZYMATIC GLUCOSE SENSOR BASED ON PLATINUM NANOPARTICLES EMBEDDED WITH ACID TREATED REDUCED GRAPHENE OXIDE 278**
M.F. Hossain and J.Y. Park
Kwangwoon University, SOUTH KOREA

In this work, a highly sensitive and selective electrochemical sensor was newly developed by using acetic acid treated reduced graphene oxide (acRGO) sheet decorated with platinum nanoparticles (PtNP), covalently bonded with enzyme composites, and coated with nafion for effectively urine glucose detection.

- W-003 A NOVEL METHOD FOR INSPECTING RAW MILK QUALITY BY USING DUAL-COIL INDUCTANCE 282**
W. Li, Y. Chiang, and C. Tsou
Feng Chia University, TAIWAN

This paper presents a novel inspection method that uses dual-coil inductance to evaluate raw milk quality. The device contains a silicon-based chip with two coplanar coils, which is fabricated using a simple microelectroplating process. Based on the effect of eddy currents, the somatic cell count of the raw milk can be determined by phase variation. The characteristics of the magnetic inductance for a specified coil design and its sensing performance are evaluated by simulation and experiment.

- M-004 AN APTAMERIC GRAPHENE NANOSENSOR FOR ANALYTE DETECTION IN SERUM 286**
X. Wang^{1,2}, Y. Zhu¹, T.R. Olsen¹, N. Sun³, W. Zhang^{2,4}, R. Pei³, and Q. Lin¹
¹Columbia University, USA, ²East China University of Science and Technology, CHINA, ³Suzhou Institute of Nano-Tech and Nano-Bionics, CHINA, and ⁴University of Saskatchewan, CANADA

This paper presents a graphene field-effect transistor nanosensor that is for the first time serially functionalized with a polyethylene glycol (PEG) nanolayer and an aptamer for specific detection of biomarkers and effective rejection of background molecules in human serum samples for applications to clinical diagnostics.

- T-005 CHEMICAL VAPOR DEPOSITION GROWN GRAPHENE DNA FIELD-EFFECT TRANSISTOR BIOSENSOR WITH GOLD NANOPARTICLES SIGNAL AMPLIFICATION 290**
C.-Y. Chan, F. Yan, and M. Yang
Hong Kong Polytechnic University, HONG KONG

This paper presents a graphene based bio-field-effect transistor (bioFET) for the detection of H7 gene using an extended long capture probe and reporter probe-AuNPs signal amplification. The long capture probe provides a stable non-covalent probe immobilization scheme and the reporter probe-AuNPs amplifies the detection signal. With this setup, our bioFET achieved lower limit of detect (LOD) of 64 fM, which is yet the lowest among other graphene based bioFET for DNA detection.

- W-006 CMOS-COMPATIBLE, GE-SIO₂ CORE-SHELL NANOWIRE FOR LABEL-FREE, HIGHLY SENSITIVE DETECTION OF CANCER BIOMARKER 294**
Q. Cai¹, L. Ye², B. Xu¹, Z. Di², X. Chen², H. Mao¹, Q. Jin¹, and J. Zhao¹
¹Chinese Academy of Sciences, CHINA and ²Bangor University, UK

In this report, arrays of controllable, highly ordered germanium nanowire (GeNW) were fabricated by combining the complementary metal-oxide semiconductor (CMOS) compatible technology and Ge-condensation technique, and the biosensor application in detection of lung cancer biomarker were investigated.

M-007 HIGH SENSITIVITY AND LARGE MEASUREMENT RANGE REFRACTOMETRIC SENSING BASED ON PHOTONICS MACH-ZEHNDER INTERFEROMETER 298

G. Zhang¹, H. Cai², Y.D. Gu², J.F. Song², B. Dong¹, Z.C. Yang³, Y.F. Jin³, Y.L. Hao³, S.P. Sivalingam¹, P.H. Yap¹, D.L. Kwong², and A.Q. Liu¹

¹Nanyang Technological University, SINGAPORE, ²Agency for Science, Technology and Research (A*STAR), SINGAPORE, and ³Peking University, CHINA

An on-chip refractive index sensor with high sensitivity and large measurement range is demonstrated in this paper. It is estimated that the wavelength sensitivity of the device will reach 3129 nm/RIU (TE- mode). Meanwhile, according to the interference pattern period change, the measured period sensitivities are 20.4 nm/RIU (TE- mode) and 78.4 nm/RIU (TM- mode), respectively.

T-008 IMPEDANCE BIOSNESOR FOR RAPID DETECTION OF LOW CONCENTRATION OF *E.COLI* 0157:H7 302

S. Ghosh Dastider¹, S. Barizuddin¹, N. Yuksek¹, M. Dweik², and M. Almasri¹

¹University of Missouri, USA and ²Lincoln University of Missouri, USA

An Impedance biosensor with specially designed focusing and sensing regions was developed for rapid detection of low concentration of E.coli O157:H7. Focusing region, exerts positive DEP forces to concentrate the bacteria towards the center of a microchannel, while the bulk fluid exits from outer two channels. The concentrated bacteria flows towards the sensing region, where it binds to antibody coated electrode arrays. The biosensor was able to detect concentrations as low as 39 CFU/mL.

W-009 IN-VIVO INTRAVASCULAR INTERVENTION WITH PARYLENE MICRO-ELECTRODE TO DIAGNOSE RUPTURE-PRONE ATHEROSCLEROTIC PLAQUE USING ELECTRICAL IMPEDANCE SPECTROSCOPY 307

Y. Luo¹, X. Zhang¹, R. Packard², R. Li², T. Hsiai², Y. Liu¹, and Y.-C. Tai¹

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²University of California Los Angeles School of Medicine, USA

Progressing from our previous work, we have developed and deployed an in-vivo, catheter integrated, Parylene-C micro electrode sensor for intra-vascular interrogation to assess the state of the atherosclerotic plaques using Electrical Impedance spectroscopy (EIS).

M-010 LABEL-FREE MONITORING OF MOLECULAR BINDING BASED ON EXTRAORDINARY OPTICAL TRANSMISSION WITH ENHANCED ACCURACY 311

L. Tu, L. Huang, S. Jin, X. Li, L. Mi, Q. Wu, and W. Wang

Tsinghua University, CHINA

This paper describes a study of the antibody-antigen interaction based on extraordinary optical transmission (EOT) enabled by a free-standing gold film perforated with periodically arrayed nano-holes. Particularly, the spectral shift caused by the microfluidic flow rate through the porous and suspended Au film has been quantified for the first time and this shift as measurement error has been decoupled and eliminated from the recorded signal to enhance the monitoring accuracy.

T-011 MICRORNA DIAGNOSIS USING COMPLEMENTARY DNA THAT BRAKES TRANSIT EVENTS THROUGH A BIOLOGICAL NANOPORE 315

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¹Kanagawa Academy of Science and Technology, JAPAN and ²University of Tokyo, JAPAN

MicroRNA was diagnosed by electrical monitoring of its transit events through a biological nanopore. The target miRNA selectively forms a duplex with complementary DNA specially designed, which makes the transit time to slow down. An artificial lipid bilayer device previously reported allowed to implement the nanopore platform just by dropping aqueous/oil solutions. Feasibility tests demonstrated rapid, selective, and label-free detection of the target miRNA.

W-012 MULTIPLEXED MOLECULAR ASSAYS USING NANO-ELECTRONICALLY BARCODED BEADS 317

P. Xie, X. Cao, and M. Javanmard

Rutgers University, USA

We introduce the concept of electronically barcoded micron-sized beads, with the potential of achieving high barcode density. Nanoelectronic barcoding works by fabricating tunable nano-capacitors on the micro-particle surface, effectively modulating the frequency dependant dielectric properties of the particles allowing one bead barcode to be distinguished from another. Multi-frequency lock-in measurements of the real to imaginary impedance ratio allows for bead differentiation.

Medical Microsystems (Probes, Implantables, Minimally Invasive, Etc.)

- M-013** **3D MULTI-FUNCTIONAL NEURAL PROBE ARRAY FOR MAPPING FUNCTIONAL CONNECTIVITIES IN A 3D NEURON CHIP** 321
H. Shin^{1,2}, S. Kim¹, N. Choi¹, H.J. Lee³, E.-S. Yoon¹, and I.-J. Cho^{1,2}
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²Korea University of Science and Technology (KUST), SOUTH KOREA, and
³Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

This work reports the first 3D multi-functional neural probe array integrated with optical, chemical, and electrical stimulation capabilities, developed for mapping the 3D functional connectivities among neurons cultured in a 3D hydrogel neuron chip. The proposed device is not only capable of stimulating neurons with various modalities but also tracking the propagated neural activities in the whole 3D hydrogel chip using the 3D electrode array.

- T-014** **A DUAL MODE MICROBUBBLE PRESSURE AND FLOW SENSOR** 325
L. Yu and E. Meng
University of Southern California, USA

We present the first microbubble (μB) based dual mode sensor for static pressure and liquid flow. The transducer harnesses the inverse pressure-volume relation and electrochemical impedance measurement to monitor size of electrolytically generated μBs . By altering sensor orientation, static pressure or flow rate can be transduced. The design features non-hermetic packaging, low power consumption, and biocompatible construction for target applications in chronic in vivo monitoring.

- W-015** **A NEW MEMS NEURAL PROBE SYSTEM INTEGRATED WITH PUSH-PULL MICROFLUIDIC CHANNELS AND BIOSENSORS FOR REAL-TIME MONITORING OF NEUROCHEMICALS** 329
U. Chae^{1,2}, H. Shin¹, H. Lee¹, J.P. Lee², N. Choi¹, Y.J. Lee¹, S.H. Lee¹,
J. Woo¹, Y. Cho¹, E.-S. Yoon¹, H.-Y. Yu², and I.-J. Cho¹
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²Korea University of Science and Technology (KUST), SOUTH KOREA, and
³Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

This paper reports a new MEMS neural probe integrated with two microfluidic channels, a mixer, and biosensors for real-time monitoring of neurochemicals and neural activities. The microchannels for push-pull operation of fluids enable infusion of drugs and extraction of brain fluid at the same time. Also, we can simultaneously monitor neural activities modulated by the infused drug. The real-time monitoring of neurochemicals using the monolithically integrated sensors.

- M-016** **A SILICON/PLASTIC HYBRID TISSUE MULTIMODAL ASSAY TWEEZER WITH INTEGRATED POLYSILICON STRAIN GAUGE DISPLACEMENT SENSOR** 333
P.-C. Chen and A. Lal
Cornell University, USA

We demonstrate a silicon/plastic hybrid tweezer that can be used for measuring multiple tissue property, and for the first time using polysilicon strain gauges for displacement measurement. We also report for the first time, simultaneous measurement of tissue Young's modulus, insertion force, and electrical impedance, to distinguish different tissue type and changes in tissue types after aging.

- T-017** **AN ANGLE-SELECTIVE CMOS IMAGER WITH ON-CHIP MICRO-COLLIMATORS FOR BLUR REDUCTION IN NEAR-FIELD CELL IMAGING** 337
E.P. Papageorgiou¹, B.E. Boser¹, and M. Anwar²
¹University of California, Berkeley, USA and ²University of California, San Francisco, USA

Microfabricated imagers placed within the resection bed intraoperatively can improve image-guided surgery, such as during cancer removal. Variations in blood and tissue surface profile cause blurring in the image. We have fabricated an angle-selective imager incorporating an array of micro-collimators in the metal layers of a CMOS process. The micro-collimators block off-axis light and effectively couples each pixel to the portion of the sample directly opposite it, thereby reducing blur.

- W-018** **AN ELECTROCHEMICAL-BASED THERMAL FLOW SENSOR** 341
A. Baldwin, L. Yu, and E. Meng
University of Southern California, USA

We present the first thermal flow sensor which measures thermal changes in ionic mobility vis-à-vis electrochemical impedance. Biocompatible construction on a flexible substrate enables unobtrusive insertion into medical implants such as shunts and catheters. Our sensor uses electrochemical impedance between an electrode pair to sense temperature changes, offering increased sensitivity and compatibility in saline environments. The simple design is ideal for extended in vivo applications.

M-019 AN IMPEDANCE WIRE INTEGRATED WITH FLEXIBLE FLOW SENSOR AND FFR SENSOR FOR CARDIOVASCULAR MEASUREMENTS 345

L. Tang, J. Liu, B. Yang, X. Chen, and C. Yang
Shanghai Jiao Tong University, CHINA

We develop a thin impedance wire which will allow simultaneous minimally invasive measurements of blood flow rate and fractional flow reserve (FFR) in coronary artery. These two sensors are based on electrochemical impedance (EI) transduction, and the EI-based sensor is the first time employed for FFR determination. A good linearity of the impedance/flow relation of the flow sensor is found over 0-250ml/min, and the FFR sensor also shows high sensitivity at the range of FFR from 0.6 to 1.

T-020 AN ULTRASONICALLY POWERED MICROPUMP FOR ON-DEMAND IN SITU DRUG DELIVERY 349

J. Zhou, A. Kim, M. Ochoa, H. Jiang, and B. Ziaie
Purdue University, USA

We introduce a smart pump (2.2×0.7×0.5 cm³) that delivers drug in situ using an ultrasonically-powered electrolytic mechanism. The smart pump is controlled wirelessly by an external ultrasonic transmitter that can power the device for distances of up to 11 cm away. Once activated, the micropump can dispense drug at a flow rate of 0.1 μL/s with a backpressure of 24.2 Torr. The device is fabricated with laser-assisted rapid prototyping techniques, allowing for low-cost production.

W-021 BIODEGRADABLE JUNCTIONLESS TRANSISTORS WITH EXTREMELY SIMPLE STRUCTURE 353

J. Guo, J.Q. Liu, B. Yang, G.H. Zhan, and C.S. Yang
Shanghai Jiao Tong University, CHINA

We reported a kind of low voltage biodegradable transistor with extremely simple structure. The proposed transistors can be operated at a low voltage of 1 V. Dissolution tests of those transistors in deionized water demonstrate their completely physical transience within 60 minutes.

M-022 DETECTION OF HIGH-FREQUENCY COMPONENT OF MECHANOMYOGRAM 356

R. Aoki, Y. Takei, N. Minh-Dung, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We report a method to detect high-frequency component of mechanomyogram (a record of muscle sound, MMG). We propose a MEMS MMG sensor with six sector-shaped piezoresistive cantilevers and measure MMG of human's biceps brachii. Experimental results show that the frequency component of the MMG of biceps brachii exists in 10 Hz–10 kHz whereas the previous studies in which microphones, accelerometers or piezoelectric contact sensors are used have not been able to detect MMG over 100 Hz.

T-023 DETECTION OF KINETIC HEARTBEAT SIGNALS FROM AIRFLOW AT MOUTH BY CATHETER FLOW SENSOR WITH TEMPERATURE COMPENSATION 359

H. Kawaoka¹, T. Yamada², M. Matsushima², T. Kawabe², Y. Hasegawa¹, and M. Shikida¹
¹*Hiroshima City University, JAPAN and* ²*Nagoya University, JAPAN*

To precisely evaluate kinetic heartbeat signals from the airflow at a mouth, we newly integrated a temperature sensor onto a catheter flow sensor to compensate the temperature change between inspiration and expiration. The catheter flow sensor was fabricated by MEMS technologies, and it was directly inserted into the rat's airway. The obtained waveform at the airway was analyzed by discrete Fourier transform, and we successfully extracted kinetic heartbeat signals from the airflow.

W-024 EFFICIENT POWER GENERATION FROM VOCAL FOLDS VIBRATIONS FOR MEDICAL ELECTRONIC IMPLANTS 363

H. Cho, A. Balakrishna, Y. Ma, J.O. Lee, and H. Choo
California Institute of Technology, USA

Using PZT-based vibration-driven electric power generators, we have successfully harvested 0.3 mW/sq.cm from the acousto-mechanical vibrations that originate from the human vocal folds and propagate along the skeletal frame and air passages in the head and neck. Our harvesters are highly efficient because vocal vibrations excite the harvesters at their resonant frequencies. More power can be harvested by forming a flexible large array, with a potential to power medical implants in the future.

M-025 ELECTROTHERMAL MEMS FIBER SCANNER WITH LISSAJOUS PATTERNS FOR ENDOMICROSCOPIC APPLICATIONS 367

Y.-H. Seo, H.-C. Park, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

We reports an electrothermal MEMS fiber scanner with Lissajous patterns. The MEMS fiber scanner comprises double hot arm structures, and a directly mounted optical fiber. Thermal expansion of hot arm enables lateral scanning, and bimorph between the scanner and mounted fiber induces vertical scanning. Besides, asymmetric cantilever enables resonance separation of the fiber, which allows Lissajous scanning. This new concept can provide a new direction for various endomicroscopic applications.

- T-026 FLEXIBLE MULTI-CHANNEL MUSCLE ELECTRODE FOR FUNCTIONAL ELECTRICAL STIMULATION AND *IN-VIVO* PH MONITORING 371**
 J. Wang, Z. Xiang, S. Lee, R. Jegadeesan, S.-C. Yen, N.V. Thakor, and C. Lee
National University of Singapore, SINGAPORE

This paper reports a flexible multi-channel muscle electrode which allows (1) Functional Electrical Stimulation (FES) on muscle with less muscle fatigue induced; (2) real-time extramuscular pH monitoring.

- W-027 FLEXIBLE SLING ELECTRODE FOR BIDIRECTIONAL NEURAL SIGNAL RECORDING AND SELECTIVE STIMULATION 375**
 S. Lee¹, S.-C. Yen¹, L.-D. Liao¹, G.G.L. Gammad¹, N.V. Thakor^{1,2}, and C. Lee¹
¹*National University of Singapore, SINGAPORE* and ²*Johns Hopkins University, USA*

We demonstrate flexible sling electrodes for bidirectional neural signal recording and selective stimulation. Slightly tilted sling design enables to closely and smoothly implant on nerves for less pressure in the nerve as well as to achieve bidirectional recording and selective stimulation of the nerve. Electrically evoked nerve signals were recorded through six sensing electrodes. Selective stimulation of the nerve was successful while monitoring CMAPs of different muscles.

- M-028 HIGH-DENSITY PROBE WITH INTEGRATED THIN-FILM MICRO LIGHT EMITTING DIODES (μ LEDs) FOR OPTOGENETIC APPLICATIONS 379**
 S. Ayub, C. Gossler, M. Schwaerzle, E. Klein, O. Paul, U.T. Schwarz, and P. Ruther
University of Freiburg, GERMANY

We report on the design, fabrication, assembly and characterization of an innovative neural probe with optical functionality for optogenetic applications. The individually addressable thin-film micro LEDs (μ LED) are directly integrated on silicon probes using a wafer-level bonding process, at a pitch of 150 μ m. An all electrical interconnection of this optical probe constitutes a distinct advantage over existing tools for in-vivo applications.

- T-029 HYDRAULIC DRIVEN ACTIVE CATHETER WITH OPTICAL BENDING SENSOR 383**
 Y. Inoue and K. Ikuta
University of Tokyo, JAPAN

We developed a novel bending sensor for real time orientation control of hydraulic pressure driven active catheter. We proposed and fabricated the bending sensor which was able to be included in the active catheter that was 3.0mm diameter. Some holes fabricated on the surface of a multimode optical fiber sensor diffused light inside of it depending on its curvatures. Measuring amount of light through the bending sensor indicated the bending angle was verified.

- W-030 IMPLANTABLE MULTI-FUNCTIONAL FLEXIBLE MICROELECTRODE COMBINING ELECTRICAL AND CHEMICAL INTERFACE 387**
 H.-C. Tian, J.-Q. Liu, X.-Y. Kang, M.-H. Wang, B.-W. Ji, B. Yang, X. Chen, X.-L. Wang, and C.-S. Yang
Shanghai Jiao Tong University, CHINA

We develop a polymer based tubular microelectrode with excellent flexibility for neural or intramuscular implant, which integrated electrical path with fluidic channel. The dimension of electrode site can be regulated precisely by patterns and modified with conducting polymer to improve the electrode performance. The excellent flexibility facilitates the implant in dynamic nerve or muscle tissue to undertake electrical stimulation or EMG recording with fluidic drug delivery simultaneously.

- M-031 *IN-VIVO* BIOTISSUE DISCRIMINATION USING ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY ON A HYPODERMIC NEEDLE WITH FINE INTERDIGITATED ELECTRODES 391**
 J. Yun, H.W. Kim, Y. Park, J.-Y. Park, H.-I. Kim, and J.-H. Lee
Gwangju Institute of Science and Technology (GIST), SOUTH KOREA

This is the first demonstration of electrical impedance spectroscopy-on-a needle (EoN) being applied to in-vivo biotissue discrimination. The interdigitated electrodes were fabricated at the tip of the round surface of a hypodermic needle. Both the width and gap between the IDEs are as small as 20 μ m. The electrodes are passivated by parylene C to ensure biocompatibility. The in-vivo discrimination capability of the EoN was evaluated using fat and muscle tissues of rat.

- T-032 LED-BASED OPTICAL COCHLEAR IMPLANT ON HIGHLY FLEXIBLE TRIPLE LAYER POLYIMIDE SUBSTRATES 395**
 M. Schwaerzle, J. Nehlich, S. Ayub, O. Paul, and P. Ruther
University of Freiburg - IMTEK, GERMANY

We report on the design, fabrication, assembly, and optical as well as thermal characterization of a novel MEMS-based optical cochlear implant (CI). The optical stimulation of the spiral ganglion neurons (SGNs) promises a pronounced increase in the number of discernible acoustic frequency channels in comparison with commercial CIs. Ten LEDs are integrated as a linear array onto an only 12- μ m-thick highly flexible polyimide (PI) substrate with three metal and three PI layers.

W-033 OXYGEN GENERATION BY ELECTROLYSIS TO TREAT RETINAL ISCHEMIA 399

N. Scianmarello¹, D. Kang¹, K. Murali², C. Cook¹, J. Han¹, M.S. Humayun², and Y.-C. Tai¹
¹California Institute of Technology, USA and ²University of Southern California, USA

We demonstrate a wireless device to produce oxygen via electrolysis to treat retinal ischemia. We present fabrication techniques, modeling, and preliminary bench top performance for the device.

