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MEMS 2014 PROGRAM SCHEDULE

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Sunday, January 26

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

Monday, January 27

08:00 **Opening and Welcome Address**
Farrokh Ayazi, *Georgia Institute of Technology, USA*
Chang-Jin "CJ" Kim, *University of California, Los Angeles, USA*

Plenary Speaker I

Session Chairs:
F. Ayazi, *Georgia Institute of Technology, USA*
CJ Kim, *University of California, Los Angeles, USA*

08:20 **MICROFABRICATED IMPLANTABLE WIRELESS MICROSYSTEMS: PERMANENT AND BIODEGRADABLE IMPLEMENTATIONS** 1
Mark G. Allen
University of Pennsylvania, USA

Session I – Biomedical Microdevices

Session Chairs:
K. Peterson, *Profusa, USA*
J. Lammertyn, *KU Leuven, BELGIUM*

09:00 **AN INTEGRATED MICROFLUIDIC SYSTEM FOR RAPID ISOLATION AND DETECTION OF LIVE BACTERIA IN PERIPROSTHETIC JOINT INFECTIONS** 5
W.H. Chang[1], C.H. Wang[1], S.Y. Yang[2], Y.C. Lin[2], J.J. Wu[3], M.S. Lee[4], and G.B. Lee[1]
[1]National Tsing Hua University (NTHU), TAIWAN, [2]Jabil Circuit Inc., Ltd, TAIWAN, [3]National Cheng Kung University, TAIWAN, and [4]Chia-Yi Chang Gung Memorial Hospital, TAIWAN

An integrated microfluidic system was presented in this work, which could distinguish the existence of live bacteria within 1 hour. This is the first time that a microfluidic platform was reported to detect live bacteria in periprosthetic joint infection samples. The results demonstrated that the proposed system can detect live bacteria successfully in the micro-environment of clinical samples. The proposed system can be a promising tool for the clinicians with timely medical decisions.

09:15 **A CABLE-TIE-TYPE PARYLENE CUFF ELECTRODE FOR PERIPHERAL NERVE INTERFACES** 9
H.Q. Yu, W.J. Xiong, H.Z. Zhang, W. Wang, and Z.H. Li
Peking University, CHINA

We design, fabricate and characterize a cable-tie-type parylene cuff electrode for peripheral nerve interfaces, whose diameter is adjustable to accommodate the nerve properly during implantation. Cuffs made of thin and flexible parylene minimize mechanical damage to surrounding tissues after implantation. Moreover, the integrated parylene cable and pads facilitate connection with external circuits through wired or wireless interfaces. The acute in vivo rat experiments were performed to verify the ability for the neural recording and selective stimulation of different nerve fascicles.

This paper reports a first-ever silicon surgical tweezer for characterizing electromechanical properties of tissue. Unlike the other probe-like tissue stiffness tactile sensors, the tweezer structure provides a platform for the clinical use during surgery. We chose to pursue an all-silicon tweezer, instead of attaching sensors to existing tweezers, for repeatable tissue assessment across surgeries without external calibration.

We present a highly-packed liposome assembly that implements lipid bilayer-lipid bilayer contact at the interfaces for mimicking cell-cell connection on living tissues. The closely packed liposomes, based on our previous technique producing a monodisperse liposome array, facilitate easy modification in size and components of the model structures as well as long-term observation of their interfaces. We believe that the assembly technique would help providing a synthetic tissue model.

10:00 **Break & Exhibit Inspection**

Session II – Gyros & Accelerometers

Session Chairs:
D. Horsley, *University of California at Davis, USA*
H. Külah, *Middle East Technical University, TURKEY*

We report the fused-silica birdbath resonator gyroscope (BRG) with a large angular gain, controlled in the whole angle (WA) mode. The BRG is fabricated using the micro-blow-torching process and exhibits good mechanical symmetry, which is ideal for WA mode operation. We adopted the control algorithm for the hemispherical resonator gyroscope (HRG). We report a large bandwidth and full-scale range of 700 deg/s with a large angular gain ($A_g = 0.27$).

This paper reports a new type of degenerate mode gyroscope with measured Q-factor of > 100,000 on both modes at a compact size of 1760 µm diameter. The toroidal ring gyroscope consists of an outer anchor ring, concentric rings nested inside the anchor ring and an electrode assembly at the inner core. Devices were fabricated using high-temperature, ultra-clean epitaxial silicon encapsulation (Epi-Seal) process.