M-034 PARYLENE-ON-OIL PACKAGING FOR IMPLANTABLE PRESSURE SENSORS 403

A. Shapero, Y. Liu, and Y.-C. Tai
California Institute of Technology, USA

This paper reports the feasibility of a parylene-on-oil encapsulation packaging method of pressure sensors targeted for long-term implantation. Commercial barometric digital-output pressure sensors are first enclosed in silicone oil and then encapsulated in situ with parylene-C or -D. This work shows that with proper designs, such a packaging method can preserve the original pressure sensitivity without offset, validated throughout accelerated lifetime tests in high-temperature saline.

T-035 SEMI-IMPLANTABLE GLUCOSE SENSOR BASED ON DUAL-STACKED POLYMERIC FILM FOR WIRELESS CONTINUOUS MONITORING 407

H.S. Yoon, X. Xuan, and J.Y. Park
Kwangwoon University, SOUTH KOREA

We have developed semi-implantable non-enzymatic glucose sensor based on dual-stacked biocompatible polymeric film for wireless continuous monitoring. The dual-stacked polymeric film is comprised of PI and hard cured SU-8 in order to improve the adhesion and durability of substrate. Nanoporous Pt was successfully deposited on polymeric film as working and counter electrodes for glucose sensor fabrication. The fabricated sensor was interconnected and tested with wireless monitoring system.

W-036 SIDE-POLISHED FIBER SPR SENSOR WITH TEMPERATURE SELF-COMPENSATION FOR CONTINUOUS GLUCOSE MONITORING 411

B. Lu, Y. Sun, X. Lai, Z. Pu, H. Yu, K. Xu, and D. Li
Tianjin University, CHINA

We proposed a side-polished fiber surface plasmon resonance (SPR) sensor modified by graphene and borate polymer for continuous glucose monitoring with temperature self-compensation. The sensor can eliminate the interference of body temperature fluctuation than the conventional SPR sensor. And the sensor can enable the detection of hypoglycemia than the conventional

M-037 THROMBUS CLEAN-UP WITH MAGNETO-ELASTIC VIBRATOR 415

C. Xue¹, J. Zhan¹, and X. Li^{1,2}
¹Chinese Academy of Sciences, CHINA and
²University of the Chinese Academy of Sciences, CHINA

This paper reports a novel magneto-elastically driven MEMS thrombus dredger, with which the mice-thrombus inside a simulated blood-vessel is broken into micro pieces and the vessel recovers to unobstructed within 1hr. By optimally exciting the micro-vibrator in its third resonating mode, the tested flow-rate in the cleaned vessel increases by 2.3 times compared with that in the blocked state.

T-038 ULTRA-THIN ELASTOMER MEMBRANE ARRAY WRINKLING FOR BLADDER CANCER DIAGNOSIS 419

J.H. Appel¹, M.L.Y. Sin², J.C. Liao², and J. Chae¹
¹Arizona State University, USA and ²Stanford University School of Medicine, USA

We report an ultra-thin silicone membrane array to simultaneously discern the presence of cancerous cells in 16 patient urine samples. This high-throughput parallel diagnostic array relies on the intrinsic properties of cancerous cells to induce wrinkling in the arrayed membrane. This point-of-care diagnostic array improves throughput compared to sequential analysis by individual membranes and may be able to enhance reliability/accuracy by coordinating controls for false results concurrently.

Nanobiotechnology

W-039 A CARBON NANOFIBER (CNF) BASED 3-D MICROELECTRODE ARRAY FOR IN-VITRO NEURAL PROLIFERATION AND SIGNAL RECORDING 423

S.-P. Fang, P.F. Jao, E. Franca, T.B. DeMarse, B.C. Wheeler, and Y.-K. Yoon
University of Florida, USA

We propose a high-aspect-ratio 3-D carbon nanofiber(CNF) microelectrode arrays(MEAs) for neural signal study. We develop and optimize the immersion lithography and high temperature carbonization process to increase the yield rate from 30% to over 95%. In-vitro neural signal and action potential are recorded for the first time on CNF MEAs. Our result also indicated CNF MEA shows approximate 50% improvements in both cell survivability and neurite length per area studies compared to CNT MEAs.

- M-040** **SOLID-STATE ALLOYED GOLD-SILVER NANOSTRUCTURES FOR PLASMON RESONANCE TAILORING AS HIGHLY SENSITIVE SERS SUBSTRATES** 427
M. Kang, M.-S. Ahn, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

This work reports straightforward approach for AuAg alloyed nanostructures with solid-state dewetting. Successive thin films evaporation and thermal annealing enable fabrication of AuAg alloyed nanostructures with well-defined sizes and shapes. The complete miscibility of Au and Ag leads to programmable tailoring of the plasmon resonance over the entire visible wavelength region, which is expected to be excellent candidates for highly sensitive SERS substrates.

Generic MEMS and Nanotechnologies

Generic MEMS and NEMS Manufacturing Techniques

- T-041** **A UNIVERSAL METHOD TO GROW AND ETCH GRAPHENE FILM** 431
N. Deng, H. Tian, H. Zhao, C. Li, L.Q. Tao, X. Wang, M.A. Mohammad, W. Mi, Y. Yang, and T. Ren
Tsinghua University, CHINA

We demonstrate a novel method to grow and etch graphene film using a one-step laser-scribing process. Three regions were observed when the graphene oxide (GO) was exposed to different laser power. Their profiles, Raman spectra, optical and electrical properties were thoroughly analyzed. These work indicate that the laser-scribing technique is promising for the fast and low cost to produce large-scale graphene for various applications, such as NEMS resonator, NEMS sensor, etc.

- W-042** **ALL SOLUTION-PROCESSED FLEXIBLE MEMORY INTEGRATED WITH TACTILE SENSOR** 435
K. Kanao, S. Nakata, T. Arie, S. Akita, and K. Takei
Osaka Prefecture University, JAPAN

This study demonstrates a tactile pressure-memorized flexible device integrated with a tactile pressure sensor and a ReRAM. Solution-processed ReRAM shows a stable switching operation with >3 orders-ON/OFF resistance ratio. A tactile pressure sensor is integrated with ReRAM. The integrated device can successfully memorize tactile information. This demonstration eventually allows us to apply for flexible human-interactive tactile array devices by memorizing tactile or other sensing information.

- M-043** **DECOUPLING OF DIAMETER AND PITCH IN NANOSTRUCTURE ARRAYS MADE BY COLLOIDAL SELF-ASSEMBLY** 439
X. Huang, M. Bjork, J.J. Kim, and J. Yeom
Michigan State University, USA

We report a general and flexible approach to fabricating ordered, sparse-array nanostructures from the two-dimensional colloidal self-assembly. Precise control of nanosphere diameters is carried out in ICP-RIE while accurate pitch control of array is enabled by a series of soft lithographic transfer and a custom-made radial stretcher. The combined top-down and bottom-up method allows us to inexpensively create an array of nanostructures with independent control over their diameter and pitch.

- T-044** **DIRECT WRITING OF THIN AND THICK METAL FILMS VIA MICRO GLOW PLASMA SCANNING** 443
A.M. Abdul-Wahed, A.L. Roy, Z. Xiao, and K. Takahata
University of British Columbia, CANADA

We report the first technique for micro-scale local deposition of metal films via sputtering of a micromachined metal electrode using a highly confined glow plasma generated between its tip and the substrate at atmospheric pressure. The controlled manipulation of the microplasma enables direct writing of electrode material, for a wide range of thicknesses from 100-nm level up to over 5 μm that is variable while writing.

- W-045** **HIGH-ASPECT-RATIO SUB-MICRON TRENCH ETCHING ON SOI USING WET METAL-ASSISTED CHEMICAL ETCHING (MACE) PROCESS** 447
B. Hamelin, L. Li, A. Daruwalla, C.-P. Wong, and F. Ayazi
Georgia Institute of Technology, USA

This paper reports the fabrication of a silicon MEMS resonator using metal-assisted chemical etching (MaCE). Submicron smooth vertical trenches were etched in silicon by MaCE with assistance of gold thin film as catalyst. During MaCE, an oxide layer served as the etching stopping layer. MaCE was found uniform across whole devices which ensured their complete release. Promising results pave the way for high-volume production of MEMS devices by MaCE with simple, fast and low cost operation.

M-046 MICRO ARCHITECTED POROUS MATERIAL WITH HIGH STRENGTH AND CONTROLLABLE STIFFNESS 451

J.H. Pikul, S. Ozerinc, R. Zhang, P.V. Braun, and W.P. King
University of Illinois, Urbana-Champaign, USA

We use microscale engineering to develop inverse opal nanoscale cellular solids (NCS) with up to 230 MPa/(Mg/m³) specific strength, which is stronger than most high strength alloys including 4143 steel and Ti-6Al-4V, and 14 – 115 GPa controllable stiffness. The NCS's regular architecture and self-assembly based fabrication allow nm control of geometry and chemistry to enable large area materials with high strength, controllable stiffness, and controllable chemistry.

T-047 PLASTIC RESHAPING TECHNIQUE FOR SILICON ORIGAMI 455

T. Kozeki, S. Inoue, and T. Namazu
University of Hyogo, JAPAN

This paper describes Si plastic reshaping technique, Si origami, by combining FIB processing and wet etching. FIB is used for local etching as well as Ga ion implantation. The combination of Ga ion doping and alkali wet etching to a Si wafer enables us to fabricate nanometer-thick Ga-ion-doped amorphous Si membrane, which can be bent to upward/downward at arbitrary angles by controlling FIB irradiation condition. The mechanism is discussed using Ga ion distribution and collision cascade effect.

W-048 RELIABLE AND FLEXIBLE FIELD EMITTER FOR X-RAY GENERATION BY IMPLANTING CNTS INTO NI FILM USING MICROMACHINING METHOD 458

B. Sun, Y. Wang, and G. Ding
Shanghai Jiao Tong University, CHINA

We develop a novel implanting Micromachining technology. By using this method, for the first time, we could implant nano-scale materials into milli-scale metal substrates at room temperature. Ni based carbon nanotube (CNT) field emitter was fabricated. Effective stable contact between Ni and CNTs was achieved by embedding CNT roots into the Ni substrate using polymer matrix as transfer media. As a result, the fabricated emitter shows excellent mechanical property and field emission stability.

M-049 RELIABLE DEPOSITION OF ULTRA-THIN PARYLENE 462

W. Wang^{1,2}, D. Kang², W. Dai¹, and Y.-C. Tai²
¹Peking University, CHINA and ²California Institute of Technology, USA

This paper reports a novel and reliable process to prepare ultra-thin parylene film based on a principle combining both molecular effusion and diffusion. For the first time, a technique for the deposition of parylene film thinner than 20 nm in a highly controllable and repeatable way is developed. Parylene films with various thicknesses could also be prepared in a single deposition run by using this method. This technique holds promising potentials in extensive applications.

T-050 SELF-ASSEMBLY OF MULTI-COMPONENT MICROSTRUCTURE USING THE ENTROPIC EFFECT 465

U. Okabe, T. Okano, and H. Suzuki
Chuo University, JAPAN

We have proposed the use of the depletion attraction for the self-assembly of microcomponents. Microcomponents fabricated by the photoresist were immersed and agitated in the solution. When the solution contains macromolecule at high concentration, they formed assembled structures, to increase the translational entropy of macromolecules in the solution. We tested the assembly of the desired structure composed of multiple components.

W-051 SILICON-NANOWIRE FIELD-EFFECT TRANSISTORS ON A FLEXIBLE SUBSTRATE USING TOP-DOWN MEMS PROCESSES 469

J.Y. Shin, K. Pi, S. Jung, and D.-I. Cho
Seoul National University, SOUTH KOREA

This paper presents the first silicon-nanowire field-effect transistors (SiNW FETs) fabricated by a top-down MEMS process on a flexible substrate. The developed method allows fabricating SiNW FETs on a flexible substrate easily using the conventional MEMS technology. Excellent characteristics are measured both before and after the transfer.

Manufacturing for Bio- and Medical MEMS and Microfluidics

M-052 A DISPOSABLE PARYLENE MICRONEEDLE ARRAY FOR BLOOD EXTRACTION ASSISTED BY VIBRATING MOTION FOR INSERTIONS 473

F.-W. Lee, W.-H. Hung, J.-W. Ma, and Y.-J. Yang
National Taiwan University, TAIWAN

This work presents a disposable parylene microneedle array for blood extraction which carries out the insertions by mimicking the vibrating motion of the mosquito's proboscis. The device consists of a high-aspect-ratio (HAR) parylene microneedle array and a chamber structure, which can be monolithically fabricated by using the embedded parylene channel fabrication process. The vibrating motion of the device which imitates the mosquito's motion was realized by using a piezoelectric actuator.

- T-053** **A LOW RESISTANCE AND LOW PARASITIC CAPACITANCE MICRO COIL FOR MRI FABRICATED BY SELECTIVE DEPOSITION ON 3D PRINTED STEPPED HELICAL STRUCTURES** 477
 Y. Yokoyama and T. Dohi
Chuo University, JAPAN

This paper reports on a bicone-shaped micro coil for MRI which has low resistance and low parasitic capacitance. The micro coil was fabricated by vacuum evaporation and electroplating of Cu onto the stepped helical structures made by 3D printer. Since the helical structure was fixed on the rotary-tilted stage, Cu was evaporated only the wiring part. Furthermore, we could reduce the resistance by electroplating and by increase the linewidth of wiring. Therefore we took high SNR MRI images.

- W-054** **A WIRELESS STRAIN SENSOR FOR WOUND MONITORING WITH DIRECT LASER-DEFINED PATTERNING ON A COMMERCIAL DRESSING** 481
 R. Rahimi¹, M. Ochoa¹, M. Zieger², R. Sood², and B. Ziaie¹
¹Purdue University, USA and ²Indiana University School of Medicine, USA

Controlled mechanical strain or stress on a wound site can promote wound healing; however, these mechanical forces have not been properly quantified. As a solution, we developed a wireless strain sensor on a commercial wound dressing with an average sensitivity of 150 kHz/%strain, in response to applied strain. The sensor features an elegant fabrication technique, consisting of defining a screen-printing mask directly over the wound dressing using a laser engraver.

- M-055** **CAPILLARY ELECTROPHORESIS AND ELECTROSPRAY IONIZATION ON A SINGLE-THREAD MICROFLUIDIC SYSTEM FOR RAPID MASS SPECTROMETRY DETECTION** 485
 C.-W. Lin and C.-H. Lin
National Sun Yat-sen University, TAIWAN

This study presents a novel microfluidic system using a single thread for sample loading, pinch focusing, sample separation and electrospray ionization for rapid MS detection of liquid biosamples. Rapid sample detection can be achieved without time consuming chip fabrication and sample preparation processes. The ingredients of commercial medicine and energy drink are successfully detected. The developed method provides a simple yet high efficient way for LC-MS detection of biosamples in ambient.

- T-056** **CATCH A CELL ON A CMOS: SELECTIVE RETRIEVAL OF SINGLE CELL USING A MICROPLATE TECHNOLOGY PERFORMED ON A CMOS IMAGING SENSOR** 489
 S. Tabata¹, S. Yoshida¹, Y. Morimoto^{1,2}, and S. Takeuchi¹
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

We propose a method to selectively retrieve single cells by combining a microplate technology with a CMOS imaging sensor. With our device, we performed individual cell identification, fluorescence light emission detection, time lapse imaging and single cell retrieval. We confirmed that each of these processes is compatible with CMOS imaging sensor substituting a conventional microscope. We believe that this technology will provide new possibilities in single cell analysis field.

- W-057** **FABRICATION OF STEEL DISPLACEMENT AMPLIFIERS INTEGRATED TO MICROFLUIDIC CHANNELS** 493
 E. Iseri, K.O. Ulgen, C. Yilmaz, and S. Mutlu
Bogazici University, TURKEY

In this study, a flexure mechanism consisting of steel thin film displacement amplifier and trapping fingers inside a microfluidic channel actuated by hand or a simple mechanical tool is realized for biology and cell analysis. This steel mechanism is fabricated via electrochemical and wet etching of 50- μ m-thick stainless steel film. It is integrated to a microfluidic channel formed between 125- μ m-thick polyethylene naphthalate (PEN) films for the first time in this work.

- M-058** **LATERAL POROUS SILICON MEMBRANES WITH TUNABLE PORE SIZE FOR ON-CHIP SEPARATION** 497
 Y. He, D. Bourrier, E. Imbernon, A. Bhaswara, X. Dollat, F. Cristiano, and T. Leïchl e
Universit e de Toulouse, FRANCE

We present a fabrication process for the creation of lateral porous silicon membranes with tunable pore size and porosity and their integration into planar microfluidics. We use ion implantation to manipulate the local dopant concentration in order to control the membrane properties. The dead-end filtration capability and the cation perm-selectivity of the fabricated membranes are demonstrated, thus enabling size- and charge-based separation.

- T-059** **MICRO PILLARS WITH THIN HYDROPHOBIC LAYER FORMED ON THE SIDE WALLS TO PREVENT CELL PROTRUSION TOWARD SIDE WALL** 501
 K. Noda, K. Hirayama, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

The paper reports on micro pillar structures with thin hydrophobic layer patterned to the side wall and the surface of the substrate where the pillars are standing. Since the cell cannot adhere to the fluorocarbon layer, the cultured cells will adhere only to the top of the pillars. Therefore, the traction force of the cells can be measured without considering the adhering position.

W-060 ORGANIC SKIN PATCH WITH BUILT-IN ENZYMATIC BATTERY 505

M. Nishizawa, K. Nagamine, and H. Kai
Tohoku University, JAPAN

We have achieved development of a completely organic, totally disposable iontophoresis patch with a built-in enzymatic biofuel cells (BFCs) that utilizes enzymes as electrocatalysts, which can work under mild conditions, i.e., body temperature and at approximately neutral pH. The patch, when mounted on the skin, generates a transdermal ionic current with the osmotic flow from anode to cathode, thereby administrating the chemical into the skin.

M-061 PROCESSING OF PLATINUM ELECTRODES FOR PARYLENE-C BASED NEURAL PROBES 509

X.C. Ong, M. Forssell, and G.K. Fedder
Carnegie Mellon University, USA

We report a method to improve the electrochemical properties of platinum electrodes fabricated using parylene-C based processes. It is found that the use of O₂-RIE to etch parylene-C, the state-of-the-art method for processing parylene-C, oxidizes a surface layer of platinum which results in high electrochemical impedance of the electrode. By introducing an Ar⁺ etch step to remove the oxidized Pt, the electrochemical impedance of the electrode is reduced by an order of magnitude.

T-062 ROLLUP FABRICATION OF MICROTUBULAR STRUCTURES BY MECHANICALLY STRETCHING/COMPRESSING THIN FILMS 513

J. Feng and S.K. Cho
University of Pittsburgh, USA

We report rollup fabrications by mechanically stretching thin films, which enables manufacturing of microtubes from single/multiple materials without complex temperature control/material combinations. Microtubes of aluminum, magnesium and parylene are successfully fabricated with control of their diameters (a few tens to thousands microns in diameter). This fabrication method may be extended to make more complex 3-D microstructures.

W-063 TOWARDS MULTISCALE FLUIDIC CHANNEL NETWORKS VIA INTERNAL OXIDATION AND OXIDE ETCHING BASED ON SELF-ASSEMBLED SILICON-ON-NOTHING STRUCTURES 517

J. Song, J. Je, and J. Lee
Sogang University, SOUTH KOREA

We report a novel fabrication method for multiscale fluidic channels ranging from sub-100 nm to a few μm in their hydraulic diameters (a factor of $\sim 50,000$ tunability in terms of cross-sectional area) while maintaining comparable height-to-width ratio by thermal oxidation and oxide etching self-assembled Silicon-on-Nothing structures. Nanochannels of which all characteristic dimensions are nanoscale far below 100 nm can be batch-fabricated without employing any nanolithographic schemes.

M-064 WAFER-LEVEL SHELLAC-BASED INTERCONNECTION PROCESS FOR ULTRATHIN SILICON CHIPS OF ARBITRARY SHAPE 520

F. Barz, R. Lausecker, U. Wallrabe, P. Ruther, and O. Paul
University of Freiburg, GERMANY

This work reports on a novel process to interface silicon-based neural probes with highly flexible Parylene-C ribbon cables. It applies sacrificial shellac substrates used to handle 50- μm -thin silicon chips in a batch process. Multi-chip assemblies were successfully fabricated and released from the sacrificial substrates. Dedicated test specimens of the silicon/polymer assemblies showed high bond strength in 90° peel tests and stable electrical interconnections.

Materials for MEMS and NEMS

T-065 CHARACTERIZATION OF SPUTTERED NICKEL-TITANIUM SHAPE MEMORY ALLOY AND MICROFABRICATED THERMAL ACTUATORS 524

C.R. Knick, M.D. Srour, and C.J. Morris
US Army Research Laboratory, USA

We report on the microfabrication and thermal characterization of shape memory alloy (SMA) thin film nickel-titanium (NiTi) bimorph cantilever actuators, which actuate between 1.2 mm radius of curvature and nearly flat states upon heating from room temperature to above 60°C, and which are suitable for MEMS applications such as electro-thermal switches, laser micro-shutters, and other applications requiring mechanical actuation in response to changes in temperature.

W-066 ELECTRODEPOSITION OF CARBON NANOTUBES-CU COMPOSITE FOR MICROELECTRICAL ELEMENTS APPLICATIONS 528

Z. An, M. Toda, and T. Ono
Tohoku University, JAPAN

We present the electrodeposition of two kinds of copper (Cu) composites with high contents of multi-walled CNTs (MWCNTs), thermally-annealed at 1200oC and 2600oC, and evaluate the properties of the composites. The Young's moduli of the composites are approximately 1.2 times and 1.1 times greater than that of the Cu film, respectively. The composites exhibit 26% and 16% lower coefficients of thermal expansion (CTE) than that of the Cu, and possess the same electrical resistivity with the Cu.

M-067 FINELY FORMED POROUS SILICA NANOPARTICLES AND THEIR STRENGTH EVALUATION 532

K. Inoue, K. Kiyohara, S. Inoue, and T. Namazu
University of Hyogo, JAPAN

Precisely controlling the shape, size, and porosity of porous silica nanoparticles by the atomized heating method is described. Self-assembly phenomenon of silica nanopowders and submicron polystyrene latex balls was used for the fabrication. At the PSL concentration of around 3wt%, pores were uniformly arranged in sphere nanoparticles. The produced porous silica nanoparticles were subjected to strength test with a MEMS-based force sensor in a SEM.

T-068 GRAPHENE-OXIDE (GO) NANO-SHEETS: LATERAL AND VERTICAL SIZE-EFFECTS ON CHEMICAL-GAS SENSITIVITY ENHANCEMENT 535

P. Xu¹, T. Xu², H.T. Yu¹, and X.X. Li¹
¹*Chinese Academy of Sciences, CHINA and*
²*Shanghai Institute of Technology, CHINA*

For the first time, size-effect of graphene-oxide (GO) nano-sheets on sensitivity of chemical-gas detection is classified as in-plane dimension lateral-effect and vertical thickness-effect, by using resonant-cantilevers to measure molecule-adsorbing induced mass. This research clearly reveals that, lateral-dimension size-effect plays a decisive role in sensitivity enhancement to reducing-gas, while thickness size-effect dominates the sensitivity to oxidizing-gas.

W-069 LARGE-AREA DIATOM FRUSTULE SELF-ASSEMBLED MONOLAYERS: FORMATION AND MANIPULATION 539

A. Li¹, W. Zhang¹, R. Ghaffarivardavagh¹, X. Wang¹, S. Anderson², and X. Zhang¹
¹*Boston University, USA and* ²*Boston University Medical Center, USA*

We present a method to form large-area, close-packed, self-assembled mono-layers using diatom frustules of *Coscinodiscus* species. The orientation of these frustules was uniformly controlled with the concave side facing downwards by blowing nitrogen gas bubbles below the water-diatom interface. The method introduced herein, taking advantage of diatom frustules' orientation and hierarchical structures, has the potential for large-scale fabrication of micro/nano-structures.

M-070 MEMS-BASED MECHANICAL CHARACTERIZATION OF CORE-SHELL SILICON CARBIDE NANOWIRES FOR HARSH ENVIRONMENTAL NANOMECHANICAL ELEMENTS 543

S. Nakata¹, K. Sugano¹, M. Negri², F. Rossi², G. Salyiati², A. Lugstein³, and Y. Isono¹
¹*Kobe University, JAPAN,* ²*IMEM-CNR Institute, ITALY, and*
³*Vienna University of Technology, AUSTRIA*

This research clarified mechanical properties of core-shell silicon carbide nanowires (C/S-SiCNWs) grown by a VLS technique, using newly developed MEMS-based nanotensile testing devices. The C/S-SiCNWs consist of a crystalline cubic silicon carbide (3C-SiC) core wrapped by an amorphous SiO_x shell. We have successfully obtained distinct stress-strain relations for individual C/S-SiCNWs and 3C-SiCNWs without the SiO_x shell.

T-071 NOVEL NANOSTRUCTURE REPLICATION PROCESS FOR ROBUST SUPERHYDROPHOBIC SURFACES 547

S. Hoshian, V. Jokinen, and S. Franssila
Aalto University, FINLAND

This paper reports a novel nanoreplication process. It consists of metal nanostructuring by acidic etching, ALD of TiO₂ and polymer replication. After PDMS casting the metal is completely etched away, revealing the nanostructured TiO₂/PDMS surface. The surface is highly robust superhydrophobic, and it repels water, wine and coffee.

W-072 PIEZORESISTIVE NANOCOMPOSITE RUBBER ELASTOMER FOR STRETCHABLE MEMS SENSOR 550

J.-J. Wang, M.-Y. Lin, H.-Y. Liang, R. Chen, and W. Fang
National Tsing Hua University, TAIWAN

This work presents piezoresistive nanocomposite rubber elastomers of 30wt% carbon black powders filled into polymethylsiloxane (PDMS) to produce conductive polymeric composites. The C-PDMS nanocomposite is utilized to measure the fractional changes in electrical resistances (dR/R₀) as resistors, which is casted and stacked into PDMS substrates with gold films deposited as bond pads to fabricate polymer-based stretchable devices.

- M-073 PREPARATION OF GRAPHENE-NICKEL NANOCOMPOSITE FOR DURABLE MICROMIRROR APPLICATION 554**
 J. Li, Z. An, and T. Ono
Tohoku University, JAPAN

We fabricate a Si micromirror with graphene-Ni nanocomposite beams and evaluate the mirror durability under resonance. A pulse-reversed electroplating is utilized to prepare the composite with uniform graphene dispersion and high loading content. The hardness and Young's modulus of the composite are enhanced by 3.5-fold and 1.4-fold, respectively. The composite mirror shows superior durability with less drift of resonant frequency and scanning angle than the Ni counterpart during a long-term test.

- T-074 SILK: NEW OPPORTUNITIES FOR AN ANCIENT MATERIAL IN MEMS/NEMS 558**
 K. Liu, J. Jiang, Z. Zhou, X. Cai, H. Tao, and N. Qin
Chinese Academy of Sciences, CHINA

We demonstrate potential uses of naturally regenerated/extracted silk proteins as a promising biomaterial platform for applications in micro- and nanofabrication.

- W-075 SOFT DIELECTRIC ELASTOMER ACTUATOR FOR MICROPUMP APPLICATION 561**
 P.S. Chee^{1,2}, C.K. Mah¹, and M.S. Mohamed Ali^{1,3}
¹Universiti Teknologi Malaysia, MALAYSIA, ²Universiti Tunku Abdul Rahman, MALAYSIA, and ³Pelabuhan Tanjung Pelepas (PTP), MALAYSIA

This study presents an out-of-plane Dielectric Elastomer Actuator (DEA) and its application in micropump. The developed micropump is operated by the expansion of an elastomer that is sandwiched between two electrodes. The membrane which is initially flat buckles when a pull-up force exerted on its surface. When voltage is applied between the electrodes, electrostatic pressure compresses the dielectric material vertically. The performance of the device is analyzed using the developed prototype.

- M-076 SOLUTION PROCESSED HIGHLY CONDUCTIVE TRANSPARENT ELECTRODES 565**
 H.S. Park, J. Jang, and L. Lin
University of California, Berkeley, USA

We fabricated transparent and conductive antimony doped tin oxide films for transparent display by using solution processing. We investigate four parameters (doping concentration, thickness, annealing temperature, and ambient gases) for increasing conductivity of highly transparent (over 95%) and conductive thin films using solution processing. We also have analyzed their surface morphology, crystallinity and electrical, optical properties.

Packaging and Assembly

- T-077 A FAST AND CMP-FREE TSV PROCESS BASED ON WAFER-LEVEL LIQUID-METAL INJECTION FOR MEMS PACKAGING 569**
 J. Gu, B. Liu, H. Yang, and X. Li
Chinese Academy of Sciences, CHINA

We demonstrated a MEMS packaging process that for the first time integrates a specifically developed TSV technology. In the proposed packaging process, after capping, alloy TSVs were fabricated by a wafer-level liquid-metal injection method that is based on combinative effect of liquid-bridge rupture and capillary action, which is capable to achieve flat via-surface, a feature that can dismiss the CMP process. Furthermore, the TSV filling can be finished in few minutes.

- W-078 A VACUUM ENCAPSULATION TECHNIQUE WITH NOVEL PARASITIC OPTIMIZATION METHODS FOR VHF MEMS RESONATORS 573**
 J. Zhao, Q. Yuan, W. Luo, X. Kan, J. Zhang, J. Yang, and F. Yang
Chinese Academy of Sciences, CHINA

This paper presents a vacuum encapsulation technique based on Au-Sn solder bonding with novel parasitic optimization methods for VHF MEMS resonators. An accurate circuit model of the packaged resonator was established. Reduction of the parasitic effect can be achieved via decreasing overlap between sealing ring and VHF traces, grounding Au-Sn ring.

- M-079 HIGH-SPEED METAL-FILLING OF THROUGH-SILICON VIAS (TSVs) BY PARALLELIZED MAGNETIC ASSEMBLY OF MICRO-WIRES 577**
 S.J. Bleiker¹, A.C. Fischer^{1,2}, and F. Niklaus¹
¹KTH Royal Institute of Technology, SWEDEN and ²Karlsruhe Institute of Technology (KIT), GERMANY

This work reports a parallelized magnetic assembly method for extremely fast and cost effective through-silicon via (TSV) fabrication. Parallelization is achieved by utilizing many magnets to simultaneously assemble multiple TSV structures. Experimental results show filling of four arrays, with 100 via-holes each, in less than 20 seconds. On wafer scale, this approach is capable of filling more than 70 wafers per hour which is much higher than industrially available TSV metallization processes.

T-080	LOW-TEMPERATURE ALUMINUM THERMO-COMPRESSION WAFER BONDING WITH TIN ANTIOXIDATION LAYER FOR HERMETIC SEALING OF MEMS	581
	S. Satoh, H. Fukushi, M. Esashi, and S. Tanaka <i>Tohoku University, JAPAN</i>	

High-yield hermetic sealing was achieved by Al-Al wafer bonding at the lowest temperature ever reported, 370-390°C. Al is the standard metal of CMOS backend, free from the risk of metal contamination and inexpensive, and thus the best candidate interlayer material for wafer bonding. However, Al creates stable surface oxide. We used thin Sn as an antioxidation layer of Al, and successfully demonstrated high-yield hermetic sealing at 370-390°C.

W-081	WIDE TEMPERATURE RANGE THROUGH SILICON VIAS MADE OF INVAR AND SPIN-ON GLASS FOR INTERPOSERS AND MEMS	585
	M.J. Laakso ¹ , M. Asiatici ^{1,2} , A.C. Fischer ^{1,3} , G. Stemme ¹ , and F. Niklaus ¹ ¹ <i>KTH Royal Institute of Technology, SWEDEN</i> , ² <i>École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND</i> , and ³ <i>Karlsruhe Institute of Technology (KIT), GERMANY</i>	

Novel high-aspect-ratio through silicon vias (TSVs) able to withstand elevated temperatures of at least 365 °C and temperature cycling between -50 °C and 190 °C were developed and characterized. The cycling range is wider than found in the literature for a complete TSV structure with surface metallization. Invar metal alloy, which has a similar coefficient of thermal expansion with silicon, was used for the first time as a TSV conductor together with spin-on glass as a TSV insulator.

MEMS for Electromagnetics

DC and Low Frequency Magnetic and Electromechanical Components and Systems

M-082	LORENTZ FORCE MEMS MAGNETOMETER WITH FREQUENCY MODULATED OUTPUT	589
	V. Kumar and S. Pourkamali <i>University of Texas, Dallas, USA</i>	

This work presents a frequency output micromachined silicon magnetometer comprised of a low stiffness thermal-piezoresistive electromechanical resonator coupled to a Lorentz force generator and magnifier. In the presented design the Lorentz force is amplified by ~55X leading to device measured sensitivity of ~7200 ppm/T/mA (frequency shifts as high as 0.123ppm per μ T shown here for bias current of 17mA).

T-083	VACUUM BOUNCING DYNAMICS DOMINATED BY VAN DER WAALS FORCES IN MEMS RELAYS	593
	B. Ma, Z. You, and Y. Ruan <i>Tsinghua University, CHINA</i>	

We develop a microelectromechanical systems (MEMS) relay with high reliability, in which van der Waals forces will be used to significantly suppress the vacuum contact bouncing. To accurately analyze the vacuum bouncing dynamics dominated by van der Waals forces, the microcantilever relay is modeled as a multi-segment beam with different cross-sections. Finally, we use a dual-pulse actuation waveform implemented by simple logic circuits to completely eliminate the vacuum contact bounces.

Free Space Optical Components and Systems (Displays, Lenses, Detectors)

W-084	INDIVIDUALLY TUNABLE LIQUID LENS ARRAYS USING TRANSPARENT GRAPHENE FOR COMPOUND EYE APPLICATIONS	597
	A. Shahini, P. Zeng, Y. Zhao, and M.M.-C. Cheng <i>Wayne State University, USA</i>	

This paper reports a tunable liquid lens array that can be individually controlled by electrowetting on dielectric (EWOD) and pneumatic pressure with planar transparent graphene electrodes on a highly deformable membrane made of PDMS and parylene. The design has many advantages for compound eye applications, including a large field of view, an extremely compact size and fast response time.

M-085 DISPERSION-CORRECTED METASURFACE FOR BEAM DEFLECTOR AND FLAT LENS 601

L. Yan¹, H. Cai², Y.D. Gu², W. Zhu³, P.C. Wu¹, Z. Yang⁴, Y. Jin⁴, Y. Hao⁴,
D.-L. Kwong², and A.-Q. Liu¹

¹Nanyang Technological University, SINGAPORE, ²Agency for Science, Technology and Research (A*STAR), SINGAPORE, and ³Peking University, CHINA

We demonstrate a reconfigurable metasurface using microfluidic technology, which controls the amplitude and phase of the incident wave at sub-wavelength resolution. A dispersion-corrected beam deflector and a flat lens are demonstrated for proof-of-principle where the flat lens and beam deflector are tuned, in response to the change of the incident wavelength, to maintain their functionalities.

T-086 ELECTROTHERMAL MEMS PARALLEL PLATE ROTATION FOR REAL TIME STEREOSCOPIC ENDOSCOPIC IMAGING 605

K.-W. Jang, S.-P. Yang, S.-H. Baek, M.-H. Kim, and K.-H. Jeong

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This work reports a micro-optic device with electrothermal actuator which allow, for the first time, real-time stereoscopic imaging using parallel plate rotation. This unique configuration slightly deflects the principal optical axis of a single camera, which results in the virtual movement of a single camera. This method can provide a new insight for realizing a single camera based stereoscopic imaging inside a medical endoscope.

W-087 FABRICATION AND CHARACTERIZATION OF SPHERICAL ABERRATION-FREE TUNABLE ASPHERICAL LENSES 609

P. Zhao, Ç. Ataman, and H. Zappe

University of Freiburg - IMTEK, GERMANY

We show the design, fabrication and characterization results for a novel type of liquid-filled tunable lens free of spherical aberration. The lens is based on a meniscus-like flexible membrane of non-uniform thickness molded using a precision mold fabricated by diamond turning. We experimentally demonstrate that using 80% of the 3mm clear aperture and at an optimized focal length, the optical performance is improved drastically compared to conventional tunable-lenses over a focal length range.

M-088 MICROFLUIDIC PATTERNING OF HEMISPHERICAL DOME-SHAPE PHOTONIC COLLOIDAL CRYSTALS FOR WIDE-VIEWING-ANGLE REFLECTIVE DISPLAY 613

N. Suzuki¹, E. Iwase², and H. Onoe¹

¹Keio University, JAPAN and ²Waseda University, JAPAN

This study describes a micropatterning method of hemispherical dome shape photonic colloidal crystals (PCCs) in microchannels. Dome-shape PCCs reflect light (structural color) in wide-viewing-angle. We succeeded in patterning of multiple types of hemispherical PCCs and confirmed that those patterned PCCs reflected their structural color in wide-viewing-angle. Our method realize an optical filter for full-color, wide-viewing-angle and low-energy-consumption reflective displays.

T-089 MICROPATTERNING OF SILK PROTEINS FOR SOFT BIOACTIVE DIFFRACTIVE OPTICAL ELEMENTS 617

Z. Zhou, X. Cai, K. Liu, N. Qin, H. Tao, and J. Jiang

Chinese Academy of Sciences, CHINA

We put forward a set of green, bioactive, low cost diffractive optical elements (DOEs) using silk fibroin proteins that can be used to "lock" and "unlock" the information stored in DOE made on silica with only water being used.

W-090 RANDOMLY CONTROLLED METAMATERIAL MODULATOR FOR DYNAMIC TUNING OF OPTICAL PROPERTY 620

Y. Mao, W. Wu, and J. Xu

Peking University, CHINA

We design and fabricate a randomly controlled metamaterial modulator (RCMM) which can dynamically tune reflection in infrared region. Word/bit-line (WBL) method is introduced to precisely control the thermoelectricity-caused bending of every individual meta-cell in the RCMM. A 2×2 RCMM exhibits 16 different states operation conditions of the device. And the corresponding optical reflection of the device will be modulated by up to 40%.

- M-091 SI PROCESS COMPATIBLE NEAR-INFRARED PHOTODETECTOR USING AU/SI NANO-PILLAR ARRAY 624**
 T. Kan, Y. Ajiki, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on a near-infrared photodetector constructed on an n-typed Si wafer. Vertically oriented Au nano-pillars formed on the n-typed Si performed as optical antennas which absorb the infrared light effectively. The absorbed energy is then transduced into photocurrent by the Schottky barrier diode formed on the Au/n-Si interface.

- T-092 SYNTHETIC ADAPTIVE OPTOELECTRONIC COLOR CAMOUFLAGE SKINS 628**
 C. Yu
University of Houston, USA

We report, for the first time, an artificial adaptive color camouflage skin device this is able to sense the surrounding environment and match its color autonomously. To produce the smart flexible skin devices, transfer printing of inorganic semiconductors for active electronics and multiple lamination of flexible devices will be employed.

- W-093 ULTRATHIN FLAT PARABOLIC REFLECTOR BASED ON GRADIENT METASURFACE 632**
 W. Ma¹, D. Jia¹, X. Yu¹, Y. Feng², and Y. Zhao²
¹*Peking University, CHINA* and ²*Beijing Institute of Technology, CHINA*

We report an ultrathin flat parabolic reflector to focus a laser beam of 1.47 μ m wavelength based on gradient metasurface. The metasurface consists of an array of sub-wavelength cross-shaped scatters arranged in a radially periodic manner. Transverse profiles of the laser spot were captured by an IR detector along the propagating direction, showing the minimum spot size to be 167 μ m at focal point with the focal length of 5.8 cm and the overall reflection efficiency of 44%.

- M-094 ULTRATHIN CAMERA INSPIRED BY VISUAL SYSTEM OF XENOS PECKII 636**
 D. Keum¹, D.S. Jeon¹, C.S.H. Hwang¹, E.K. Buschbeck², M.H. Kim¹, and K.-H. Jeong¹
¹*Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA* and ²*University of Cincinnati, USA*

This paper reports miniature camera inspired by imaging principle of Xenos peckii. The camera consists of microprism arrays, microlens arrays, and aperture arrays. The microprism arrays were implemented by a microimprint process and a backside lithography. The light absorbing structures were also formed between the microprism arrays. Each channel of the camera detects different part of the whole field of view, and captured images are reconstructed in the following image processing step.

Manufacturing for Electromagnetic Transducers

- T-095 AN ELECTROMAGNETIC MINIATURIZED GRASPER WITH A LARGE ROTATIONAL RANGE 640**
 Y.-Y. Feng, P.-H. Hsieh, and S.-J. Chen
National Central University, TAIWAN

We design and manufacture a novel micro grasper which can be electrically controlled with a very large angular range. With electromagnetic induction mechanism, the grasper is capable of capturing the object bigger than itself.

- W-096 MICROMETER SCALE MAGNETIZATION OF NEODYMIUM MAGNET FOR INTEGRATED MAGNETIC MEMS 643**
 R. Fujiwara, W. Hijikata, and T. Shinshi
Tokyo Institute of Technology, JAPAN

To realize integrated magnetic MEMS devices, micrometer scale magnetization technique of a magnet is necessary to generate micro and complicated magnetic circuit. This paper discusses a micro magnetization method utilizing the reduction of magnetic coercivity by laser assist heating. To fabricate the intended magnetization pattern, the paths of heat conduction in the magnet substrate are designed. Finally, a micrometer scale magnetization of a magnet was experimentally tested and evaluated.

Other Electromagnetic MEMS

- M-097** **DESIGN OF THE MICROWAVE FREQUENCY SENSOR FOR POWER-UNKNOWN SIGNAL BASED ON MEMS TECHNOLOGY** 647
Z. Yi, X. Liao, and Z. Zhang
Southeast University, CHINA

A microwave frequency sensor is designed for 11-13GHz application for the first time. The novelty is that the proposed sensor can realize microwave frequency detection for the unknown-power signal. In addition, the MEMS thermoelectric sensor and capacitive sensor are applied to measure low and high power, respectively.

Photonic Components and Systems

- T-098** **INTEGRATION OF MICRO-OPTICAL ELEMENTS ON AN OPTICAL FIBER TIP USING DMD-BASED MASKLESS LITHOGRAPHY** 651
J.-B. Kim and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

This paper reports a facile and low-cost technique for fabrication of micro-optical elements on the tip of an optical fiber using maskless UV exposure system. The Digital Micromirror Device based maskless lithography was employed to fabricate 2D and 3D microstructures. Based on this approach, various micro-photon structures were successfully fabricated onto the fiber tip. This technique can be extended to develop miniaturized photonic devices for bioimaging or fiber-based sensing applications.

- W-099** **A 1550 NM PHASE CHANGE ELECTRO-OPTICAL SHUTTER ARRAY** 655
M. Jafari and M. Rais-Zadeh
University of Michigan, USA

We introduced and fabricated a new approach for designing a high speed light intensity modulator required in optical fibers, scanners, printers, etc. This modulator utilizes the phase change material, which is Germanium Telluride in our design, based on active joule heating. This modulator is integratable with CMOS, doesn't need constant power, with less than 10us switching time as opposed to liquid crystals that operates at 100s of microseconds with static power in one phase.