This paper reports on the design, fabrication and characterization of single proof-mass tri-axial capacitive accelerometers coexisting in a wafer-level packaged (WLP) low-pressure environment with high-frequency gyroscopes, for the implementation of monolithic 6-degree-of-freedom (6-DOF) inertial measurement units (IMUs). The accelerometers are designed to operate as quasi-static devices (i.e. non-resonant sensors) in high vacuum levels (1 – 10 Torr) by increasing squeeze-film air damping through the use of capacitive nano-gaps (< 300 nm).

This paper presents a novel “in operation acceleration sensing and compensation method" for a single-mass mode-matched MEMS gyroscope. In this method, the amplitudes of the sustained residual quadrature signals on the differential sense-mode electrodes are compared to measure the linear acceleration acting on the sense-axis of the gyroscope. Measuring the acceleration along the sense-axis, the sensitivity of the gyroscope output to linear accelerations along this axis is eliminated without using a dedicated accelerometer.

11:45 **Lunch & Exhibit Inspection**

13:00 **Poster/Oral Session I**

Session III– Materials and Process Characterization

Session Chairs:
M. Despont, *CSEM, SA, SWITZERLAND*
H. Toshiyoshi, *University of Tokyo, JAPAN*

15:00 **A STATIC CAPACITANCE PROBE STRUCTURE FOR RESOLVING THE SIDEWALL SKEW ANGLE OF SILICON DEEP REACTIVE-ION ETCHING** 36
K. Jia, A. Geisberger, A. Dickens, R. Steimle, D.C. Chang, P. Winebarger, L. Liu, and A. McNeil
Freescale Semiconductor Inc., USA

This work presents a design that enables quantitative characterization of the silicon Deep Reactive-Ion Etching sidewall skew angle using static LCR prober at ambient pressure, which provides an easy, accurate and batch solution to the long existing challenge of resolving such process features in an industrial manufacturing environment.

15:15 **INVAR-36 MICRO HEMISPHERICAL SHELL RESONATORS** 40
N. Mehanathan, V. Tavassoli, P. Shao, L. Sorenson, and F. Ayazi
Georgia Institute of Technology, USA

We report the successful fabrication as well as operational characterization of electroplated Invar micro-hemispherical shell resonators. Additionally, the heat treatment of the samples and its effect on the quality factor of the resonators is studied. We show that thermal annealing shifts the coefficient of thermal expansion (CTE) of the alloy towards its minimum, as a result of which the Q increases at least 3 times and reaches ~7500. An annealed electroplated Invar μHSR shows Q of 7500, where unannealed electroplated Invar μHSRs have Qs in the range 2000-3000.

15:30 **IMPLEMENTATION OF SINGLE/MULTI-LAYER MAGNETIC-ANISOTROPY MAGNETIC POLYMER COMPOSITES FOR MAGNETIC PROPERTY MODULATION** 44
F.-M. Hsu, W.-C. Chen, W.-M. Lai, Y.-C. Sun, and W. Fang
National Tsing Hua University (NTHU), TAIWAN

This study extends the two-stage solidification technology to fabricate the isotropic/anisotropic magnetic polymer composites (MPC, polymer with magnetic particles). Multilayer magnetic-anisotropy/isotropic MPC film can also be implemented using the two-stage solidification process layer by layer. Merits of proposed technology: (1) material properties of magnetic-anisotropy MPC layer is realized using the two stage solidification and anisotropic-magnetization processes, and (2) film of various magnetic properties can also be implemented using the different combination of multilayer magnetic-anisotropy MPCs. In applications, the multilayer polymer-NdFeB magnetic composites are realized in silicon substrate and further integrate with MEMS structures. The 1-4 layers of different magnetic-anisotropy MPC are demonstrated. Performances enhancement of magnetic-anisotropy 30wt%-NdFeB MPC (vs isotropic MPC) are: coercivity force (3.4%), remanence (304%), and saturation magnetization (268%). Anisotropic magnetostatic shielding effect (reduce from 0.45Telsa to 0.3-0.35Telsa) is achieved. Moreover, change of magnetic field distributions after stacking of different magnetic-anisotropy MPC layers is also demonstrated.

15:45 **CNT BUNDLES GROWTH ON MICROHOTPLATES FOR DIRECT MEASUREMENT OF THEIR THERMAL PROPERTIES** 48
C. Silvestri, B. Morana, G. Fiorentino, S. Vollebregt, G. Pandraud, F.Santagata,
G.Q. Zhang, and P.M. Sarro
Delft University of Technology, THE NETHERLANDS

Vertically aligned Carbon Nanotubes (CNT) arrays were successfully grown on top of freestanding microheaters. This was made to investigate the thermal dissipation properties of CNTs bundles and their applicability as heat exchanger. The 70μm high bundles have a diameter of 20 and 200μm. A Platinum thin film microheater, integrated on a freestanding SiN membrane, is used as heat source and as temperature sensor. The power consumption of the micro-heaters with different CNTs patterns, is measured in air. At 300 ºC a power increase up to 31% was recorded for the microheaters equipped with the CNTs.

16:00 **Break & Exhibit Inspection**

Session IV– Fabrication

Session Chairs:
J. Kim, *Pohang University of Science & Technology, SOUTH KOREA*
B. Pruitt, *Stanford University, USA*

16:30 **3D ICE PRINTING AS A FABRICATION TECHNOLOGY OF MICROFLUIDICS WITH PRE-SEALED REAGENTS** 52
H.Z. Zhang, H. Li, M.X. Wu, H.Q. Yu, W. Wang, and Z.H. Li
Peking University, CHINA

We propose a innovative and inexpensive method to fabricate 3D structure featured by ice printing.This "bottom-up" 3D fabrication method is achieved by printing water onto the cold substrate and turning into ice structure layer by layer.Through this method, fluid with reagents, such as drugs and nanoparticles, is sealed into microfluidics during fabrication which can be used for drug delivery or other medical care applications.Moreover, a complex microchannels is easily fabricated using 3D ice structure as soft lithography mould, which can be used for microfluid-mixer, three dimensional flow focusing ect.

16:45 **LIQUID-FILLED SEALED MEMS CAPSULES FABRICATED BY FLUIDIC SELF-ASSEMBLY** 56
M. Mastrangeli, L. Jacot-Descombes, M.R. Gullo, and J. Brugger
Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND

We present an innovative method based on fluidic self-assembly for the encapsulation of functional liquids into sealed picoliter MEMS capsules. Capsules self-assembly and liquid co-encapsulation are achieved through the interplay of global fluidic stirring and local capillary forces ensuing from a selectively-precipitated insoluble polymeric phase. Our encapsulation method is massively parallel, scalable and compatible with batch MEMS fabrication. It can address a large variety of applications, including distributed MEMS sensors, self-healing materials, fragrance release and drug delivery.

17:00 **3D MASK MODULES USING TWO-PHOTON DIRECT LASER WRITING TECHNOLOGY FOR CONTINUOUS LITHOGRAPHY PROCESS ON FIBERS** 60
M. Hayashi[1,2], Y. Zhang[1], M. Hayase[2], T. Itoh[1], and R. Maeda[1]
[1]*National Institute of Advanced Industrial Science and Technology (AIST), JAPAN and*
[2]*Tokyo University of Science, JAPAN*

In this paper, we report a new fabrication method of 3D mask modules using two-photon direct laser writing technology in 140 μm-diameter half-pipe structures on quartz substrates. For the first time, the two-photon direct laser writing technology is utilized for the high resolution patterning process on a curved surface. The minimum feature sizes of about 2 μm line and space are successfully fabricated across the whole 140 μm-diameter half-pipe structures. Using the new 3D mask modules, fine metal patterns are prepared on 125 μm-diameter fiber.

17:15 **FABRICATION OF A MONOLITHIC MICRODISCHARGE-BASED PRESSURE SENSOR FOR HARSH ENVIRONMENTS** 64
X. Luo, C.K. Eun, and Y.B. Gianchandani
University of Michigan, USA

We present a 6-mask monolithic fabrication process for a pressure sensor that uses a differential microdischarge signal to sense diaphragm deflection. Microdischarge-based transduction is advantageous for harsh environments because of its immunity to temperature and inherently large signals. This work reports the first monolithic fabrication process that successfully addresses a number of challenges for microdischarge-based pressure sensors. Compared to prior work, it results in a ≈30× smaller exterior volume (0.05mm3), a ≈30× wider pressure range (40MPa), and backside terminals for appropriate packages.