RF MEMS Components and Systems

- M-100** **1.02 GHZ CROSS-SECTIONAL LAMÉ MODE RESONATOR WITH HIGH K_T^2 EXCEEDING 4.6%** 659
C. Cassella, Z. Qian, G. Hummel, and M. Rinaldi
Northeastern University, USA

We describe, for the first time, a novel AlN resonator based on the excitation of a Lamé mode in the cross-section of an AlN plate. As the resonator uses both the AlN e31 and e33 piezoelectric coefficients, a kt^2 in excess of 4.6% at 1.02 GHz, was measured. To the best of our knowledge such a high kt^2 value is the highest ever reported in AlN resonators using metallic IDTs to excite mechanical vibrations.

- T-101** **A MICROMECHANICAL HIGH- Q ELLIPTIC DISK DISPLACEMENT AMPLIFIER** 663
W.-C. Li, Z. Ren, and C.T.-C. Nguyen
University of California, Berkeley, USA

An 89-MHz micromechanical elliptic-disk displacement amplifying resonant switch ("resoswitch") with a displacement gain of 2.04 has achieved a Q of 101,600--more than $9\times$ higher than that of previous array-based and slotted-disk approaches. This ability to affect displacement amplification while maintaining $Q > 100,000$ should provide more than 10dB sensitivity improvement for recent resoswitch-based zero-quiescent radio receivers.

- W-102** **DAMPING DIRECTLY IMPACTS FLICKER FREQUENCY NOISE OF PIEZOELECTRIC ALUMINUM NITRIDE RESONATORS** 667
H.J. Kim, J. Segovia-Fernandez, and G. Piazza
Carnegie Mellon University, USA

We present an analysis on the effect of damping on flicker frequency ($1/f$) noise of 1.1 GHz AlN contour mode resonators. A total of 52 different resonators are systemically designed to give a wide range of quality factors (Q), allowing the study of how two major damping mechanisms, 1) anchor loss and 2) thermoelastic damping, affect the resonator $1/f$ noise. The results confirm that $1/f$ noise shows a clear power law dependence of $1/Q^3$, independently of the main nature of the damping mechanism.

- M-103 DECIPHERING INTERMODULATION IN AIN
LATERALLY VIBRATING RESONATORS 671**
R. Lu, A. Gao, and S. Gong
University of Illinois, Urbana-Champaign, USA

This work reports an analytical and quantitative method that, for the first time, precisely predicts the third-order in-termodulation distortion (IMD3) in AIN laterally vibrating resonators (LVRs). The simulated IMD3 reaches excellent agreement with the measurements of a 453.4 MHz AIN LVR. The method provides an unprecedented framework for enhancing the power handling and reducing the nonlinearity of AIN LVRs to meet the requirements of RF frontend filtering.

- T-104 LOW-LOSS GOLD-LACED PZT-ON-SILICON RESONATOR
WITH REDUCED PARASITICS 675**
R.Q. Rudy¹, J.S. Pulskamp¹, S.S. Bedair¹, M.G. Breen¹, J.M. Puder^{1,2}, and R.G. Polcawich¹
¹*US Army Research Laboratory, USA and* ²*Cornell University, USA*

This paper reports, for the first time, that adding high-conductivity, low-quality-factor material to resonators with low motional resistance (Rm) can significantly improve 50Ω-terminated insertion loss (1.73 dB vs. 7.11 dB) and unloaded circuit quality factor (2663 vs. 735) because parasitic resistance dominates the loss. This has significant implications for the extraction of Rm and allows for impedance matching which can produce low-loss, wide-bandwidth, steep roll-off filters.

- M-105 MULTI-FREQUENCY LiNbO₃ LAMB WAVE RESONATORS
WITH < 3Ω IMPEDANCE 679**
R. Wang¹, S.A. Bhave², S. Zhgoon³, and K. Bhattacharjee⁴
¹*Cornell University, USA,* ²*Purdue University, USA,*
³*Moscow Power Engineering Institute, RUSSIA, and* ⁴*Qorvo, Inc., USA*

We present monolithic multi-frequency LiNbO₃ Lamb wave resonators fabricated on a 3in. X-cut thin-film LN-SiO₂-LN wafer. Resonators with four different frequencies (667MHz, 793MHz, 846MHz, and 713MHz) are demonstrated. Resonators with the first three frequencies operate in S₀ mode, while resonators with the last frequency utilize the SH₀ wave. Exploiting a long transducer design, the resonators exhibits spur-suppressed response, <3Ω impedance at resonance, and $k_{eff}^2 > 17\%$ without any de-embedding, and the highest k_{eff}^2 achieved is 24.1%.

THz MEMS Components and Systems

- W-106 TUNABLE METAMATERIALS FOR TERAHERTZ ULTRA-BROADBAND
ABSORPTION DRIVEN BY MICROFLUIDIC 683**
Q.H. Song^{1,2}, H. Cai³, Y.D. Gu³, P.C. Wu², W. Zhang², W.M. Zhu², Q.X. Liang⁴, Z.C. Yang⁵,
Y.F. Jin⁵, Y.L. Hao⁵, D.-L. Kwong⁵, T. Bourouina¹, Y. Leprince-Wang¹, and A.-Q. Liu²
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³*Agency for Science, Technology and Research (A*STAR), SINGAPORE,*
⁴*Xian Jiaotong University, CHINA, and* ⁵*Peking University, CHINA*

A THz ultra-broadband absorber is realized using tunable metamaterials driven by microfluidic system. In this work, a new technology is developed to precisely and continuously control the height of micro liquid pillars, through which a tunable THz absorber is shown to have absorption frequency tuning from 0.245 THz to 0.415 THz. These tunable metamaterials have promising applications in detector, sensor, imaging system and stealth.

Micro- and Nanofluidics Lab-on-Chip Medical Diagnostic Devices

- T-107 A PARYLENE MICROPIPETTE ARRAY FOR ENABLING
SIMULTANEOUS DETECTION OF DIFFERENT TARGET
ANALYTES ON A CMOS SENSOR ARRAY 687**
C.-W. Ma, C.-M. Chang, H.-T. Hsueh, P.-H. Kuo, C.-T. Lin,
C.-T. Lin, S.-S. Lu, and Y.-J. Yang
National Taiwan University, TAIWAN

This study reports a 4×1 parylene micropipette array for locally and selectively functionalizing the surface of a CMOS-based hall sensor array with different capture antibodies. The proposed device is the key to enable simultaneously detecting different target analytes in a sample solution on a SoC chip. Experiment results showed the micropipette can locally functionalize capture antibodies on the top of individual Hall sensors.

- W-108 HIGH-THROUGHPUT BIOMIMETIC 3D GEL-ISLAND CHIP FOR INVESTIGATING CANCER CELL HETEROGENEITY 691**
 Z. Zhang, Y.-C. Chen, Y. Luan, and E. Yoon
University of Michigan, USA

We report a novel microfluidic platform enabling single-cell tracking in biomimetic 3D microenvironment for investigating heterogeneous cellular drug responses. This platform achieves: single cell encapsulation in 3D gel-islands, high-throughput drug screening, and automatic single cell lineage tracking. Using this chip, we demonstrate the correlation between cell lineage history and its drug response. Certain cancer subpopulation is targeted as the major contributor of cancer drug resistance.

- M-109 MEASURING THE VIBRATION OF CELLS SUBJECTED TO ULTRASOUND USING A MEMS-BASED FORCE SENSOR ARRAY 695**
 H. Park, N. Thanh-Vinh, K. Hirayama, T. Tsukagoshi, K. Noda, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We develop a new method to measure vibration occurring on the surface of cell membrane using an array of piezoresistive cantilever-type force sensors which allows simultaneous force measurement at the different locations of a single cell. Sensor chip consists of an array of 13 piezoresistive cantilevers with the spatial resolution of 5µm was fabricated to measure the change of frequency response and phase delay to the ultrasound-induced vibration when 3T3 cells adhere to the sensor array.

- T-110 PIEZORESISTIVE CANTILEVER INTEGRATED MICROFLUIDIC CHANNEL FOR MEASURING CELLULAR PROPERTIES 698**
 K. Hirayama, T. Tsukagoshi, N. Thanh-Vinh, Y. Ichikawa, and I. Shimoyama
University of Tokyo, JAPAN

We propose a microfluidic device that has piezoresistive cantilever on the bottom wall of its microchannel wall. This sensor allows us to measure force applied to the wall of microfluidic channel directly with high sensitivity and with high time resolution. Our device is able to detect mechanical properties of mammalian cells by the piezoresistive cantilever, while handling cells using by fluidic techniques.

Materials for Bio- and Medical MEMS and Microfluidics

- W-111 AGPDMS ELECTRODES FOR SINGLE CELL IMPEDANCE SPECTROSCOPY 701**
 Y. Wei¹, M.A. Cachia¹, J. Nguyen¹, Z. Xu¹, Y. Zheng¹, C. Wang², and Y. Sun¹
¹University of Toronto, CANADA and ²Mount Sinai Hospital, CANADA

We present a microfluidic device with sidewall electrodes made of AgPDMS for measuring the electrical properties of single cells. AgPDMS is, for the first time, used for impedance spectroscopy. The AgPDMS composite has high conductivity, and the large channel design of the microfluidic device overcomes device clogging and permits multiple use of the device. Experimental results demonstrate that the device has adequate sensitivity for the electrical characterization of cells.

- M-112 CIRCUMFERENTIALLY ORIENTED COLLAGEN NANOFIBERS ON THE CYLINDRICAL STRUCTURE 705**
 E. Nam^{1,2}, W.C. Lee^{1,2}, and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

Collagen nanofibers are self-aligned on 3D surfaces by applying cyclic stretch during the gelation process of collagen solution. The aligned collagen nanofibers induce the alignment of cells on 3D surfaces without any mechanical force within the cultivation period. We believe that this method for collagen and cell alignments contributes to the regenerative medicine, which needs a scaffold that provides microenvironments and biological structures on 3-dimensional surfaces of tissues and organs.

- T-113 CORE-SHELL MICROPARTICLES FORMATION WITH CENTRIFUGAL COAXIAL MICROFLUIDIC DEVICE 708**
 J. Sawayama and S. Takeuchi
University of Tokyo, JAPAN

This paper describes centrifuge-based core-shell microparticles formation utilizing a coaxial microfluidic device. We revealed encapsulation of human dermal fibroblast cells into the microparticles and culturing in the microparticles. Here we integrated a coaxial micro fluidic structure to fabricate the core-shell microparticles, and demonstrated the easy process cell encapsulation.

- W-114 HIGH-PERFORMANCE MICROELECTRODE OF PEDOT/Pt-BLACK FOR LOW VOLTAGE NEUROSTIMULATION 710**
K. Yamaguchi, M. Tanaka, S. Yamagiwa, H. Sawahata, R. Numano, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

We report a material for low-voltage and micro-scale electrode neurostimulation that combines high charge injecting and low impedance characteristics of Poly (3, 4-ethylenedioxythiophene) (PEDOT) with the large effective surface area platinum black (PT-black). The assembled PEDOT/PT-black electrode exhibits the great charge-injection delivery capacity, while the in vivo animal experiments using mouse's nerves confirm the low-voltage and microscale stimulation capabilities of the electrode.

- M-115 SILICON CARBIDE (SiC) MICROMECHANICAL SELF-SUSTAINED OSCILLATOR OPERATING IN LIQUID 714**
H. Tang, H. Jia, and P. Feng
Case Western Reserve University, USA

This work reports on the first experimental demonstration of self-sustained feedback oscillators that utilize silicon carbide (SiC) micromechanical resonators operating in liquid, with stable oscillations and greatly enhanced effective quality (Q) factors. Together with the appealing mechanical, optical properties, and biocompatibility, such SiC micromechanical self-sustained oscillators may pave the way for real-time and in-situ biosensing and monitoring.

- T-116 MICROFLUIDIC FORMATION OF MONODISPERSE TETRA-PEG HYDROGEL MICROBEADS FOR CELL ENCAPSULATION 718**
T. Watanabe and S. Takeuchi
University of Tokyo, JAPAN

We developed core-shell tetra-arm poly(ethylene glycol) hydrogel microbeads encapsulating insulin-secreting cells using microfluidic emulsification with a double coaxial device and spontaneous gelation induced by self-diffusion of two kinds of tetra-PEG macromonomers at the core-shell interface in the precursor aqueous droplets. This process allowed to prepare biocompatible hydrogel microbeads with narrow size distribution under mild condition in the absence of heating and UV-irradiation.

- W-117 MUSCLE-ACTUATED BIO-HYBRID MEMS BY CELL CULTURE AND DIFFERENTIATION ON METAMATERIAL MICRO-SCAFFOLDS 721**
M.R. Gullo¹, S. Takeuchi², and O. Paul¹
¹*University of Freiburg, GERMANY* and ²*University of Tokyo, JAPAN*

This paper reports on a 3D bio-hybrid metamaterial MEMS scaffold for the culture and differentiation of C2C12 muscle precursor cells. The micro scaffolds are based on concatenated bowtie elements fabricated by two-photon lithography. Compared to state-of-the-art gel-based cell culture substrates, mechanical metamaterials can be shaped into arbitrary complex 3D geometries opening pathways towards muscle-driven bio-hybrid MEMS.

- M-118 SPUTTER-COATED RUTILE-TiO₂ ON TOPOLOGICAL MICRO-STRUCTURE FOR PROVIDING HIGH PHOTORESPONSIVITY IN A WIDE RANGE WETTABILITY SWITCHING 725**
H. Maeda, T. Kobayashi, and S. Konishi
Ritsumeikan University, JAPAN

This paper describes excellent performance of wettability switching by selecting a combination of attractive material and structural design. Rutile-TiO₂ combined with the topological microstructure to provide faster photoresponsivity in a wide range wettability switching will be presented.

- T-119 THREE-DIMENSIONAL DIFFERENTIATION OF HUMAN IPS CELLS THROUGH CORE-SHELL HYDROGEL MICROFIBER 729**
S. Nagata^{1,2}, T. Okitsu^{1,2}, K. Ikeda¹, and S. Takeuchi^{1,2}
¹*University of Tokyo, JAPAN* and ²*Japan Science and Technology Agency (JST), JAPAN*

We developed a system for 3D differentiation of induced pluripotent stem (iPS) cells by cell fiber technology. The core-shell microfibers containing human iPS cell in core (iPSC fibers) could maintain the pluripotency and differentiate into ectoderm and mesendoderm with sustaining the fibrous structure. The iPSC fiber-derived ectodermal and mesendodermal fibers promise for in vitro reconstruction of 3D organs by assembling and further differentiation through recapitulation of the organogenesis.

- W-120** **ULTRARAPID SYNTHESIS OF MICROBEADS WITH TUNEABLE SURFACE PROBE DENSITY** 731
 X.C. Zhou, F. Suderleith, S. Stanke, W. van der Wijngaart, and T. Haraldsson
KTH Royal Institute of Technology, SWEDEN

We demonstrate, for the first time:1) the microfluidic synthesis of thiolated and allyl-functional microbead.2) with native reactive surface probes, of which the surface density is very well controlled and can be easily tuned.3) in an ultra rapid manufacturing process (~ 1s UV crosslinkings).This allows readily manufacturing of microbeads with capture kinetics optimised for their intended bioassay.

Microfluidics and Nanofluidics

- M-121** **A MICROFLUIDIC SYSTEM FOR ASSESSING FRYING OIL QUALITY** 735
 M. Liu^{1,2,3}, S. Xie^{1,3}, J. Ge³, Z. Xu³, Z. Wu¹, C. Ru⁴, and Y. Sun²
¹Shanghai University, CHINA, ²Chinese Academy of Sciences, CHINA, ³University of Toronto, CANADA, and ⁴Soochow University, CHINA

We reports the first microfluidic system and technique for assessing frying oil degradation. Compared to existing bulky instruments and methods, this device and measurement technique are fast, simple, and cost-effective.

- T-122** **A MICROMACHINED CORONA-BASED UNIPOLAR AEROSOL CHARGER HAVING SEPARATED IONIZATION AND CHARGING ZONES FOR REDUCING THE ELECTRICAL LOSSES OF CHARGED PARTICLES** 739
 H.-L. Kim, J. Hyun, S.-M. Lee, H.-B. Gown, J. Hwang, and Y.-J. Kim
Yonsei University, SOUTH KOREA

MEMS-based airborne particle processing devices such as a micro virtual impactor and a micro corona charger were presented in our previous research. Unlike conventional liquid-based microfluidic systems, airborne particle processing devices handle a mixture of gas and particles. MEMS-based airborne particle processing technique was the first attempt. In this paper, a new micromachined corona-based unipolar aerosol charger is proposed for improving particle charging efficiency.

- W-123** **A NEW PICOINJECTOR IN MICROFLUIDICS** 742
 H. Zhou, Q. Jin, and J. Zhao
Chinese Academy of Sciences, CHINA

This paper reports a new self-triggered picoinjector. Compared with others' work, our injector is more practical and reliable. First, our sample injection is achieved passively with no need of detection of the droplet. Second, by adjusting the adding pressure, the dosing volume can be precisely controlled. Third, as the electrodes are integrated near the nozzle, the trigger voltage can be lowered to only several volts.

- M-124** **A NOVEL MIXING SURFACE ACOUSTIC WAVE DEVICE FOR LIQUID SENSING APPLICATIONS** 745
 T.H. Bui¹, B. Morana¹, T. Scholtes¹, T. Chu Duc², and P.M. Sarro¹
¹Delft University of Technology, THE NETHERLANDS and
²Vietnam National University (VNU), VIETNAM

This paper presents a novel mixing SAW device using the multiple IDT layers for liquid sensing applications. The stronger mechanical wave beam generated by the multiple input-IDT layers on the thin film (1 μm) AlN, consists of different-phase acoustic waves that can travel through a liquid medium. The experimental results show that it is possible to interact with the liquid medium placed on the surface and extract information about the liquid volume based on the phase change.

- T-125** **A SINGLE-CELL IMPEDANCE FLOW CYTOMETRY MICROSYSTEM BASED ON 3D SILICON MICROELECTRODES** 749
 X. Xing and L. Yobas
Hong Kong University of Science and Technology, HONG KONG

We develop the first account of a single-cell impedance flow cytometry microsystem based on 3D silicon microelectrodes. Such microelectrodes emerge being readily aligned during lithographic patterning and thus relieve the burden of alignment that comes with planar microelectrodes and their opposing arrangement for a maximum sensitivity.

W-126 ALL-SiC SURFACE MICROMACHINED NANOREACTOR FOR IN-SITU TRANSMISSION ELECTRON MICROSCOPY 753

B. Morana, C. Silvestri, J.F. Creemer, and P.M. Sarro
Delft University of Technology, THE NETHERLANDS

We present a SiC-based surface micromachined nanoreactor for in-situ characterization of reactions between solid nanostructured materials and gasses in transmission electron microscopes (TEMs). For the first time SiC is used as construction material for this device. This allows for easier and more reliable fabrication of the complete microsystems and for improved performance. Additionally, a novel two-level height gas-microchannel is implemented to ease the loading of the specimens.

M-127 AUGMENTATION OF GAS EXCHANGE USING OSCILLATING MICROBUBBLE ARRAY 757

H. Geng, J. Feng, and S.K. Cho
University of Pittsburgh, USA

We report a novel concept and experimental proof to substantially augment gas exchange between liquid and gas in microfluidics. The key idea is to use an oscillating bubble array to generate microstreaming flows perpendicularly to the main laminar liquid stream. The laminar flow stream experiences substantially increased mixing and gas exchange through the adjacent permeable membrane.

T-128 BIO-INSPIRED FLUIDIC THERMAL ANGULAR ACCELEROMETER 761

H. Alrowais¹, P. Getz¹, M.-G. Kim¹, J.-J. Su^{1,2}, and O. Brand¹
¹*Georgia Institute of Technology, USA* and ²*Texas Instruments, USA*

This paper reports on a bio-inspired angular accelerometer based on a simple two-mask microfluidic process using a PDMS mold. The sensor is inspired by the semicircular canals in mammalian vestibular system and pairs a fluid-filled microtorus with a thermal detection principle based on thermal convection. With inherent linear acceleration insensitivity, the sensor features a dynamic range of 14,000deg/s² and detection limit of ~20deg/s².

W-129 EXPERIMENTAL VERIFICATION OF ION CONCENTRATION DISTRIBUTION NEAR ION CONCENTRATION POLARIZATION LAYER AND ITS APPLICATIONS 765

W. Kim¹, S. Park¹, K. Kim¹, G.Y. Sung², and S.J. Kim¹
¹*Seoul National University, SOUTH KOREA* and ²*Hallym University, SOUTH KOREA*

This paper reported the experimental analysis of concentration distributions near an ion concentration polarization layer to show that most of cations were transported through nanoporous membrane, while previous studies had reported both co- and counter-ions were rejected from the membrane. Accordingly, we discretarily utilized (1) the brine stream for ink-desalter, (2) the purified stream for recycling dialysate, or (3) the buffer stream for collecting cationic species.

M-130 RAPID AND REVERSIBLE IMMOBILIZATION OF CAENORHABDITIS ELEGANS WITH AN OPTOELECTRIC DEVICE AND PLURONIC F-127 769

W.-Y. Chuang and H.-S. Chuang
National Cheng Kung University, TAIWAN

This paper reports a development of an optoelectric device with Pluronic (P) F-127 for reversibly immobilizing *Caenorhabditis (C.) elegans*. The gelation time was less than 5 s, and *C. elegans* also recovered from the immobilization within 10 s. The proposed device achieved addressable immobilization for long-term observation and imaging with less stress acting on worms. Assessments regarding growth, progeny, lifespan and stress were conducted. Worms imposed with simultaneous laser irradiation and an electric field in the PF-127 solution within 3 h incurred no adverse reactions. The technique is expected to benefit the research work on drug screening in the future.

T-131 MICRO TOTAL MRNA EXTRACTION SYSTEM FROM BIOPSIED SKELETAL MUSCLE TISSUE 772

K. Tsuda, K. Hattori, H. Wada, Y. Makanae, S. Fujita, and S. Konishi
Ritsumeikan University, JAPAN

We propose a micro total mRNA extraction system from biopsied skeletal muscle tissue. Developed system is composed of a micro mill and a micro pillar array for mRNA extraction, and a micro column for mRNA recovery. 430 ng of mRNA could be recovered in our experiments by using developed devices. Furthermore, a total system on a chip integrated with the components will be also presented on site.