17:30 **Adjourn for the day**

Tuesday, January 28

08:00 **ANNOUNCEMENTS**

Plenary Speaker II

Session Chairs:
H. Toshiyoshi, *University of Tokyo, JAPAN*
X. Wang, Tsinghua *University, CHINA*

We have fabricated ultrathin, ultra-lightweight, ultraflexible, organic devices, such as organic thin-film transistors (TFTs), organic photovoltaic (OPV) cells, and organic light-emitting diodes (OLEDs) on polymeric films with the thickness of only 1 μm. The ultrathin organic devices are utilized to fabricate human-machine interfaces such as a touch sensor and wearable electronic systems such as an electromyogram measurement sheet with a two-dimensional array of organic amplifiers. The transistor films exhibit extraordinarily tough mechanical robustness such as minimum bending radius of 5 μm for organic TFTs.

Session V – Optical & Magnetic Microdevices

Session Chairs:
N. Miki, *Keio University, JAPAN*
H. Zappe, *University of Freiburg, GERMANY*

We develop a micro variable optics array which modulates the direction of a light beam. Each pixel of the device has an interface of two immiscible liquids at which the lights are deflected and the interface is actuated on the four separated wall electrodes of the pixel by electrowetting. The four separated electrodes enable the every single pixel to work independently with multiple degrees of freedom, e.g. various tilting angles in every direction for prism or a large number of curvatures for lens mode.

Magnetoelastic resonators are of considerable interest for passive wireless interrogation and detection. This paper presents miniaturized magnetoelastic tags using hexagonal resonators with an overall size of about ø1.3mm X 27μm, and a resonant frequency as high as 2.13MHz. The tags are 100X smaller than typical commercial tags. The frame-suspension results in ≈75X improvement in signal amplitude of hexagonal tags compared to that of non-suspended disc tags. This paper also demonstrates that the signal amplitude can be boosted by utilizing signal superposition of an ensemble of tags.

This work demonstrates a 3-axis Lorentz force magnetometer for electronic compass purposes. The magnetometer measures magnetic flux in 3 axes using a single structure with sub-30 nT/√Hz resolution. Assuming 10 μT Earth's field, the magnetometer has an angular resolution of 0.17 deg/√Hz with 1 mW power consumption. Compared to the 3-axis Hall sensors currently used in smartphones, the 3-axis magnetometer shown here has the advantages of 10× lower noise floor and the ability to be co-fabricated with MEMS inertial sensors.

This paper reports our recent progress on a highly flexible actively tunable metamaterial (MM) perfect absorber at terahertz frequencies. The MM array on GaAs thin-film was patterned on 5μm polyimide substrate via transfer printing technique, and the backside of the substrate was coated with gold. THz time-domain-spectroscopy measurements show that the absorptivity at resonance frequency of 1.59THz can be tuned up to 60% by photo-excitation of free carriers in GaAs patches. Our flexible tunable MM perfect absorber has potential applications in energy harvesting, and imaging.

09:45 **TUNABLE META-FLUIDIC-MATERIALS BASE ON MULTILAYERED MICROFLUIDIC SYSTEM** 88
W.M. Zhu[1], B. Dong[1], Q.H. Song[2], W. Zhang[1], R.F. Huang[3], S.K. Ting[3], and A.Q. Liu[1,2]
[1]Nanyang Technological University, SINGAPORE, [2]Xi'an Jiao Tong University, CHINA, and [3]Temasek Laboratories, SINGAPORE

We demonstrate a multilayered microfluidic system with a flexible substrate, which has tunable optical chirality within THz spectrum range. The optical properties of the multilayered microfluidic system can be tuned by either changing the liquid pumped into each layer or stretching the flexible substrate. It is feasible for the multilayered microfluidic structure to be integrated to an optofluidic system, where strong or tunable optical chirality are needed, which not only can be used as traditional optic components such as THz polarizers and filters but also has potential applications on imaging and sensor of bio-materials.

10:00 **Break & Exhibit Inspection**

Session VI – Fluidic Microdevices

Session Chairs:
G.-B. Lee, *National Tsing Hua University (NTHU), TAIWAN*
A. Dietzel, *Technische Universität Braunschweig, GERMANY*

10:45 **MULTIPLE SIZE-ORIENTED PASSIVE DROPLET SORTING DEVICE AND BASIC APPROACH FOR DIGITAL CHEMICAL SYNTHESIS** 92
S. Numakunai, A. Jamsaid, D.H. Yoon, T. Sekiguchi, and S. Shoji
Waseda University, JAPAN

This paper presents a multiple size-oriented passive droplet sorting utilizing a balance between surface free energy and flow force. We propose a multi-stage sorting structure and passive five different-sized droplets sorting of about 100 droplets/sec is achieved without any active elements. Also, we fabricated a prototype of the integrated micro fluidic system with droplet generation, merging and sorting for digital chemical synthesis.

11:00 **SURFACE ENERGY MICROPATTERN INHERITANCE FROM MOLD TO REPLICA** 96
G. Pardon, T. Haraldsson, and W. van der Wijngaart
KTH Royal Institute of Technology, SWEDEN

We report a novel surface energy patterning phenomenon, in which a novel polymer composition inherits the surface energy of the medium it is in contact with during polymerization. This process occurs via spontaneous alignment of hydrophilic and hydrophobic monomers contained in the prepolymer. This single-step method for simultaneous structuring and surface energy micropatterning of polymer structures is potentially more robust and lower cost than state-of-the-art. We further demonstrate the self-assembly of a liquid droplet array on the replicated polymer surfaces.

11:15 **ELECTROSPRAY DEPOSITION FROM AFM PROBES WITH NANOSCALE APERTURES** 100
J. Geerlings[1], E. Sarajlic[1,2], J.W. Berenschot[1], R.G.P. Sanders[1], L. Abelmann[1,3], and N.R. Tas[1]
[1]MESA+, University of Twente, THE NETHERLANDS, [2]SmartTip B.V., THE NETHERLANDS, and [3]Korea Institute of Science and Technology (KIST) – Europe, GERMANY

In this contribution we present for the first time extraction of liquid from nano-sized apertures in fountain pen AFM probes by means of electrospray. This technique allows for contactless deposition and we show that droplets with radii in the order of one micrometer can be deposited. The required onset voltage for electrospray as function of gap spacing and applied pressure is studied and a simple model is presented which is in qualitative agreement with our measurements.

11:30 **A MICROBUBBLE PRESSURE TRANSDUCER WITH BUBBLE NUCLEATION CORE** 104
L. Yu and E. Meng
University of Southern California, USA

We present a microchannel-based microbubble (μB) pressure transducer (μBPT) with μB nucleation core for characterization of μB dynamics and pressure transduction in wet environments with low power consumption. The transducer leverages electrochemical impedance-based measurement to monitor the instantaneous response of μB size induced by hydrostatic pressure changes. We demonstrated on-demand μB nucleation and real-time pressure tracking (0-350 mmHg). Biocompatible construction and liquid-based operation of μBPTs are ideal for *in vivo* pressure monitoring.

11:45 **MICROFLUIDIC ELECTROCHEMILUMINESCENCE (ECL) INTEGRATED CELL FOR PORTABLE FLUORESCENCE DETECTION** 108
M. Tsuwaki[1], J. Mizuno[1], T. Kasahara[1], T. Edura[2], E. Kunisawa[2], R. Ishimatsu[2], S. Matsunami[2], T. Imato[2], C. Adachi[2], and S. Shoji[1]
[1]Waseda University, JAPAN and [2]Kyushu University, JAPAN

We propose a portable electrochemiluminescence (ECL)-induced fluorescence chip which consists of flow channels for fluorescence sample and multi-color emitting ECL excitation source. A prototype ECL-induced fluorescence chip was fabricated by conventional photolithography and bonding technique. Device performance was evaluated using ECL of rubrene as excitation source and resorufin as fluorescent dye. Fluorescence of 500 μM resorufin (600 nm) was successfully detected using 10 mM rubrene solution (560 nm) under the applied voltage of 4 V. The proposed principle is applicable for portable and on-demand multi fluorescence detection device using its freedom of choice for combination of the ECL light source.