W-132 MULTIFUNCTIONAL LIQUID LENS FOR HIGH-PERFORMANCE MINIATURE CAMERAS 776

I.S. Park, J.W. Yang, S.H. Oh, and S.K. Chung
Myongji University, SOUTH KOREA

This paper presents a novel multifunctional liquid lens (MLL) for miniature cameras. MLL firstly offers variable-focus and variable-zoom in a single lens system using two different actuation schemes-electrowetting-on-dielectric(EWOD) actuation for controlling the lens curvature and electromagnetic actuation for controlling the lens position. The proposed MLL offers a simple design structure but covers a wide range of variable lens curvatures and positions for high optical performance.

M-133 PRESSURE DRIVEN LIQUID CHROMATOGRAPHY IN SELF-ENCLOSED GLASS MICROCAPILLARIES INTEGRATED ON SILICON 780

L. Duan, Z. Cao, and L. Yobas

Hong Kong University of Science and Technology, HONG KONG

A planar integrated glass microcapillary array has been employed here and demonstrated the high efficient separation under pressure driven liquid chromatography. The channels present great length scale (several centimeter) while the cross section profile is uniform distributed along the capillary length. The separation performance of the capillary array is particularly investigated under automatic pressure driven system.

T-134 RHEOLOGICAL MANIPULATION FOR IMPROVED RELIABILITY IN INKJET PRINTING OF LIVING CELLS 784

E. Cheng, H. Yu, A. Ahmadi, and K.C. Cheung

University of British Columbia, CANADA

One of the main challenges in using inkjet technology for biofabrication applications is achieving reliable cell printing, particularly, consistent cell count per drop. We show how increased solution viscosity and density affect the trajectory of suspended cells during inkjet printing using piezoelectrically actuated nozzles. The increased viscosity alters the likelihood of cell deposition as visualized by high-speed imaging; improved reliability is quantified in cells per drop dispensed.

W-135 SINGLE-CHIP MASS FLOW CONTROLLER WITH INTEGRATED CORIOLIS FLOW SENSOR AND PROPORTIONAL CONTROL VALVE 788

J. Groenesteijn¹, D. Alveringh¹, M.S. Groen¹, R.J. Wiegerink¹, and J.C. Lötters^{1,2}

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²Bronkhorst High-Tech BV, THE NETHERLANDS

We have designed, fabricated and tested the -to our knowledge- first ever single-chip mass flow controller with an integrated Coriolis mass flow sensor and a proportional control valve. We demonstrated that the integrated system can control mass flow up to 70mg/h nitrogen gas at an applied pressure of 500mbar. Using a proportional controller, the flow measurement is used to set the position of the valve plate using a piezo-electric actuator.

M-136 SELECTIVE WIRELESS CONTROL OF A PASSIVE THERMOPNEUMATIC MICROMIXER 792

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¹Universiti Teknologi Malaysia, MALAYSIA, ²Islamic University of Madinah, SAUDI ARABIA,

and ³Flextronics, MALAYSIA

We develop a novel wireless control of a thermopneumatic micromixer by selectively activating two passive wireless heaters enabled by field-frequency modulation, with mixing-ratio controllability for local drug delivery and other applications. The developed thermopneumatic micromixer is operated by LC resonant circuits that behave as frequency-sensitive wireless heaters. Each LC circuit generates heat when exposed to an RF magnetic field with a frequency that matches its resonant frequency.

T-137 TIMING AND SYNCHRONIZATION OF DROPLETS ON RATCHET CONVEYORS 796

H.R. Holmes, A.E. Gomez, and K.F. Böhringer

University of Washington, USA

We report on a novel anisotropic ratchet conveyor (ARC) system, a type of digital microfluidic device that transports droplets with a passive silicon dioxide surface pattern and applied vibrations. We discovered the vibration amplitude required to transport droplets depends on the duty cycle of recurring features. From this concept we developed 'droplet gates', which can selectively pause droplet motion for timing, synchronization, and mixing of droplets in automated lab-on-a-chip systems.

W-138 TUNABLE, HIGH-SPEED, AND THREE-DIMENSIONAL MICROFLUIDIC DEVICE FOR ULTRA-HIGH PRECISION SIZE-BASED PARTICLE SEPARATION 800

Y.-C. Kung and P.-Y. Chiou

University of California, Los Angeles, USA

We report a novel microfluidic-based dielectrophoretic (DEP) mechanism for ultra-high precision microparticle and cell focusing and separation in high-speed flows. For the first time, particle size difference as small as 1µm can be separated with high purity (>90%) with sub-micron upstream precision (variation <0.2 µm) focusing function.

- M-139** **ULTRA-THIN NANOCHANNEL-BASED LIQUID TEM CELL FOR EELS ANALYSIS AND HIGH RESOLUTION IMAGING** **804**
 Y.B. Arik^{1,2}, R. Matsui², E. Sarajlic¹, Y. Takayama², B. Boom^{1,2}, E. Berenschot¹,
 S. Le Gac¹, N.R. Tas¹, and H. Fujita²
¹MESA+, University of Twente, THE NETHERLANDS and ²University of Tokyo, JAPAN

We present a nanochannel-based liquid TEM cell for the observation of biomolecules in aqueous environment inside Scanning TEM. It aims at achieving high resolution imaging using a sub-micron liquid layer surrounded by ultra-thin channel walls. The device was monolithically fabricated without any post-fabrication, improving its handling and fabrication yield. Finally, for the first time and thanks to a unique design, we confirm the presence of aqueous solutions in the nanochannels using EELS.

- T-140** **VARIABLE-FOCUS SMARTPHONE BASED MICROSCOPE USING AN ELASTOMER LIQUID LENS** **808**
 H. Huang, K. Wei, and Y. Zhao
 Ohio State University, USA

We develop a portable microscope using a liquid lens as the optical objective for in situ microscopic imaging with smartphones. The liquid lens with tunable focusing power allows for imaging at different magnifications without changing objectives or increasing the device size. The device is small enough to fit within a pocket wallet, and works readily with a smartphone. It is thus expected to contribute to optical observations/measurements for various lab-on-chip systems.

- W-141** **VORTEX GENERATION AND SENSING IN MICROFABRICATED SURFACE CHANNELS** **812**
 D. Alveringh¹, R.G.P. Sanders¹, R.J. Wiegerink¹, and J.C. Lötters^{1,2}
¹MESA+, University of Twente, THE NETHERLANDS and
²Bronkhorst High-Tech BV, THE NETHERLANDS

We developed a structure that is able to generate vortices inside a microfluidic channel, and is compatible with the surface channel technology. Initial measurements prove that the structure is able to act as a vortex flow sensor, since the vortex frequency is dependent on the flow velocity, making this the first microfluidic vortex flow sensor. The structure can also be used for passive mixing.

Physical Sensors

Fluidic Sensors (Flow, Pressure, Density, Viscosity, Etc.)

- M-142** **A NOVEL 0-3 KPA PIEZORESISTIVE PRESSURE SENSOR BASED ON A SHURIKEN-STRUCTURED DIAPHRAGM** **816**
 T. Guan, F. Yang, W. Wang, X. Huang, B. Jiang, J. He, L. Zhang,
 F. Fu, D. Li, R. Li, Q. Zhao, W. Wang, and D. Zhang
 Peking University, CHINA

We reported a novel high sensitivity and linearity 0-3 kPa piezoresistive pressure sensor by carefully trade-offing the stress on the beam edge and the deflection of the sensing diaphragm. A shuriken-structured diaphragm (SSD) was proposed for the first time to improve both sensitivity and linearity for the piezoresistive pressure sensor. The fabricated sensor showed a sensitivity of 4.72 mV/kPa/V and a nonlinearity of 0.18% FSO (full scale output) in the pressure range of 0-3 kPa.

- T-143** **ABSOLUTE PRESSURE SENSING WITH BIPOLAR CORONA DISCHARGE: DESIGN, SIMULATION AND EXPERIMENTAL VALIDATION** **820**
 V.T. Dau¹, T.T. Bui², T.X. Dinh³, T. Terebessy⁴, and H.T. Phan⁵
¹Sumitomo Chemical Ltd., JAPAN, ²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN, ³Ritsumeikan University, JAPAN,
⁴Atrium Innovation Ltd., UK, and ⁵Hanoi University of Industry, VIETNAM

In this paper we present, for the first time, a reliable cost-effective absolute pressure sensor based on a novel bipolar corona system, which monitors pressure by producing both polarity of corona discharges. The unique setup increases sensitivity and stability of the sensor. Systematical design study, numerical simulation and experiment of prototypes acquired consistent results. With sub-microampere operating current, the sensors have temperature-free sensitivity and good repeatability.

- W-144 AIRBORNE PARTICULATE MATTER CLASSIFICATION AND CONCENTRATION DETECTION BASED ON 3D PRINTED VIRTUAL IMPACTOR AND QUARTZ CRYSTAL MICROBALANCE SENSOR 824**
 J. Zhao¹, M. Liu¹, W. Wang², and J. Xie¹
¹Zhejiang University, CHINA and ²Hangzhou Dianzi University, CHINA

We develop a miniature system for detection of airborne particulate matter (PM) using a 3D printed virtual impactor for the first time to classify particles. The 3D printed virtual impactor can avoid assembly tolerance and maintain accurate alignment, which can minimize nozzle wall losses. A quartz crystal microbalance is utilized as a sensor to detect mass of the particles. The proposed system can fast complete measurement of PM concentration of 35 $\mu\text{g}/\text{m}^3$ in only 23 seconds.

- M-145 LOW-PRESSURE GAS SENSOR EXPLOITING THE KNUDSEN THERMAL FORCE: DSMC MODELING AND EXPERIMENTAL VALIDATION 828**
 A.D. Strongrich, A.J. Pikus, I.B. Sebastiao, D. Peroulis, and A.A. Alexeenko
 Purdue University, USA

We design and characterize a new microscale low-pressure gas sensor which exploits the Knudsen thermal force, a phenomenon arising in rarefied gases of non-uniform temperature. Results demonstrate a non-monotonic transition in force magnitude between the free-molecular and continuum limits, exhibiting peak output near a Knudsen number of unity. Experimental measurements are supported by atomistic stochastic numerical simulations based on the DSMC method, elucidating the mechanisms governing force production.

- T-146 MEASURING TEMPERATURE DEPENDENT VISCOSITY OF LIQUIDS USING AN ATOMIC FORCE MICROSCOPE CANTILEVER WITH A SOLID STATE HEATING ELEMENT 832**
 H.J. Kim, M.R. Rosenberger, and W.P. King
 University of Illinois, Urbana-Champaign, USA

We present a study on dynamic response of AFM cantilever with a solid state heating element in liquid and its application for measuring the temperature-dependent viscosity of liquids from 20 to 55 °C with high sensitivity. This technique requires neither a modification to commercial AFMs nor an external heater, while only heating a liquid volume of about 10 nl, which is more than 1000X less compared to state-of-the-art cantilever-based temperature-dependent viscosity measurement systems.

- W-147 MEASUREMENT OF VACUUM PRESSURE WITH CANTILEVER-BASED DIFFERENTIAL PRESSURE SENSOR UTILIZING VAPOR PRESSURE AND NARROW GAP OF CANTILEVER 836**
 N. Namioka, Y. Takei, N. Minh-Dung, T. Usami, N. Thanh-Vinh, H. Takahashi, T. Takahata, K. Matsumoto, and I. Shimoyama
 University of Tokyo, JAPAN

This paper reports a measurement method of wide-range vacuum pressure with a piezoresistive cantilever-based differential pressure sensor (DPS). The DPS has a chamber under the cantilever and its internal pressure is kept constant by saturated water vapor pressure. The DPS can detect the differential pressure between the internal pressure and the vacuum pressure, from the resistance change of the cantilever caused by mechanical deformation. We can measure 60 Pa to 1280 Pa with our device.

- M-148 SENSITIVITY ENHANCEMENT OF A CANTILEVER-TYPE AIRFLOW SHEAR STRESS SENSOR VIA SURFACE ROUGHNESS MODIFICATION 839**
 R. Kazama, H. Takahashi, N. Thanh-Vinh, T. Takahata, K. Matsumoto, and I. Shimoyama
 University of Tokyo, JAPAN

We develop a method to enhance the sensitivity of an airflow shear stress sensor by using a micropillar array. When airflow is applied to the proposed sensor, the shear stress is generated on the surface of not only the cantilever but also the micropillar array. Therefore, the horizontal strain of the cantilever with the micropillar array is larger than that of flat one. Experimental results show that the micropillar structure improves the sensor sensitivity ⁵ times compared with the flat one.

- T-149 THE SOUND OF A SLIDING DROPLET 843**
 N. Thanh-Vinh, H. Takahashi, T. Tsukagoshi, K. Matsumoto, and I. Shimoyama
 University of Tokyo, JAPAN

A direct measurement of the vibration on the surface of a droplet during its sliding on a micropillar array is reported. We show that the frequency of the vibration during the sliding of a droplet on a micropillar array does not depend on the sliding velocity nor the volume of the droplet, but increases with the increase of the micropillar array density. These results show good agreement with a previously proposed theoretical model.

- W-150** **ULTRA-COMPACT AND HIGHLY SENSITIVE PRESSURE SENSOR BASED ON NANO-GAUGE DETECTION AND COINTEGRATED WITH INERTIAL SENSORS** 846
P. Rey, A. Berthelot, G. Jourdan, H. Duchemin, R. Anciant, H. Blanc, and P. Robert
CEA-LETI, FRANCE

This paper reports the experimental pressure response of an ultra-compact and highly linear absolute pressure sensor based on suspended piezoresistive nano-gauges with mechanical amplification and embedded low voltage self-test that can be used in high temperature and harsh environments. Drastic miniaturization is achieved (0.12mm× footprint for a 1 bar structure). The M&NEMS technology used for the manufacturing enables its direct cointegration with inertial sensors.

Force and Displacement Sensors (Tactile, Force, Torque, Stress and Strain Sensor)

- M-151** **3-AXIS FULLY-INTEGRATED SURFACE-MOUNTABLE DIFFERENTIAL CAPACITIVE TACTILE SENSOR BY CMOS FLIP-BONDING** 850
S. Asano¹, M. Muroyama¹, T. Bartley¹, T. Nakayama², U. Yamaguchi²,
H. Yamada², Y. Hata³, Y. Nonomura³, and S. Tanaka¹
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³Toyota Central R&D Labs., Inc., JAPAN

We developed a 3-axis MEMS-CMOS integrated surface mountable tactile sensor for covering the whole body of a robot. This 3-axis sensor uses a bran-new CMOS-LSI with 4 channels of capacitive sensing circuit and other extended functionality. The completed sensor with a flipped CMOS-diaphragm and Au through vias outputs coded digital signals according to applied 3-axis force with small cross-sensitivity.

- T-152** **A FLEXIBLE CAPACITIVE TACTILE SENSOR ARRAY WITH HIGH SCANNING SPEED FOR DISTRIBUTED CONTACT FORCE MEASUREMENTS** 854
Y. Wang, G. Liang, D. Mei, L. Zhu, and Z. Chen
Zhejiang University, CHINA

We develop a capacitive tactile sensor array for three-axis contact force measurements. The upper and lower electrodes generate four capacitors in one sensing unit that decompose the contact force into three-axis force components. To enhance the flexibility, a thin PDMS bump (0.5 mm) and truncated pyramid dielectric layer with finer dimensions are utilized. To increase the scanning speed, the sensor array is divided into four regions and can be detected simultaneously.

- W-153** **A NANOMACHINED TORQUE SENSOR WITH ULTRAHIGH SENSITIVITY** 858
J.G. Huang^{1,2,3}, H. Cai², Y.D. Gu², B. Dong^{2,3}, J.F. Song², Z.C. Yang⁴, Y.F. Jin⁴,
Y.L. Hao⁴, J.H. Wu¹, T.N. Chen⁴, D.-L. Kwong², and A.Q. Liu³
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SINGAPORE, ³Nanyang Technological University, SINGAPORE, and
⁴Peking University, CHINA

This paper reports a novel nanoscale torque sensor in a splitting ring resonator for the first time. By taking advantage of extreme sensitivity of ring resonator, the torque sensor achieves a displacement noise floor of 80 fm Hz^{-1/2}. This is corresponding to small torque as small as 0.17×10⁻¹⁸ Nm. Particularly, the platform opens new door for a wide range of physical measurements involving extremely small torques.

- M-154** **A TACTILE SENSOR FOR SIMULTANEOUS MEASUREMENT OF APPLIED FORCES AND FRICTION COEFFICIENT** 862
T. Okatani, H. Takahashi, K. Noda, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports a tactile sensor that can measure not only normal and tangential forces but also friction coefficient simultaneously for slip prediction. Using three pairs of piezoresistive beams, normal and tangential displacement and the derivative of tangential displacement in elastic body can be detected. We demonstrate that friction coefficient can be estimated from the ratio of the resistance changes of the beams without influence of the applied forces.

- T-155** **CANTILEVER WITH 10-FOLD TUNABLE SPRING CONSTANT USING LORENTZ FORCE** 866
W. Ohnishi, H. Takahashi, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We report a cantilever with over 10-fold tunable spring constant. The spring constant can be tuned both larger and smaller using Lorentz force generated by direct current which flows through the wiring on the cantilever. The change of the spring constant was evaluated from the resonance frequency shift. The experimental result shows the resonant frequency can be controlled from 1.1 kHz to 3.8 Hz, and the ratio of the tuned spring constant to initial value is evaluated to be from 0.22 to 2.6.

W-156 DIRECT-WRITE POLYMERIC STRAIN SENSORS WITH ARBITRARY CONTOURS ON FLEXIBLE SUBSTRATES 869

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¹University of California, Berkeley, USA, ²National Tsing Hua University, TAIWAN, and

³US Army, USA

Here we demonstrate direct-write all-polymer nanofibers as uniaxial strain sensors for flexible and wearable devices. Compared to the state-of-art, the unique characteristics include: 1) direct-write all polymeric stain sensors for the first time on flexible substrates; 2) local strain sensing with arbitrary contours and designated sensing directions; and 3) 10X higher gauge factor than that of commercial metal strain sensors.

M-157 FLEXIBLE AND HIGH SELECTIVE PRESSURE SENSITIVE RUBBER FOR TACTILE SENSING 873

S. Nakata, K. Kanao, S. Harada, T. Arie, S. Akita, and K. Takei

Osaka Prefecture University, JAPAN

This study proposes and demonstrates a pillar-like, carbon/polydimethylsiloxane (PDMS)-based pressure sensor embedded in silicone rubbers to realize high selectivity of tactile pressure against bending of substrate. By arranging the design of sensing material and structure, high selective flexible PSR is realized in this study. This finding and demonstration eventually can be applied to the low-cost, high precise tactile sensor that can be conformally covered over any surfaces.

T-158 HIGH PERFORMANCE MEMS TACTILE SENSOR ARRAY WITH ROBUSTNESS AND FABRICATION SIMPLICITY 877

Q. Guo, C. Mastrangelo, and D. Young

University of Utah, USA

A 13 x 26 tactile sensor array is designed and fabricated, where the PDMS membrane is fabricated by using a 3D-printed micro-molding technique, and electrodes are fabricated on a flexible kapton substrate. The design provides a self-compensation to the misalignment, which makes sensor's nominal capacitance being highly tolerant to fabrication misalignment, thus greatly simplifying the fabrication process.

W-159 SPATIAL RESOLUTION MAXIMIZATION FOR CAPACITIVE TACTILE SENSORS 881

M. Chandra, D.-J. Yao, R. Chen, and C.-Y. Lo

National Tsing Hua University, TAIWAN

Unlike conventional four-capacitor tactile sensors, this work presents a two-capacitor arrangement to reduce the size of sensing unit and to enhance the spatial resolution without losing sensitivity and accuracy. The shapes of the capacitors were simultaneously modified from squares to rectangles to realize balanced spatial resolutions in the x- and y-direction.

M-160 THREE-AXIS FORCE-TORQUE SENSOR WITH FULLY DIFFERENTIAL CAPACITIVE READOUT 885

R.A. Brookhuis, R.G.P. Sanders, B.N.A. Sikkens, and R.J. Wiegerink

MESA+, University of Twente, THE NETHERLANDS

We present a 3-axis force/torque sensor fabricated in a single SOI wafer with fully differential capacitive readout also for the normal force measurement. Fabrication is straightforward, with only two masks for deep reactive ion etching and one release etch. Furthermore, out-of-plane displacements are limited by the buried oxide layer thickness which allows for simple overload protection. The chip has a diameter of 5 mm, a normal force range of 1 N and a torque range from -4 to +4 Nmm.

Gas and Chemical Sensors

T-161 3D POROUS GRAPHENE HYDROGEL FOR IMPROVED GAS SENSING PERFORMANCE AT ELEVATED TEMPERATURE 889

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²Massachusetts Institute of Technology, USA

The cost-effective hydrothermal synthesized graphene hydrogel is employed to fabricate a high performance NO₂ and NH₃ sensor with the assistance of an integrated microheater. For the first time, the microheater is exploited to enhance the selectivity of the graphene sensor for NO₂ sensing by elevating substrate temperature. Besides, the microheater is employed to speed up the signal recovery process. Importantly, the 3D GH exhibits 10 times higher sensitivity than 2D graphene counterpart.

W-162 A NOVEL PHOTONIC DEW-POINT HYGROMETER WITH ULTRA-HIGH ACCURACY 893

J. Tao, L. Wang, H. Cai, T. Sun, J. Song, and Y.D. Gu
*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

Here, we propose a compact dew-point hygrometer microsystem based on integrated photonics technology, which features with high accuracy, small size and low cost. Its compelling performance is demonstrated in both dew-point temperature and relative humidity detection via measuring ambient temperature synchronously. This design paves the way for the development of on-chip optically dew-point temperature and RH detection for broaden applications.