12:00 **A MONOLITHIC KNUDSEN PUMP WITH 20 sccm FLOW RATE USING THROUGH-WAFER ONO CHANNELS** 112
S. An, Y. Qin, and Y.B. Gianchandani
University of Michigan, USA

We report a lithographically microfabricated Knudsen pump for high gas flow. Knudsen pumps operate by thermal transpiration and require no moving parts. To achieve high gas flow, high-density arrays of microchannels are used in parallel (with over 4000 channels/mm^2). These vertically oriented microchannels have 2×120 μm^2 openings surrounded by 0.1 μm-thick silicon oxide-nitride-oxide (ONO) sidewalls. The thin ONO sidewalls provide thermal isolation between a heat sink formed within the Si substrate, and a Cr/Pt thin film heater formed above the microchannels that provides a temperature bias for thermal transpiration. The Knudsen pump is monolithically microfabricated on a single SOI wafer using a four-mask process. It has a total footprint of 8×10 mm^2. It produces a measured air flow of 20 sccm, with typical response times of 0.1-0.4 sec.

12:15 **MEMS 2015 Announcement**

12:30 **Lunch on Own**

14:00 **Poster/Oral Session II**

Session VII– Resonant Microdevices & Sensors

Session Chairs:
M. Rais-Zadeh, *University of Michigan, USA*
L. Buchaillot, *IEMN, FRANCE*

16:00 **SUSPENDED NANOCHANNEL RESONATORS AT ATTOGRAM PRECISION** 116
S. Olcum[1], N. Cermak[1], S.C. Wasserman[1], K. Payer[1], W. Shen[2], J. Lee[3], and S.R. Manalis[1]
[1]Massachusetts Institute of Technology, USA, [2]Innovative Micro Technology, USA, and [3]Sogang University, SOUTH KOREA

We developed a nanomechanical resonator that can directly measure the mass of individual nanoparticles down to 10 nm in solution at room temperature with single-attogram precision, also enabling access to many of the engineered nanoparticles used in nanomedicine, most of the virions like HIV, HCV, and natural sub-cellular structures like exosomes. To achieve this, we demonstrate an oscillator system with frequency stability down to 4 ppb, approaching the fundamental limit imposed by intrinsic thermomechanical fluctuations of the resonator.

16:15 **DUAL-MODE VERTICAL MEMBRANE RESONANT PRESSURE SENSOR** 120
R. Tabrizian and F. Ayazi
Georgia Institute of Technology, USA

We present a novel dual-mode resonant pressure sensor operating based on mass loading of air molecules on transversely vibrating vertical silicon membranes. Identical piezoelectrically-transduced silicon bulk acoustic resonators are acoustically coupled through thin vertical membranes, resulting in two high-Q resonance modes with small frequency split, but large difference in pressure sensitivity. Being proportional to the flexural resonance frequency of the thin membranes, the small beat frequency (fb) extracted from subtraction of the two coupled modes shows amplified pressure sensitivity. A proof-of-concept device implemented on silicon substrate and transduced by aluminum nitride film shows an fb of 370 kHz with a linear pressure sensitivity of 280 ppm/kPa.

16:30 **HIGHLY RESPONSIVE CURVED ALUMINUM NITRIDE PMUT** 124
S. Akhbari[1], F. Sammoura[1,2], S. Shelton[3], C.Yang[1], D. Horsley[3], and L. Lin[1]
[1]University of California, Berkeley, USA, [2]Masdar Institute of Science and Technology, UAE, and [3]University of California, Davis, USA

We have successfully demonstrated highly responsive, curved piezoelectric micromachined ultrasonic transducers (PMUT) based on a CMOS-compatible fabrication process using AlN as the transduction material for the first time. A prototype device using a 2µm-thick AlN layer on a curved diaphragm surface with a radius of curvature of 1065µm and physical size of 140µm in diameter has shown a measured resonant frequency at 2.19MHz. The DC response has been experimentally measured as 1.1nm/V, which is 50X higher than that of a planar device with same size and operation conditions. As such, this new class of curved PMUT could replace the state-of-art, planar PMUT to achieve high electromechanical coupling for various ultrasonic transduction applications, including gesture recognition and medical imaging.

16:45 **ENCASED CANTILEVERS FOR LOW-NOISE FORCE AND MASS SENSING IN LIQUIDS** 128
D. Ziegler[1], A. Klaassen[2], D. Bahri[1], D. Chmielewski[1], A. Nievergelt[1], F. Mugele[2], J.E. Sader[3], and P.D. Ashby[1]
[1]Lawrence Berkeley National Laboratory, USA, [2]MESA+, University of Twente, THE NETHERLANDS, and [3]University of Melbourne, AUSTRALIA

Viscous damping severely limits the performance of cantilever based sensing in liquids. Encased cantilevers achieve low damping in liquids by keeping the resonator dry. This is achieved by fabricating a hydrophobic encasement from which only few microns of the sensing tip protrude into the liquid. We achieve Q-factors and associated noise levels as if operating in air. We discuss fabrication of these devices and demonstrate successful application for low-noise mass sensing and gentle AFM imaging of soft matter in liquids.

17:00 **RESONANT MICRO-SENSOR PLATFORM FOR CONTACT-FREE CHARACTERIZATION OF LIQUID PROPERTIES** 132
J.M. Gonzales and R. Abdolvand
Oklahoma State University, USA

This paper presents a novel resonant microsensor platform which maintains high quality factors(Q) when measuring ultrasonic properties of liquid samples such as blood. By avoiding the direct contact of the liquid with the resonator, significant losses due to liquid loading are mitigated and the physical properties of various fluids, including viscous samples, can be determined without adversely affecting the resonator performance. Devices have been fabricated and tested, achieving quality factors up to 6000 in air and the results show that the output signals measured from the device are sensitive to the properties of the liquid under test.

17:15 **NOVEL IN-PLANE GAP CLOSING CMOS-MEMS MICROPHONE WITH NO BACK-PLATE** 136
C.-I. Chang[1], S.-C. Lo[1], C. Wang[2], Y.-C. Sun[1], and W. Fang[1,2]
[1]National Tsing Hua University (NTHU), TAIWAN and [2]MotionsTek Inc., TAIWAN

The stacking of metal/tungsten layers as the sensing electrodes for CMOS-MEMS microphone without the back-plate has been proposed and demonstrated for the first time (Fig.1a). The acoustic pressure will deform the spring-diaphragm structure and further cause the in-plane gap-closing between sensing electrodes (Fig.1b). Thus, acoustic pressure and dynamic response of spring-suspension can be determined by the sensing capacitance changes. Such design has the following merits: (1) no back-plate is required, (2) bias voltage to pull diaphragm close to back-plate is not required, (3) in-use pull-in and process stiction between diaphragm and back-plate is also prevented, (4) easy integration with sensing circuits [1]. The design was implemented using the standard TSMC CMOS process. Typical microphone with 200µm-diameter diaphragm and 48-pairs sensing electrodes has been realized. Measurements show the sensitivity of microphone is -67.17dBV/Pa at 1KHz.

17:30 **Adjourn for the day**

Wednesday, January 29

08:00 **ANNOUNCEMENTS**

Plenary III

Session Chairs:
J. Brugger, *Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND*
W. van der Wijngaart, *KTH – Royal Institute of Technology, SWEDEN*

08:05 **CAVITY QUANTUM OPTOMECHANICS: COUPLING LIGHT AND MICROMECHANICAL OSCILLATORS** 140
E. Verhagen, S. Deléglise, S. Weis, A. Schliesser, and **Tobias J. Kippenberg**
Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND

Session VIII – Nanodevices

Session Chairs:
L. Lin, *University of California, Berkeley, USA*
Y.-J. Yang, *National Taiwan University, TAIWAN*

08:45 **AMORPHOUS CARBON ACTIVE CONTACT LAYER FOR RELIABLE NANOELECTROMECHANICAL SWITCHES** 143
D. Grogg[1], C.L. Ayala[1], U. Drechsler[1], A. Sebastian[1], W.W. Koelmans[1], S.J. Bleiker[2], M. Fernandez-Bolanos[1], C. Hagleitner[1], M. Despont[1], and U.T. Duerig[1]
[1]IBM Research – Zurich, SWITZERLAND and [2]KTH Royal Institute of Technology, SWEDEN

This paper reports an amorphous carbon (a-C) contact coating for ultra-low-power curved nanoelectromechanical (NEM) switches. a-C addresses important problems in miniaturization and low-power operation of mechanical relays: i) the surface energy is lower than that of metals, ii) active formation of highly localized a-C conducting filaments offers a way to form nano-scale contacts, and iii) high reliability is achieved through the excellent wear properties of a-C, demonstrated in this paper with more than 100 million hot switching cycles.