M-163 ELECTROLYTE-OXIDE-SEMICONDUCTOR STRUCTURES AS PH SENSORS BASED ON RESISTIVE-SWITCHING CHARACTERISTIC 897

H. Wang, Z. Chen, X. Chen, and W. Wu
Peking University, CHINA

We fabricated an electrolyte-oxide-semiconductor (EOS) structure as a pH sensor, which provides a new method of pH sensing based on resistive-switching characteristic for the first time. The concept of conductive filaments is introduced for EOS structures to explain their resistive-switching property. The threshold voltage shift in the C-V and I-V curves approximately linearly increases with the augment of electrolyte solution's pH value from 1 to 12 of a linear sensitivity about 46.3mV/pH.

T-164 HIGHLY SELECTIVE SENSOR FOR TRACE ARSENITE DETERMINATION USING ANODIC STRIPPING VOLTAMMETRY 901

L. Wang¹, G. Jing¹, W. Lu¹, and T. Cui²
¹Tsinghua University, CHINA and ²University of Minnesota, USA

We develop a new approach using an arsenic selective membrane of ionophore on a micro gold electrode surface to determine trace arsenic using anodic stripping voltammetry. Compared with a sensor without an ionophore membrane, the selectivity of a sensor with an ionophore membrane is greatly enhanced.

W-165 HIGHLY-SELECTIVE MULTI-TARGET 3D-PRINTED MICROFLUIDIC-BASED BREATH ANALYZER 905

M. Paknahad, J.S. Bachhal, A. Ahmadi, and M. Hoorfar
University of British Columbia, CANADA

This paper presents a low-cost, portable, and highly selective 3D-printed gas sensor for detection of human breath biomarker gases. To show the diagnostic power of the developed miniaturized gas sensor, capable of differentiating small concentrations (ppm level) of different volatile organic compounds (VOCs), the binary and triple mixtures of different biomarkers in breath are tested.

M-166 PHOTONIC NANOFENCES FOR INTEGRATED SUB-WAVELENGTH STRUCTURES-BASED SENSING APPLICATIONS 909

V.J. Cadarso¹, A. Llobera², M. Puyol³, and H. Schiff¹
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Photonic nanofences (PNFs) are introduced here as sub-wavelength advanced high-sensitivity chemical sensors. Such configuration allows evanescent field higher than 70%, while keeping the light confined, thus achieving an unprecedented light-analyte interaction strength. We demonstrate the waveguiding capabilities of these structures by presenting bent PNFs, proving their efficient light coupling. Finally, PNFs are implemented as absorbance sensor for the monitoring of lead in water environment.

T-167 PLASMONIC CRYSTAL GAS SENSOR INCORPORATING GRAPHENE OXIDE FOR DETECTION OF VOLATILE ORGANIC COMPOUNDS 913

S. Tabassum, Q. Wang, W. Wang, S. Oren, M.A. Ali, R. Kumar, and L. Dong
Iowa State University, USA

We develop an optical gas sensor built on a plasmonic crystal structure coated with graphene oxide (GO). The plasmonic crystal is formed by an array of mushroom nanosts with gold disks at the top and perforated nanoholes in a gold film at the bottom. The optical response of the device is tuned, due to absorbing different concentrations of gas. The index change of the GO coating with different thicknesses allows for selective detection of different gases by using principal component analysis.

- W-168 POLYANILINE-POLYSTYRENE NANOFIBERS DIRECTLY WRITTEN ON CHEAP FLEXIBLE SUBSTRATES BY ELECTROSPINNING, A LOW-COST AND SENSITIVE HYDROGEN SULFIDE GAS SENSOR 917**
 S. Mousavi, K. Kang, J. Park, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

A gas sensor based on polyaniline-polystyrene nanofibers doped by camphorsulfonic acid is developed. The obtained sensor has good sensitivity, low detection limit and very good recovery time compared with the previously proposed H₂S sensors based on PANi. The sensor was fabricated by a simple and low cost procedure. Using electrospinning method, high quality nanofibers were deposited directly on the interdigitated electrodes, which were fabricated on paper and polyimide substrates beforehand.

- M-169 SENSOR ARRAY BASED ON METAL OXIDE MODIFIED GRAPHENE FOR THE DETECTION OF MULTI-COMPONENT MIXED GAS 920**
 D. Zhang¹, J. Liu¹, P. Li², and B. Xia¹
¹China University of Petroleum, CHINA and ²Tsinghua University, CHINA

This paper reports a novel sensor array combining with neural network toward multi-component gases detection. Metal oxides modified graphene were used as sensing materials. The sensor array was fabricated via a facile hydrothermal route and LbL self-assembly method on substrate. And furthermore, this work successfully achieves the recognition and prediction of components in toxic gas through the combination of graphene-based sensor array and neural network-based signal processing technologies.

- T-170 WEARABLE SWEAT MONITORING SENSOR BASED ON IONIC LIQUID GEL 924**
 Y. Takei, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We fabricated wearable flexible humidity sensor that can measure human sweat. Our sensor is based on Ionic-liquid-Gel-coated Fabrics and Cloths (IG-Fabric/Cloth). We use EMIMBF₄ as ionic liquid, which has a characteristic that it absorbs H₂O and changes its impedance. We fabricated the humidity sensor on the surface of polyester t-shirt and measured the human's sweat transition when exercising and cooling down.

Inertial Sensors (Gyros, Accelerometers, Resonators, Etc.)

- W-171 A CMOS-INTEGRATED FOUR-QUADRANT SYMMETRIC MICRO-G ACCELEROMETER 926**
 W. Zhu, Y. Zhang, G. Meng, C.S. Wallace, and N. Yazdi
Evgia Systems, Inc., USA

This paper reports a CMOS-integrated MEMS microgravity accelerometer that implements a novel four-quadrant symmetric device structure with a full-bridge capacitive output. A robust silicon-on-insulator (SOI) MEMS process integrated with a standard CMOS wafer offers a high-sensitivity, low-noise and low-drift accelerometer that achieves measurement of acceleration in micro-g level. The accelerometers are fabricated and packaged on wafer-level with a silicon cap wafer.

- M-172 A HIGH-FREQUENCY EPITAXIALLY ENCAPSULATED SINGLE-DRIVE QUAD-MASS TRI-AXIAL RESONANT TUNING FORK GYROSCOPE 930**
 S. Wisher¹, P. Shao¹, A. Norouzpour-Shirazi¹, Y. Yang², E. Ng², I. Flader²,
 Y. Chen², D. Heinz², T. Kenny², and F. Ayazi¹
¹Georgia Institute of Technology, USA and ²Stanford University, USA

We introduce, for the first time a 'high-frequency' resonant tri-axial tuning fork gyroscope with a single-drive mode of operation. In contrast to conventional resonant tuning fork gyros, the resonant frequencies are designed to be relatively high (~138kHz) permitting high bandwidth for mode-matched operation and enhancing shock and vibration resistance. The results show sensitivity to all three axes with mode-matched operation for the Z-axis and mode-split for the X- and Y- axes.

- T-173 A HIGHLY SENSITIVE BIAxIAL RESONANT ACCELEROMETER WITH TWO-STAGE MICROLEVERAGE MECHANISMS 934**
 H. Ding, J. Zhao, B. Ju, and J. Xie
Zhejiang University, CHINA

We report a biaxial resonant accelerometer with two-stage microleverage mechanisms. Experimental results demonstrate that the average differential sensitivity of the resonant accelerometer is 275 Hz/g at resonant frequency of 290 kHz under polarization voltage of 5V. The sensitivity is higher than the previous reported data, which owns to the great amplification factor of the two-stage microleverage mechanisms. The measured cross-axis sensitivity is lower than 3.4%.

W-174 A MODE LOCALIZATION BASED RESONANT MEMS TILT SENSOR WITH A LINEAR MEASUREMENT RANGE OF 360° 938

B. Li, H. Zhang, J. Zhong, and H. Chang
Northwestern Polytechnical University, CHINA

We reported a mode localization based resonant MEMS tilt sensor and its full-measurement-range is extended to $[-90^\circ, 90^\circ]$ with the non-linearity less than 4.5%. The sensitivity of the amplitude ratio metric (7641 ppm/°) is 169 times higher than that of the frequency (45 ppm/°). To improve the sensitivity and linearity, two mode localization based accelerometers are packaged perpendicularly and their amplitude ratios are selected alternatively per 90° to be the output of the tilt sensor.

M-175 A NOVEL IMPACT TESTER FOR IN SITU EVALUATING THE SHOCK RELIABILITY OF MICRO-STRUCTURES 942

L. Zhang, F. Yang, R. Li, T. Guan, J. He, F.S. Fu, D. Li and D. Zhang
Peking University, CHINA

We reported a novel impact tester which was, for the first time as far as the authors know, able to generate an in situ impact acceleration high than 120000 g to evaluate the shock reliability of microfabricated structures. Besides, the tester was fabricated with the same process as those widely used for comb-based MEMS sensor, which made it suitable for in situ process quality monitoring and basic structure property evaluation in mass production.

T-176 ACCELERATION-INSENSITIVE FULLY-DECOUPLED TUNING FORK (FDTF) MEMS VIBRATORY GYROSCOPE WITH 1°/HR BIAS INSTABILITY 946

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¹*National Tsing Hua University, TAIWAN and*
²*Taiwan Semiconductor Manufacturing Company Ltd. (TSMC), TAIWAN*

We demonstrate a single-axis MEMS vibratory gyroscope with fully-decoupled mechanism and tuning fork architecture (FDTF gyro) to enhance the acceleration rejection and bias instability. Different spring designs are utilized for specific purposes (moment balance, low quadrature error, spurious modes elimination...). As the result, this device can achieve 126 deg/s coupling error and 1.6 deg/s/g acceleration sensitivity. Moreover, the bias instability is 1 deg/hr and ARW is 7.2 deg/hr/rtHz.

W-177 ANTI-STICTION METHOD FOR MEMS ACCELERATION SWITCH EMPLOYING AN ADDITIONAL MASS STRUCTURE 950

S. Jang, J. Hwang, and Y.-K. Kim
Seoul National University, SOUTH KOREA

We propose a novel anti-stiction method for MEMS acceleration switch employing an additional mass structure. The additional mass is constructed to provide additional restoring force to the proof mass. The additional mass pushes the proof mass back to its initial position when the stiction failure is occurred. The proposed method requires no additional fabrication steps nor deliberately induced electrostatic force to resolve the stiction failure.

M-178 COMPARISON OF LONG-TERM STABILITY OF AM VERSUS FM GYROSCOPES 954

B. Eminoglu¹, Y.-C. Yeh¹, I.I. Izyumin¹, I. Nacita², M. Wireman², A. Reinelt², and B.E. Boser¹
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A vibrating ring gyroscope is operated in AM and FM mode to demonstrate improved long-term stability of FM operation. Both bias and scale-factor (SF) accuracy were tested over a one-month period with devices power cycled between measurements. Bias and SF improve by more than two orders-of-magnitude from 335mdps to 2.86mdps and from 518ppm to 4.31ppm in the AM and FM modes, respectively.

T-179 COMPREHENSIVE MODELLING AND EXPERIMENTAL VERIFICATION OF AIR DAMPING COEFFICIENTS IN MEMS OF COMPLEX GEOMETRY 958

G. Laghi¹, A.A. Frangi¹, P. Fedeli¹, G. Gattere², and G. Langfelder¹
¹*Politecnico di Milano, ITALY and* ²*ST Microelectronics, ITALY*

The work presents a tool for damping estimation at frequencies, gaps and pressures typical of MEMS gyroscopes. After modelling the damping contributions, validation is obtained through measurements on 292 devices of 37 geometries. The structures are initially tested in package. Each package is then subject to a focus ion beam, so that the devices can be operated at variable pressures in a vacuum chamber. Predictions are confirmed with a $\pm 15\%$ accuracy, limited by the reference pressure sensor.

W-180 ENCAPSULATED DISK RESONATOR GYROSCOPE WITH DIFFERENTIAL INTERNAL ELECTRODES 962

C.H. Ahn, D.D. Shin, V.A. Hong, Y. Yang, E.J. Ng, Y. Chen, I.B. Flader, and T.W. Kenny
Stanford University, USA

In this study we demonstrate for the first time integration of differential internal electrodes into a Disk Resonator Gyroscope (DRG) design within a wafer-scale encapsulation process. The differential internal electrodes design enables the mode-matching operation of the device with low DC power supplies (± 5 V) thanks to the enhanced transduction area, while maintaining similar performance to the previously reported baseline DRG. The mode-matching operation yields a scale-factor of 1.37 mV/(°/s) and an ARW of $0.29^\circ/\sqrt{\text{hr}}$.

M-181 EPITAXIALLY-ENCAPSULATED QUAD MASS GYROSCOPE WITH NONLINEARITY COMPENSATION 966

P. Taheri-Tehrani¹, M. Kline², I. Izyumin², B. Eminoglu², Y.-C. Yeh², Y. Yang³,
Y. Chen³, I. Flader³, E.J. Ng³, T.W. Kenny³, B.E. Boser², and D.A. Horsley¹

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³Stanford University, USA

We present an epitaxially-encapsulated 2mm by 2mm quad mass gyroscope (QMG). Due to the device's small size, high quality factor (Q) and large oscillation amplitude are required to achieve low noise. However, the device's high Q (85,000) makes it highly sensitive to mechanical nonlinearity, resulting in amplitude-frequency dependence and instability of the oscillator loop at large amplitudes. To overcome these problems, we demonstrate electrostatic compensation of the mechanical nonlinearity.

T-182 HIGH-Q LOW IMPEDANCE UHF-BAND ALN-ON-SI MEMS RESONATORS USING QUASI-SYMMETRICAL LAMB WAVE MODES 970

H. Zhu, C. Tu, and J.E.-Y. Lee

City University of Hong Kong, HONG KONG

This paper describes for the first time the phase velocity dispersion characteristics of Lamb waves propagating in AlN-on-Si plates to achieve Q>10000 and motional resistance of 20Ω at 260MHz in air by using the fundamental quasi-symmetrical mode (QS0). The ratio of the Si layer thickness over the acoustic wavelength imposes a limit on frequency scaling by reducing electromechanical coupling for the QS0 mode while enhancing the spurious quasi-antisymmetrical (QA0) mode.

W-183 INDUCTIVE CMOS MEMS ACCELEROMETER WITH INTEGRATED VARIABLE INDUCTORS 974

Y. Chiu, H.-C. Hong, and C.-W. Lin

National Chiao Tung University, TAIWAN

This paper reports an inductive CMOS MEMS accelerometer with integrated variable inductors as the position sensing elements to reduce the dependence of device characteristics on stress-induced structural deformation. The variable inductors are used in on-chip LC tank oscillators. The oscillation frequency variation is proportional to the inductance change induced by the external acceleration. Experimental results showed the proposed accelerometer had a sensitivity of 150 kHz/g.

M-184 MEMS ABOVE CMOS PROCESS FOR SINGLE PROOF-MASS 3-AXIS LORENTZ-FORCE RESONANT MAGNETIC SENSOR 978

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¹National Tsing Hua University, TAIWAN and

²Taiwan Semiconductor Manufacturing Company, Ltd., TAIWAN

This study designs and implements a silicon-based 3-axis Lorentz-force resonant magnetic sensor with single proof-mass using TSMC bulk MEMS above CMOS process. Features of this study: (1) novel spring design acts as current-carrying and enables torsion/linear motions by magnetic-fields; (2) single proof-mass for 3-axis magnetic-fields detection; (3) compatible with MEMS inertial sensors process platform. A proof-mass with gap-closing sensing for 3-axis magnetic-fields detection is demonstrated.

T-185 MICRO-OVEN-CONTROLLED N⁺⁺ [100] LENGTH-EXTENSIONAL-MODE OSCILLATOR FOR NEAR ZERO TEMPERATURE DRIFT 982

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¹Chinese Academy of Sciences, CHINA and ²Fudan University, CHINA

This paper reports a uniformly heated micro-oven-controlled oscillator operating at the turnover temperature point of an N⁺⁺ [100] length-extensional-mode structure. Because the TCF around the turnover point is close to zero, it is shown for the first time that an open-loop polynomial fitting algorithm based on the thermoresistor outside the micro-oven is sufficiently accurate to achieve a frequency stability of ±0.8 ppm from 25 °C to 65 °C.

W-186 MOLECULAR ELECTRONIC TRANSDUCER BASED PLANETARY SEISMOMETER WITH NEW FABRICATION PROCESS 986

M. Liang¹, H. Huang¹, V. Agafonov², R. Tang¹, R. Han¹, and H. Yu¹

¹Arizona State University, USA and ²Moscow Institute of Physics and Technology, RUSSIA

We developed a novel design and implementation of short period seismometer based on molecular electronic transducer (MET) to decrease the noise floor for the purpose of planetary exploration.

M-187 **PIEZOELECTRIC MICRO DITHER STAGE CALIBRATION OF 6-AXIS IMU** 990
V. Pinrod, S. Nadig, S. Ardanuç, and A. Lal
Cornell University, USA

We demonstrate the use of a multi-axis, micro piezoelectric stage for simultaneous extraction of the scale factor and cross axis sensitivity of a commercially available 6-DOF IMU (MAX21105). Small dimensions of the stage and inertia allow on-the-fly calibration and tracking of scale factor drift using rotation dither rates and accelerations as high as 100 deg/sec and 90 m/s², respectively. We measure gyroscope cross-axis sensitivities of 2.4%, which is within the IMU specifications.

T-188 **Q-FACTOR OPTIMIZATION IN DISK RESONATOR GYROSCOPES VIA GEOMETRIC PARAMETERIZATION** 994
D.D. Gerrard, C.H. Ahn, I.B. Flader, Y. Chen, E.J. Ng, Y. Yang, and T.W. Kenny
Stanford University, USA

We present an assortment of geometrically parameterized disk resonator gyroscopes (DRGs) designed independently for resonant frequency (f) and quality factor (Q). This demonstrates the capability to consistently model and predict Q in fabricated devices, and to use this to significantly improve a key performance metric for the DRG. We show that Q can be increased by a factor of 2.6 and demonstrate that future DRG Q optimization can be done by making geometric/topological changes.

W-189 **STOCHASTIC METHOD FOR DISK RESONATING GYROSCOPE MODE MATCHING AND QUADRATURE NULLING** 998
I.B. Flader, C.H. Ahn, E.J. Ng, Y. Yang, V.A. Hong, and T.W. Kenny
Stanford University, USA

A new method is described for mode-matching and quadrature nulling of a MEMS wineglass mode gyroscope utilizing particle swarm optimization. Derivative-free optimization allowed for multiobjective optimization of gyroscopic performance parameters. Optimal values for frequency split, quadratures, and principle axis amplitudes were found which greatly increased the scale factor of the sensor as well as enhanced the noise performance.

M-190 **THE CMOS-MEMS 3-AXIS CAPACITIVE ACCELEROMETER TO MEET THE COMMERCIAL SPECIFICATIONS** 1002
M.-H. Tsai¹, C.-M. Sun¹, W.-J. Mao², and W. Fang²
¹*PixArt Imaging Inc., TAIWAN* and ²*National Tsing Hua University, TAIWAN*

We successfully developed world first post CMOS-MEMS 3-axis accelerometers with LGA package to meet the commercial specifications. The CTE mismatch of CMOS materials induced thermal deformation and drift problem has been totally solved using process and structure design methodology.

Manufacturing Techniques for Physical Sensors

T-191 **EXPERIMENTAL STUDY OF OUT-OF-PLANE ADHESION FORCE EVOLUTION (AND REGRESSION) FOR MEMS ACCELEROMETERS** 1006
S. Dellea¹, F. Rizzini², A. Tocchio², R. Ardito¹, and G. Langfelder¹
¹*Politecnico di Milano, ITALY* and ²*ST Microelectronics, ITALY*

The work investigates adhesion evolution in out-of-plane (OOP) test devices fabricated in an industrial surface micromachining process. The aim is to mimic the behavior of OOP accelerometer. The experiments include: measurements of pristine adhesion force; application of dynamic impacts at known contact velocity and adhesion evolution monitoring; adhesion force monitoring within 40 days after the former test ends. The adhesion force increases during cycles and it decreases after the end of them.

W-192 **FABRICATION OF SMOOTH-SURFACED FLEXIBLE THERMAL SENSOR FOR DETECTING WALL SHEAR STRESS** 1010
Y. Hasegawa¹, T. Yamada², and M. Shikida¹
¹*Hiroshima City University, JAPAN* and ²*Nagoya University, JAPAN*

We newly proposed a novel type of smooth-surfaced flexible thermal shear stress sensor, and developed fabrication process on a micro-machined PDMS structure and film transfer technology. The proposed sensor has the advantages that it can place on curved streamlined surface of the conveyance because of its flexibility, and also can measure the shear stress with high degree of accuracy because of smooth sensor surface.

- M-193 HARPSS-FABRICATED NANO-GAP COMB-DRIVE FOR EFFICIENT LINEAR ACTUATION OF HIGH FREQUENCY BAW RESONATORS 1014**
 H. Wen, A. Daruwalla, R. Mirjalili, and F. Ayazi
Georgia Institute of Technology, USA

We present a HARPSS-fabricated nano-gap comb-drive actuator providing a significantly higher linear force density than conventional silicon comb-drive. The combined large force density and linear range makes it an enabling actuator for BAW resonators. Annulus BAW resonators with nano-gap comb-drive are designed, fabricated, and tested. Results confirm the elimination of electrical nonlinearity and reveal a spring hardening nature of (100) wine-glass mode for N-doped annulus BAW resonators.

- T-194 IMPROVEMENT OF POLARIZATION LIFETIME BY USING WAFER-LEVEL MICRO SPHERICAL RUBIDIUM VAPOR CELLS FOR CHIP-SCALE ATOMIC MAGNETOMETERS 1018**
 Y. Ji, Q. Gan, L. Wu, and J. Shang
Southeast University, CHINA

This paper presents a novel design for chip scale atomic magnetometers using a micro spherical rubidium vapor cell. Compared with the traditional planar rubidium vapor cell with the same internal volume and buffer gas pressure, the micro spherical rubidium vapor cell is demonstrated with improved polarization time.

- W-195 MASS SENSITIVITY AMPLIFICATION BY USING GAUSSIAN-SHAPED QUARTZ CRYSTAL RESONATOR 1022**
 H. Kutsuwada, S. Watanabe, M. Sohgewa, and T. Abe
Niigata University, JAPAN

We report the mass sensitivity amplification of Gaussian-shaped quartz crystal resonator (Gaussian-shaped QCR). To achieve this purpose, a fabrication process of the QCR was developed by using photolithographic methods. Interestingly, the sensitivity amplification in the QCR was observed at the central portion. The mass response was 3 times higher than theoretical value for flat shape resonator. This resonator is expected to apply for the mass measurement of the various micro/nanoparticles.

- M-196 STIFFNESS TRIMMING OF HIGH Q MEMS RESONATORS BY EXCIMER LASER ANNEALING OF GERMANIUM THIN FILM ON SILICON 1026**
 B. Hamelin, A. Daruwalla, and F. Ayazi
Georgia Institute of Technology, USA

This paper reports on optical resonance frequency trimming of high-Q resonators. Germanium on top of a silicon MEMS resonator is heated by a UV laser beam to high temperatures, enabling the crystallization of SiGe. The mechanical properties of SiGe crystals reduce the resonance frequency. Both large trimming range and high resolution are demonstrated while preserving the quality factor constant. Frequency characteristics of a trimmed resonator stay stable after annealing (450°C for 30 minutes).

- T-197 ULTRA-THIN PIEZOELECTRIC STRAIN SENSOR 5 X 5 ARRAY INTEGRATED ON FLEXIBLE PRINTED CIRCUIT FOR STRUCTURAL HEALTH MONITORING BY 2D DYNAMIC STRAIN SENSING 1030**
 T. Kobayashi¹, T. Yamashita¹, N. Makimoto¹, S. Takamatsu¹, T. Itoh^{1,2}, and H. Okada¹
¹National Institute of Advanced Industrial Science and Technology (AIST), JAPAN and
²University of Tokyo, JAPAN

We have fabricated ultra-thin piezoelectric strain sensor 5x5 array on PEN FPC. Twenty five of MEMS-based ultra-thin piezoelectric strain sensors made of PZT(2um)/Si(3um) plate were transferred onto the FPC with adhesive layer by a chip mounter with a specially designed rubber collet. PZT and Cu wiring were connected with Ag paste by screen printing. The fabricated dynamic strain sensors have 0.16 mV/ue of sensitivity, which is similar to that of conventional strain gauges.

Materials for Physical Sensors

- W-198 GIANT ELECTRO-MECHANICAL TRANSDUCTION IN ALL-ORGANIC MEMS FOR PHYSICAL AND CHEMICAL SENSORS 1034**
 D. Thuau, M. Abbas, G. Wantz, L. Hirsch, I. Dufour, and C. Ayela
Université de Bordeaux, FRANCE

We report an all-organic MEMS sensor with a cutting-edge electro-mechanical transducer based on an active OFET. The strategy lies in the integration of a piezoelectric (P(VDF/TrFE)) copolymer as active gate dielectric layer in an OFET device mounted on a polymer cantilever. This original transducer amplifies and converts the charges generated by the piezoelectric layer due to surface stress into record drain current variations.

- M-199 HIGH PERFORMANCE FLEXIBLE ULTRAVIOLET PHOTODETECTORS BASED ON TiO₂/GRAPHENE HYBRID 1038**
C. Zhou, X. Wang, X. Kuang, and S. Xu
Tsinghua University, CHINA

We report a novel ultraviolet photodetector based on TiO₂/Graphene hybrid. In the hybrid material, Graphene brings two major benefits: (1) large surface area, (2) the generated electrons are instantly collected which can overcome the low quantum efficiency of pristine TiO₂. Thus, the collaboration of TiO₂ and Graphene contributes to the high performance of the device. Moreover, this device is fabricated on a flexible substrate which broadens the future of photodetectors in wearable devices.

- T-200 MICROFABRICATED VANADIUM OXIDE RESONANT THERMAL SENSOR WITH A HIGH TEMPERATURE COEFFICIENT OF RESONANT FREQUENCY 1042**
N. Inomata, L. Pan, M. Toda, and T. Ono
Tohoku University, JAPAN

This study describes our newly fabricated resonant thermal sensors based on vanadium oxide and investigates the temperature dependences of their resonant frequencies and Q factor. The value of temperature coefficient of the resonant frequency is -1308 ppm/K in the range of 20–100°C. The temperature and thermal resolution of the vanadium oxide resonator are estimated as 1.69 mK/√Hz and 4.3 nW/√Hz, respectively.

- W-201 SMART DIGITAL MICRO-CAPACITOR BASED ON DOPED NANOCRYSTALLINE SILICON WITH HfO₂ HIGH K INSULATOR 1046**
Y.Q. Fu¹, J.K. Luo², S. Milne³, A.J. Flewitt³, and W.I. Milne³
¹Northumbria University, UK, ²Bolton University, UK, and ³University of Cambridge, UK

A novel digitally tuning variable capacitors was developed. As top multi-cantilevers have different lengths, increasing the applied voltage pulls down cantilever beams sequentially, realizing increase of the capacitance with the applied voltage. The capacitance is determined by thickness of insulator and dielectric constant. Increase of the voltage pull-in the remaining cantilever beams one by one from long to short, realizing a step increase in capacitance.

Nanoscale Physical Sensors

- M-202 REAL TIME SENSING IN THE NON LINEAR REGIME OF NEMS RESONATORS 1050**
M. Sansa^{1,2}, V.-N. Nguyen³, S. Baguet³, C.-H. Lamarque³, R. Dufour³, and S. Hentz^{1,2}
¹Université Grenoble Alpes, FRANCE, ²CEA-LETI, FRANCE, and ³Université de Lyon, FRANCE

This paper reports the proof of concept of a non-linear detection scheme for Nanoelectromechanical (NEMS) resonators for sensing applications. This set-up increases the dynamic range of a resonant sensor by operating it at amplitudes beyond its limit of linearity. Unlike other works in non-linear sensing, this method allows the tracking of the resonance frequency in real time, while being suitable for multi-mode operation and hence, single-particle detection for example.

- T-203 TEMPERATURE-DRIFT REJECTION AND SENSITIVITY TO MISMATCH SYNCHRONIZED STRONGLY-COUPLED M/NEMS RESONATORS 1054**
P. Prache^{1,2}, A. Uranga², N. Barniol², and J. Juillard¹
¹Geeps, FRANCE and ²Universitat Autònoma de Barcelona, SPAIN

We model and develop an architecture to strongly couple two MEMS resonant sensors. We obtain a differential measurement with enhanced sensitivity to the mismatch between the resonators. The differential measurement also rejects drifts like temperature changes. These two properties are shown here and proven to be according to the theory.

- W-204 ULTRA-SENSITIVE PHOTON SENSOR BASED ON SELF-ASSEMBLED NANOPARTICLE PLASMONIC MEMBRANE RESONATOR 1058**
X. Wang^{1,2}, K.J. Si³, J. Yang², X. Wu¹, Q. Qin², W. Cheng³, and Y. Lu²
¹National University of Defense Technology, CHINA, ²Australian National University, AUSTRALIA, and ³Monash University, AUSTRALIA

We demonstrate, for the first time, an ultra-sensitive photon sensor based on a membrane mechanical resonator which consists of a freestanding one-particle-thick super-lattice sheet of self-assembled nanoparticles. Because of plasmonic resonances, the membrane resonator has very strong light-matter interactions, which converts photons to heat at a very high efficiency; and the inorganic-organic hybrid nature of the membrane owns an extremely temperature-sensitive stiffness and low mass.

Other Physical Sensors

- M-205** **A HIGH LINEARITY CAPACITIVE TEMPERATURE SENSOR
FABRICATED BY METALMUMPS PROCESS** 1062
Q. Ren, L. Wang, Q. Huang, and L. Dong
Southeast University, CHINA

This paper presents the design, analysis and measurement of a high linearity capacitive temperature sensor. The capacitive temperature sensor consists of two kinds of temperature sensitive capacitors. By using lateral capacitors to compensate the nonlinearity of vertical capacitors, high linearity and proper sensitivity characterization is achieved. The measured nonlinearity of the capacitive temperature sensor is less than 1%, and its sensitivity is 19.4 fF/K.

- T-206** **A LOW-COST WEARABLE RADIATION SENSOR BASED ON
DOSE RESPONSE VIABILITY OF YEAST CELLS** 1066
C.K. Yoon, A. Kim, M. Ochoa, T. Parupudi, and B. Ziaie
Purdue University, USA

Our dosimeter uses yeast housed in a low cost wearable MEMS structure as a biologically-sensitive radiation indicator (canary in the coal mine). The dose response viability of yeast cells and the resulting gas generation in presence of sucrose solution is used to deflect a PDMS membrane and activate an LED indicator. The sensor allows radiation detection with sensitivity of -0.183 mm/decade-rad (1–1000 rad).

- W-207** **HORIZONTAL CHIP-SCALE CASCADE IMPACTOR WITH
INTEGRATED RESONANT MASS BALANCES** 1070
M. Maldonado-Garcia¹, J.C. Wilson², and S. Pourkamali¹
¹*University of Texas, Dallas, USA* and ²*University of Denver, USA*

Design and fabrication of a chip-scale horizontal cascade aerosol impactor for airborne particulate size separation and mass concentration measurement. The device is comprised of two micromachined silicon substrates: 1. the main SOI substrate, with resonant mass balances, micro-nozzles, and air feedthroughs, and 2. a silicon sealing cap with air-paths and feedthroughs for electrical contacts. Tests were performed in laboratory and the particle mass concentrations were measured for two cut sizes.

- M-208** **HIGH-RESOLUTION AND LARGE DYNAMIC RANGE ELECTROMETER
WITH ADJUSTABLE SENSITIVITY BASED ON MICRO RESONATOR
AND ELECTROSTATIC ACTUATOR** 1074
J. Zhao¹, H. Ding¹, S. Ni¹, L. Fu¹, W. Wang², and J. Xie¹
¹*Zhejiang University, CHINA* and ²*Hangzhou Dianzi University, CHINA*

We report a novel resonant electrometer with resolution of sub-1 femto coulomb, in which scheme of adjustable sensitivity is firstly proposed to realize both high resolution and large dynamic range. The resonant electrometer includes a double-ended tuning fork resonator, dual micro-levers for sensitivity amplification and an electrostatic comb-drive actuator for sensitivity adjustment and ensuring the large dynamic range.

- T-209** **REAL-TIME MASS SENSING AND DYNAMIC IMPACT MONITORING
OF PRINTED PICO-LITER DROPLETS REALIZED BY A
THERMAL-PIEZORESISTIVE SELF-SUSTAINED OSCILLATOR** 1078
E.-C. Chang, C.-C. Chen, and S.-S. Li
National Tsing Hua University, TAIWAN

In this work, we successfully demonstrated a real-time mass sensor utilizing a thermal-piezoresistive self-sustained micromechanical oscillator (TPO) fabricated by a standard silicon-on-insulator (SOI) MEMS process. The proposed TPO mass sensor has several key features, including real time monitoring, fast response time, high mass sensitivity of 3.4Hz/pg, and most importantly very high mass resolution of only 100fg estimated from the TPO's Allan deviation.

- W-210** **SELF-ALIGNED, GATED BULK MOLYBDENUM
FIELD EMITTER ARRAYS** 1082
N. Zhu¹, K. Xu¹, Y. Zhai², Z. Tao², and J. Chen¹
¹*Peking University, CHINA* and ²*Southeast University, CHINA*

This paper reports the fabrication of bulk molybdenum field emitter arrays with integrated, self-aligned extractor gates using Molybdenum DRIE. The fabrication process is much simpler than that of the conventional Spindt array, and the distance of gate to emitter can be precisely controlled by the thickness of SiO₂. A current densities of 8.4mA/cm² were produced by a very uniform array of 2500 tips in 1mm² at gate-emitter voltages of 120 V.

Sonic and Ultrasonic MEMS Transducers (Microphones, PMUTs, Etc.)

- M-211 ALN-ON-SOI PLATFORM-BASED MEMS HYDROPHONE WITH ULTRA LOW OPERATION FREQUENCY AND ULTRA-HIGH NOISE RESOLUTION 1086**
J. Xu, X. Zhang, S.N. Fernando, S. Merugu, K.T. Chai, and A.V. Gu
*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

This paper reports a piezoelectric aluminum nitride (AlN) based MEMS hydrophone with ultra-low operation frequency and ultra-high noise resolution. The fabricated hydrophone achieved a non-linearity of 0.11%, a sensitivity of $-182.5\text{dB}\pm 0.3\text{dB}$ (ref. to $1\text{Vrms}/\mu\text{Pa}$) and a noise resolution 57.5dB referenced to $1\mu\text{Pa}/\sqrt{\text{Hz}}$ at the ultra-low operation frequency of $10\text{Hz}\sim 100\text{Hz}$.

- T-212 COMPARATIVE CHARACTERIZATION OF BIMORPH AND UNIMORPH ALN PIEZOELECTRIC MICRO-MACHINED ULTRASONIC TRANSDUCERS 1090**
L. Lou¹, H. Yu², M.T.X. Haw¹, S. Zhang¹, and Y. Gu¹
¹*Agency for Science, Technology and Research (A*STAR), SINGAPORE and*
²*Huazhong University of Science and Technology, CHINA*

We report a rigorous comparative study of bimorph and unimorph AlN piezoelectric micro-machined ultrasonic transducer (pMUT) for the first time. By deactivating the actuation function of its top Mo/AlN layers, we realized same-device, high-fidelity comparative study by eliminating all negatively contributing factors. The reported bimorph pMUT has dynamic deflection of 77% increase compared to the unimorph.

- W-213 DESIGN AND IMPLEMENTATION OF 3D "DISK-SHAPED" MEMS VECTOR HYDROPHONE FOR ACOUSTIC ORIENTATION 1094**
R. Wang, Y. Liu, W. Xu, M. Liu, B. Bai, G. Zhang, C. Xue, J. Liu, W. Zhang, and B. Zhang
North University of China, CHINA

In order to obtain the explicit underwater orientation, high-sensitivity 3D "Disk-structure" MEMS Vector Hydrophone (3DDVH) is proposed, which realizes tri-axial acoustic pressure sensing via appropriate structure design and piezoresistor distribution. Compared to previously reported 3D MEMS vector hydrophone, 3DDVH is advanced in tri-axial match so that it's promising in accurate acoustic orientation.

- M-214 MEMS DIGITAL PARAMETRIC LOUDSPEAKER 1098**
A. Arevalo¹, D. Castro¹, D. Conchouso¹, J. Kosel¹, and I.G. Foulds^{1,2}
¹*King Abdullah University of Science and Technology (KAUST), SAUDI ARABIA and*
²*University of British Columbia, CANADA*

We designed, fabricated and characterized MEMS transducer arrays suitable for Digital Sound Reconstruction and Parametric Directional Loudspeakers. We used the electrostatic principle actuation and the piezoelectric principle. Our devices can be operated for either in the Digital Sound Reconstruction mode or Parametric Loudspeaker mode, depending on the controlled input signals with which they are actuated.

- T-215 DUAL-ELECTRODE BIMORPH PMUT ARRAYS FOR HANDHELD THERAPEUTIC MEDICAL DEVICES 1102**
S. Akhbari¹, A. Voie², Z. Li^{1,3}, B. Eovino¹, and L. Lin¹
¹*University of California, Berkeley, USA, ²BURL Concepts, Inc., USA, and*
³*Xi'an Jiaotong University, CHINA*

A CMOS-compatible, dual-electrode bimorph pMUT array is developed to generate high intensity of $30\text{--}70\text{mW}/\text{cm}^2$ into tissue using 5Vac , suitable for handheld therapeutic devices that use LIPUS for fracture healing. The fabrication also introduces a novel method using SiO_2 as the barrier to increase the breakdown voltage and parasitic resistance of AlN for better yield. The prototype array is measured to have the highest normalized intensity (i.e. $\text{In}=\text{I}/(\text{VNd}_{31})^2$) among all reported pMUT arrays.

- W-216 ELECTRICALLY SWITCHABLE MULTI-FREQUENCY PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER (PMUT) 1106**
T. Wang and C. Lee
National University of Singapore, SINGAPORE

This paper proposed a new piezoelectric micromachined ultrasonic transducer (pMUT). Conventionally one pMUT works at one frequency, and such transducer needs to be physically changed to meet different frequency requirements. The proposed pMUT, however, can switch among three frequencies by activating different electrodes. The sensitivity is better than or comparable to the conventional pMUT at these frequencies. The frequency switching is realized by the same device for the first time.

- M-217 MICROMACHINED PIEZOELECTRIC ULTRASONIC TRANSDUCER BASED ON DOME-SHAPED DIAPHRAGM SUPPORTED BY FLAT SQUARE DIAPHRAGM 1110**
 Y. Tang, Y. Wang, L. Zhao, A. Shkel, and E.S. Kim
University of Southern California, USA

We designed and microfabricated an ultrasonic transducer based on a piezoelectrically actuated SiN dome-shaped diaphragm supported at the center of a flat square diaphragm. The spherical diaphragm is fabricated by silicon isotropic etching while the whole diaphragm is released by KOH etching with a novel dicing-based front-to-back alignment method. Shadow masks are used for patterned film depositions on 3D dome diaphragm. The measured sound pressure level is up to 79.9 dB between 12 ~ 40 kHz.

- T-218 MULTI-BAND ASYMMETRIC PIEZOELECTRIC MEMS MICROPHONE INSPIRED BY THE *ORMIA OCHRACEA* 1114**
 Y. Zhang, R. Bauer, J.F.C. Windmill, and D. Uttamchandani
University of Strathclyde, UK

We present a piezoelectric directional MEMS microphone inspired by the parasitoid fly *Ormia ochracea*, which is fabricated by using the PiezoMUMPs foundry process. This device achieves, for the first time, sound localization within four frequency bands, all lying below 15 kHz. Due to its asymmetric geometry and opened backside, the device acts as a pressure gradient microphone with bi-directional polar patterns in all frequency bands.

- W-219 PRINTED MEMBRANE ELECTROSTATIC MEMS MICROSPEAKERS 1118**
 A. Murarka, J.H. Lang, and V. Bulović
Massachusetts Institute of Technology, USA

We report the fabrication and operation of MEMS microspeakers formed by the contact-transfer of thin gold membranes onto patterned silicon dioxide substrates. The membranes suspended over cavities in a dielectric layer atop a conducting electrode deflect upon electrostatic actuation and produce sound. The speakers are operated at a significantly lower bias voltage of 10 V, thus enabling the use of electrostatic sound sources in portable audio applications such as hearing aids and earphones.

- M-220 WOOD MONITORING USING MEMS ACOUSTIC SENSOR 1122**
 K. Matsudaira, N. Minh-Dung, Y. Takei, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We developed wood monitoring method using a piezoresistive MEMS sensor. The sensor utilizing the structure of liquid-on-beam, which is highly sensitive and is able to measure vibration in a wide frequency range. Surface of the sensor is PDMS (Polydimethylsiloxane), whose acoustic impedance is matched with that of xylem. Experiments demonstrated that the sensor can monitor the crack generation on woods and can discriminate the moisture difference.

PowerMEMS and Actuators Actuator Components and Systems

- T-221 A NOVEL SHOCK PROTECTION METHOD BASED ON MEMS COMPLIANT LATCHING STOPPER 1125**
 K. Xu¹, N. Zhu¹, X. Zhang², W. Su¹, W. Zhang¹, and Y. Hao¹
¹*Peking University, CHINA and* ²*Chinese Academy of Science, CHINA*

We develop a novel shock protector based on compliant latching system for the shock resistance enhancement of inertial MEMS devices applied in high shock environment. For the first time, MEMS latches have been employed to dissipate energy during impact and thus reduce the impact force applied on microstructures. In this work, the compliant latching stopper has been verified to provide multi-fold shock resistance improvement compared to some traditional shock protection structure.

- W-222 DESIGN AND OPTMIZATION OF A NONLINEAR OSCILLATOR FOR DRAG REDUCTION ON AIRFOILS 1129**
 M.B. Mansoor, S. Koeble, P. Woias, and F. Goldschmidtboeing
University of Freiburg - IMTEK, GERMANY

We demonstrate a novel resonant piezoelectric oscillator design for the manipulation of the turbulent boundary layer on airfoils. A thorough analysis of the system's non-linear dynamics help convert the abrupt, chaotic and irregular response to a desirable smooth hardening response. The high force-actuator shows an amplitude of 500 to 700 μm in the frequency range of 900 to 1200 Hz, while the MEMS counterpart shows a stroke of up to 200 μm in the same frequency range.

M-223 ELECTROSTATIC FLAPPING WINGS WITH PIVOT-SPAR BRACKETS FOR HIGH LIFT FORCE 1133

Z. W. Liu¹, X. J. Yan¹, M. J. Qi¹, and L. W. Lin²

¹Beihang University, CHINA and ²University of California, Berkeley, USA

We present artificial electrostatic flapping wings using the "pivot-spar" brackets to achieve high lift force for the first time as compared to the state-of-art: (1) 2.5X higher lift force at 82.4μN; (2) 3X lower overall weight at 330mg using wings made of metal beams and 3 micron thick PET membranes; and (3) 7.5X higher total output force/weight efficiency for the whole system. As such, this work advances the field of Micro Aerial Vehicles toward autonomous flying.

T-224 ELECTROTHERMAL OUT-OF-PLANE-DRIVE WITH NOVEL BISTABLE MECHANISM FOR PORTABLE BRAILLE DISPLAYS 1137

M. El Khoury, C. Nakic, T. Winterstein, and H.F. Schlaak

Technische Universität Darmstadt, GERMANY

A novel polymer-based bistable out-of-plane-drive with electrothermal actuation for portable Braille displays is presented. The drive consists of an out-of-plane-actuator which moves a Braille-pin out of the display surface and an in-plane-actuator which locks the pin position. The system is fabricated using UV-lithography of the epoxy based dry film photo resist SUEX. It has a high out-of-plane-deflection of more than 300 μm at 150 mW power consumption and a footprint of 10.7 x 1 x 2.5 mm².

W-225 FABRICATION OF AN ELECTRO-THERMAL MICRO GRIPPER USING SILVER-NICKEL INK 1141

Y.-Y. Feng, S.-J. Chen, and P.-H. Hsieh

National Central University, TAIWAN

We develop, model, and optimize a miniaturized electro-thermal gripper with a novel fabrication process applying composite silver-nickel ink. To achieve millimeters range of thermal actuation, a thick resistive structure is dispensed on a silicon wafer, and the fabricated micro gripper can grip a small ball with a diameter larger than 1 mm.

M-226 HAPTOSKIN - A FLEXIBLE SHEET-TYPE TACTILE DISPLAY WITH A CNT ELECTRODE 1145

R. Hatada, H. Ishizuka, M. Kawazoe, and N. Miki

Keio University, JAPAN

We developed a flexible sheet-type tactile display 'Haptoskin' with a CNT electrode that can be attached to objects and decorate the objects with extra tactile characteristics, such as smooth and rough. We fabricated Haptoskin with MEMS-process friendly materials, PDMS and CNTs. We attached the Haptoskin and requested subjects to answer the minimum voltage when they could recognize the tactile sensation. The Haptoskin successfully presented tactile sensations to the subjects.

T-227 LOW VOLTAGE ELECTROMAGNETICALLY DRIVEN ARTIFICIAL FLAPPING WINGS 1149

X. Yan¹, Z. Liu¹, M. Qi¹, and L. Lin²

¹Beihang University, CHINA and ²University of California, Berkeley, USA

We present low voltage electromagnetically driven artificial flapping wings for the first time under an estimated output power of 64.8μW at 22Hz using a driving voltage of only 5.5V. The flapping wings are directly driven by small-size electromagnetic actuator without using any mechanical regulating mechanism, and unsynchronized flapping modes are achieved by commanding individual wing operations independently for flight controls.

W-228 TRANSIENT MICROPACKETS FOR SILICON DIOXIDE AND POLYMER-BASED VAPORIZABLE ELECTRONICS 1153

V. Gund, A. Ruyack, K. Camera, S. Ardanuc, C. Ober, and A. Lal

Cornell University, USA

We report arrayable transient micropackets for vaporizable electronics. The transience is controlled by one-shot low-power micro-valve triggers to expose reactive rubidium to air, which oxidizes exothermically to vaporize the low-temperature degradable polymer substrate. For transience of electronics, we use micropackets of sodium bifluoride, which decomposes on heating to etch the oxide substrate of the electronics. Thus, we demonstrate a pathway to fully transient packaged electronics.

M-229 TWO AXES ACTUATORS ($x-z$ OR $x-\theta$) DRIVEN BY IN-LINE ELECTROSTATIC COMB-DRIVES 1157

I. Grinberg, S. Shmulevich, and D. Elata

Technion-Israel Institute of Technology, ISRAEL

We present two axes actuators which can be moved both in-plane, and out-of-plane. The actuators are driven by two in-line, in-plane electrostatic comb-drives. Previously we demonstrated motion conversion mechanisms for translating in-plane to out-of-plane motion. In this work we demonstrate two-axis actuation, and a new device that can be actuated in both in-plane and tilting motions. Specifically, we demonstrate linear relation between tilt angle and in-plane electrostatic force.

Manufacturing for Actuators and PowerMEMS

- T-230 FLEXIBLE SELF-FORMING SWIMMERS WITH CATALYTIC PROPULSION AND MAGNETIC NAVIGATION 1161**
M. Ochoa, C.K. Yoon, and B. Ziaie
Purdue University, USA

We developed an inexpensive rapid process for creating soft, mm-scale self-forming catalytic swimmers for biomedical and environmental applications. The swimmers contain a catalyst such that when exposed to H₂O₂, they self-propel. We control their navigation magnetically by the incorporation of ferrofluid. The fabrication process features techniques which are scalable, economical, and adaptable for large-volume manufacturing, along with materials which are non-toxic and eco-friendly.

- W-231 MINIATURE TACTILE ELEMENTS FOR TACTILE DISPLAY WITH HIGH STIFFNESS RESOLUTION WITH MAGNETORHEOLOGICAL FLUID 1165**
H. Ishizuka and N. Miki
Keio University, JAPAN

In this paper, we newly developed PDMS navity membrane and hspitic devive with this membrane.

- M-232 PENCILING A TRIBOELECTRIC POWER SOURCE ON PAPER 1169**
X. Zhang¹, J. Brugger¹, and B. Kim²
¹*École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND and*
²*University of Tokyo, JAPAN*

We present a novel triboelectric nanogenerator (TEG) based on a paper-Teflon configuration fabricated by easy and cost-efficient processing. Carbon electrodes were hand-drawn by means of a graphite pencil on commercial paper cards. Sandpaper-based imprinting was used to increase the surface roughness yielding a more than 6-fold enhancement of power density that achieved ~17 uW/cm². The arch-shaped TENG shows robust output power when pressed by fingers to power a LCD.

- T-233 SPUTTERING DEPOSITION OF MULTI-LAYER Pb(Zr,Ti)O₃ THIN FILMS FOR LOW VOLTAGE ACTUATORS 1173**
R. Sano, K. Kanda, J. Inoue, T. Fujita, and K. Maenaka
University of Hyogo, JAPAN

Piezoelectric multimorph structure of Pb(Zr,Ti)O₃ (PZT) thin films by using sputtering deposition is realized for the applications of low-voltage and large generative force actuators. Test microcantilevers with four PZT layers are fabricated by a wafer level and batch-compatible dry etchings. All layers work well as piezoelectric material. In addition, limit of the lamination for PZT multimorph is also evaluated as an index of total stress.

Materials for Actuators and PowerMEMS

- W-234 A BETAVOLTAIC MICROBATTERY USING ZINC OXIDE NANOWIRES UNDER BUILD IN POTENTIAL DIFFERENCE 1177**
Q. Zhang¹, N. Wang¹, P. Zhou¹, C. Chen¹, H. San¹, K. Wang², and X. Chen²
¹*Xiamen University, CHINA and* ²*Buskerud and Vestfold University College, NORWAY*

We developed a betavoltaic mircrobattery using 1D ZnO nanowires. 1D ZnO NWs were synthesized using a mixture of ZnO and graphite powder by a thermal evaporation in a tube furnace in a mixed gas of oxygen and inert. A 10 mCi of ⁶³Ni source was assembled to ZnO NWs/Ti to form sandwich type betavoltaic devices. By I-V measurements, the betavoltaic device exhibits a significant effective energy conversion efficiency of 27.92% with open-circuit voltage of 2.74 V and short-circuit current of 18.4 nA.

- M-235 A FLEXIBLE AND WEARABLE GENERATOR WITH FLUOROCARBON PLASMA INDUCED WRINKLE STRUCTURE 1181**
X. Cheng, X. Chen, B. Meng, M. Han, M. Shi, H. Chen, Y. Song, and H. Zhang
Peking University, CHINA

We present a flexible generator based on the contact-electrification effect. A plasma induced wrinkle structure is employed as the friction layer. Its performance is enhanced by the wrinkle scale which can be adjusted by the thickness of friction layer. Facilitated by this method, 225 V peak voltage and 375 uA maximum current is achieved under finger typing. Due to its well flexibility and simple manufacturing process, it has much potential in converting human-motion energy into electricity.

- T-236 FABRICATION OF NANOCONE FORESTS WITH HIGH OPTICAL ABSORPTION BASED ON A PLASMA REPOLYMERIZATION TECHNIQUE 1185**
 Y. Wang^{1,2}, L. Tang^{1,3}, H. Mao¹, C. Lei^{1,3}, W. Ou^{1,2}, J. Xiong³,
 W. Wang¹, L. Wang⁴, and J. Hu⁴
¹Chinese Academy of Sciences, CHINA, ²Jiangsu R&D Center for Internet of Things, CHINA,
³North University of China, CHINA, and ⁴Henan Agricultural University, CHINA

Nanocone forests with high optical absorption and high photoelectric conversion efficiency are presented. Plasma repolymerization forming nanowires during Ar-plasma bombardment is the key technique. And the self-generated nanowires are further utilized as nanomasks in reactive ion etching for nanocone forests. Furthermore, a feasible fabrication process is proposed for solar cells, which predicts further potential applications of the nanocone forests for powerMEMS devices.

Nanoscale Actuators and PowerMEMS

- W-237 CARDIOMYOCYTES DRIVEN PIEZOELECTRIC NANOFIBER GENERATOR WITH ANISOTROPIC ENHANCEMENT 1189**
 X. Liu and X. Wang
 Tsinghua University, CHINA

We present a novel biomechanical energy harvester termed as cardiomyocytes-driven piezoelectric nanofiber (CDPN) biogenerator, which conceptually introduces quantitative mechanical-to-electrical energy conversion of neonatal cardiomyocytes. We highlight the novelties that flexible nanostructures interact with cardiomyocytes, (1) as physical cue to guide the cardiomyocytes to align specifically, and (2) create mechanical interfaces of contractile cardiomyocytes and piezoelectric nano fibers.

- M-238 HIGH-K THIN FILMS AS DIELECTRIC TRANSDUCERS FOR FLEXURAL M/NEMS RESONATORS 1193**
 C. Fuinel¹, K. Daffé¹, A. Laborde¹, O. Thomas², L. Mazonq¹,
 L. Nicu¹, T. Leichlé¹, and B. Legrand¹
¹Université de Toulouse, FRANCE and ²Arts et Meétiers Paris Tech, FRANCE

We show that a nanometer-thick high-K material can be used as an electromechanical transducer to actuate the flexural mode of micro/nanoresonators. In this study, a 15-nm silicon nitride layer is employed on top of 320-nm thick silicon beams. The devices, smaller by 2 orders of magnitude than in previous studies, are successfully driven into vibration at resonance frequencies greater than 1 MHz, nanometer amplitudes, and quality factors greater than 2000 in vacuum.

- T-239 MAGNETIC ALIGNMENT OF CO-DOPED ZINC OXIDE NANORODS FOR STRETCHABLE ENERGY HARVESTER 1197**
 S. Kim and K.-S. Yun
 Sogang University, SOUTH KOREA

In this paper, we propose a skin attachable piezoelectric energy harvester which was implemented by using magnetic alignment of cobalt (Co)-doped zinc oxide nanorods (ZnO NRs) to enhance the piezoelectric effect. Co-doped ZnO NRs with ferromagnetic property can be easily obtained by hydrothermal process, and their uni-directional alignment can be easily obtained by applying external magnetic field.

Other Actuators and PowerMEMS

- W-240 ELECTRICAL THERMAL ACOUSTIC POINT SOURCE BASED ON MEMS TECHNOLOGY 1200**
 Q.-Y. Xie, Z.-Y. Ju, H. Tian, L.-Q. Tao, Y.-Q. Chen, M.A. Mohammad, Q.-T. Xue,
 X.-Y. Zhang, Y. Yang, and T.-L. Ren
 Tsinghua University, CHINA

We demonstrate, model and fabricate an electrical thermal acoustic (ETA) point source based on MEMS technology which is of much higher efficiency comparing to formal ETA sources and the frequency response spectrum of which is of good flatness. To realize the high efficiency and flatness, an accurate model based on thermodynamic equation is proposed and a structure of point source is fabricated by ICP-RIE technology.

- M-241 INSECT-TYPE MICROROBOT WITH MOUNTED BARE CHIP IC OF ARTIFICIAL NEURAL NETWORKS 1204**
 K. Iwata, Y. Okane, Y. Ishihara, K. Sugita, S. Ono, M. Abe, S. Chiba, M. Takato,
 K. Saito, and F. Uchikoba
Nihon University, JAPAN

We developed an extremely small size insect-type microrobot fabricated by using MEMS technology. Hexapod legs were used for moving mechanism of the robot. The robot was driven by the integrated circuit (IC) of artificial neural networks that was newly developed. The bare chip IC was mounted on the microrobot system. As a result, proposed microrobot system could perform hexapod locomotion without using any software programs. The only external connection wire was to the power source.

- T-242 PERFORMANCE LIMITATIONS IN RESISTIVE-CAPACITIVE POROUS SUPERCAPACITOR ELECTRODES 1208**
 R. Warren¹ and L. Lin²
¹University of Utah, USA and ²University of California, Berkeley, USA

We present the first demonstration of a one-dimensional (1-D), "resistive-capacitive" porous electrode study both analytically and experimentally for pseudo supercapacitors. Specific accomplishments compared to state-of-the-art include: (1) a macroscale approach for ohmically-limited porous supercapacitor electrodes; (2) experimental verifications for metal oxide- and conducting polymer-carbon nanotube (CNT) pseudocapacitors; and (3) identification of performance-limiting factors.

- W-243 PERFORMANCE VERIFICATION OF MEMS VARIABLE EMISSIVITY RADIATOR FOR SPACECRAFT THERMAL CONTROL SYSTEMS 1212**
 S.-H. Han, S.-J. Kang, H.-U. Oh, and T. Kim
Chosun University, SOUTH KOREA

MEMS variable emissivity radiator proposed in the present study is possible to vary the emissivity effectively by using a momentary electrostatic force without any mechanical devices. The radiator does not require the continuous power supply and mechanical actuators to control the emissivity so that the power consumption can be reduced significantly and structural problems can be minimized in the harsh launch environment.

PowerMEMS Components and Systems

- M-244 A COAXIAL CARBON FIBER MICRO SUPERCAPACITOR 1216**
 Y. Xie^{1,2}, C. Shen¹, M. Sanghadasa³, Y. Tang², and L. Lin¹
¹University of California, Berkeley, USA, ²South China University of Technology, CHINA, and
³US Army, USA

We present a solid-state coaxial carbon fiber micro supercapacitor with 100X smaller diameter as compared with the state-of-art, including: (1) an overall size of 10µm in diameter; (2) well-controlled electrolyte and electrode coatings toward high volumetric energy density and power density; and (3) scalable and low-cost processes. As such, we believe this energy storage device can be integrated in fabrics for future wearable electronics.

- T-245 A DYNAMIC REGULATING MECHANISM FOR INCREASED AIRFLOW SPEED RANGE IN MICRO PIEZOELECTRIC TURBINES 1220**
 H. Fu, M. D'Auria, G. Dou, and E.M. Yeatman
Imperial College London, UK

We present a micro-planar spring used to decrease the start-up airflow speed in a micro piezo turbine. The turbine's transduction is achieved by magnetic plucking of a piezo beam. A self-regulating mechanism is employed to adjust the magnetic coupling, making it weak under static conditions and intensified after start-up. The start-up airspeed was 2.34 m/s, showing a 30% improvement against the non-regulated one. A maximum power of 742 µW was achieved at 4.21 m/s for a turbine of 18.5 mm radius.

- W-246 A HYBRID FLAPPING-LEAF MICROGENERATOR FOR HARVESTING WIND-FLOW ENERGY 1224**
 Y. Xia, J. Zhou, T. Chen, H. Liu, W. Liu, Z. Yang, P. Wang, and L. Sun
Soochow University, CHINA

We demonstrate a hybrid flapping-leaf microgenerator for wind-flow energy harvesting. Both the piezoelectric and the triboelectric parts will generate power from wind flow. The output performance can be improved by changing the connecting position between the cantilever and leaf. At a wind speed of 4.5 m/s, the maximum power of the piezoelectric and triboelectric parts can be obtained as 8.1 µW and 13.6 µW at optimized load resistance of 1 MΩ and 0.75 MΩ, respectively.

- M-247 A SINGLE-ELECTRODE WEARABLE TRIBOELECTRIC NANOGENERATOR BASED ON CONDUCTIVE & STRETCHABLE FABRIC 1228**
M. Shi, J. Zhang, M. Han, Y. Song, Z. Su, and H. Zhang
Peking University, CHINA

This paper reports a wearable triboelectric nanogenerator based on the conductive and stretchable composite fabric, which are cost-effective and can be easily mass produced for the first time. Multi-wall carbon nanotubes are directly composited with the cotton knitting fabric through dipping and drying method.

- T-248 STRETCHABLE MICROSUPERCAPACITOR ARRAYS WITH A COMPOSITE HONEYCOMB STRUCTURE 1232**
J. Pu^{1,2}, X. Wang¹, X. Kuang¹, S. Xu¹, S. Li¹, and K. Komvopoulos²
¹*Tsinghua University, CHINA* and ²*University of California, Berkeley, USA*

A novel stretchable microsupercapacitor (MSC) array with single-wall carbon nanotube (SWCNT) electrodes and honeycomb polydimethylsiloxane (PDMS) substrate was fabricated and tested. The stretchability of the MSC array system is controlled by the deformation of the honeycomb structure.

- W-249 BROADBAND ENERGY HARVESTING USING NONLINEAR 2DOF MEMS ELECTRET POWER GENERATOR 1236**
K. Tao¹, J. Wu¹, L.H. Tang², N. Wang¹, S.W. Lye¹, and J.M. Miao¹
¹*Nanyang Technological University, SINGAPORE* and ²*University of Auckland, NEW ZEALAND*

We develop a nonlinear 2DOF MEMS electret power generator. Two effective and close peaks are achieved. Upon the increase of acceleration, hardening nonlinearity induced by end-stop effect is engaged, resulting in resonant frequency drift and bandwidth convergence.

- M-250 EFFECT OF ION CURRENT RECTIFICATION ON ENERGY HARVESTING BY REVERSE ELECTRODIALYSIS 1240**
C. Wang, E. Choi, G.T. Jang, and J. Park
Sogang University, SOUTH KOREA

This study shows that the directionality of ion transport can be controlled by the cooperation and competition between the directional ion transport induced from asymmetric geometry in microchannel and the diffusive ion transport from electrolyte concentration gradient. Also, it was shown that the preferential ion transport control can improve the power efficiency from electrolyte gradient.

- T-251 EIGHT PARAMETRIC RESONANCES IN A MULTI-FREQUENCY WIDE-BAND MEMS PIEZOELECTRIC VIBRATION ENERGY HARVESTER 1244**
Y. Jia^{1,2}, S. Du¹, and A.A. Seshia¹
¹*University of Cambridge, UK* and ²*University of Chester, UK*

This paper reports a multi-order parametric resonant MEMS piezoelectric vibration energy harvester, using a disk membrane topology, which is capable of achieving over an order of magnitude broader operational frequency bandwidth than a conventional directly excited resonator; and over 3 folds improvement in power density than its direct counterpart when subjected to band-limited white noise excitation. This result, thus lays the foundation for an inherently multi-frequency responsive solution.

- W-252 FILM-EVAPORATION MICROTHRUSTER FOR CUBESATS 1248**
A.G. Cofer¹, W.J. O'Neill¹, S.D. Heister¹, E.H. Cardiff², and A.A. Alexeenko¹
¹*Purdue University, USA* and ²*NASA Goddard Space Flight Center, USA*

We develop and experimentally characterize a MEMS thruster for picosat propulsion and thermal control with a propellant-to-system mass at least x10 greater compared to state of the art. The film-evaporation concept utilizes microscale effects in liquid surface tension to achieve up to 100 microNewton thrust per nozzle at 0.1 W input power and a cooling-to-input power up to 14:1 in a dry system volume of < 0.05 cm³.

- M-253 LIQUID METAL DROPLET BASED TUBE-SHAPED ELECTROSTATIC ENERGY HARVESTER 1252**
H. Chen, Y. Song, M. Han, B. Yu, X. Cheng, X. Chen, D. Chen, and H. Zhang
Peking University, CHINA

This paper presents a liquid metal droplet (LMD) based tube-shaped electrostatic energy harvester, which for the first time, utilize LMD as tribo-electrification material. This device use double-helix electrodes around the tube to obtain cycle transferred charges which multiples output frequency and enhance efficiency tremendously. Thanks to the tube-shaped structure, this generator can be wind up to be worn on human wrist to harvest energy from human movement.

T-254 MEMS BASED PIEZOELECTRIC ULTRASONIC ENERGY HARVESTER FOR SELF-POWERED UNDER-WATER APPLICATIONS 1256

Q. Shi¹, T. Wang¹, T. Kobayashi², and C. Lee¹

¹*National University of Singapore, SINGAPORE and*

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

We report a MEMS based piezoelectric ultrasonic energy harvester (PUEH). Compared to the commonly used millimeter-scale bulk PZT in acoustic energy transfer, the PUEH consists of miniaturized PZT diaphragms array. It can be easily integrated with other electrical components for lab-on-a-chip and implantation applications. Due to the broadband frequency response of the soft PZT diaphragms, we can apply frequency modification to minimize the standing wave effect for a given distance.

W-255 SILVER AS A CATHODE FOR SILICON-BASED MICRO SOLID OXIDE FUEL CELLS 1260

C.C. Yu, J.D. Baek, and P.C. Su

Nanyang Technological University, SINGAPORE

This paper reports the use of silver as a cathode for silicon micro-solid oxide fuel cells (μ -SOFCs). The use of nanoscale thin-film electrolyte has minimized Ohmic resistance and reduce the operating temperature of μ -SOFCs drastically. Lower operating temperature enables the utilization of silver. We adopt a simple and cost effective inkjet-printing method to fabricate silver cathode with comparably good performance.

M-256 STACKABLE DUAL-LAYER COIL BASED ON WAFER-LEVEL TRANSFER TECHNIQUE FOR ELECTROMAGNETIC ENERGY HARVESTER 1264

Y. Wang, Q. Zhang, L. Zhao, A. Shkel, Y. Tang, and E.S. Kim

University of Southern California, USA

This paper reports a stackable dual layer coil based on thermal-release-tape transfer technique for electromagnetic energy harvester. Five of microfabricated dual-layer coil plates are stacked for 450 turns for an electromagnetic vibration-energy harvester with permanent magnets and acrylic spring, which produces 116 μ W from 3.6 g vibration at 160 Hz.