09:00 **NEAR INFRARED PHOTO-DETECTOR USING SELF-ASSEMBLED FORMATION OF ORGANIC CRYSTALLINE NANOPILLAR ARRAYS** 147
Y. Ajiki[1,4], T. Kan[2], M. Yahiro[3], A.Hamada[3], J. Adachi[3], C. Adachi[3], K. Matsumoto[2], and I. Shimoyama[2]
[1]Olympus Corporation, JAPAN, [2]University of Tokyo, JAPAN, [3]Kyushu University, JAPAN, and [4]NMEMS Technology Research Organization, JAPAN

We proposed a near infrared photo-detector (NIR-PD) using self-assembled formation of organic crystalline arrays, which were formed on an n-type silicon (n-Si) substrate and covered with an Au film. These structures act as antennas for near infrared (NIR) light, resulted in an enhancement of the light absorption on the Au film. In this paper, the fabrication process of the NIR-PDs and the estimation results of photo-responsivity are described. The maximum value of the responsivity to NIR light (wavelength = 1.2 μm) was 1.79 mA/W without applying forward bias. This value is 10 times larger than that of a conventional Au/n-Si typed Schottky diode, which is fabricated as a reference.

09:15 **ULTRASENSITIVE SI NANOWIRE PROBE FOR MAGNETIC RESONANCE DETECTION** 151
Y.J. Seo, M. Toda, Y. Kawai, and T. Ono
Tohoku University, JAPAN

We have fabricated and evaluated an atto-newton-sensitive Si nanowire probe with a Nd-Fe-B magnet for magnetic resonance force microscopy. The width, thickness and length of the nanowire are 210 nm, 200 nm and 32 μm, respectively. The nanowire probe has a resonance frequency f0 of 11.256 kHz and a Q factor of order 12000. Then, we have demonstrated the measurement of force mapping based on electron spin resonance for three-dimensional imaging of radicals.

09:30 **A VERTICALLY INTEGRATED NANOSCALE TIPPED MICROPROBE INTRACELLULAR ELECTRODE ARRAY** 155
Y. Kubota, H. Oi, H. Sawahata, A. Goryu, Y. Ando, R. Numano, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

Here we report an integration of vertical 120-μm-long nanoscale tipped microprobe electrode (NTE) array and the intracellular recordings using a gastrocnemius muscle of a mouse. The tip diameter of the NTE was < 200 nm, with the height of 4 μm exposed from the parylene-shell. The impedance of the NTE exhibited 3.1 MΩ at 1 kHz in saline, with the output/input signal amplitude ratio of 50% for intracellular recordings. The penetrated NTE into the muscle of a mouse detected the residual potentials with the amplitude of ~ -200 mV, confirming the intracellular recording capability of the NTE.

09:45 **Break & Exhibit Inspection**

Session IX – Energy Harvesting & Power

Session Chairs:
Z. Li, *Peking University, CHINA*
J. Judy, *University of Florida, USA*

10:30 **ENERGY HARVESTING USING UNIAXIALLY ALIGNED CARDIOMYOCYTES** 159
X. Liu[1,2], X. Wang[1], S. Li[2] and L. Lin[2]
[1]Tsinghua University, CHINA and [2]University of California, Berkeley, USA

This study presents the concept of energy harvesting from uniaxially-aligned cardiomyocytes on a flexible substrate for the first time. Experimentally, synchronously contracting neonatal rat ventricular cardiomyocytes (NRVCs) at 0.5Hz have been found to cause the mechanical straining of a piezoelectric energy harvester to produce 87.5nA and 92.3mV of peak current and voltage, respectively. This work presents a successful step toward mechanical energy harvesting via living biological cells and tissues.

10:45 **DIFFUSION REFUELING BIOFUEL CELL MOUNTABLE ON INSECT** 163
K. Shoji[1], Y. Akiyama[1], M. Suzuki[2], N. Nakamura[2], H. Ohno[2], and K. Morishima[1]
[1]Osaka University, JAPAN and [2]Tokyo University of Agriculture and Technology, JAPAN

This paper reports an insect-mountable biofuel cell (imBFC) using trehalose, main sugar of insect hemolymph. The imBFC is refueled trehalose by diffusion from insect hemolymph automatically and generates electric power by oxidizing glucose which is obtained by hydrolyzing trehalose enzymatically. We fabricated the imBFC consisted of a connector, two chambers separated by a dialysis membrane and electrodes and succeeded in driving a light-emitting diode by the imBFC. The results have shown a potentially to be applied for a battery of novel ubiquitous robots such as insect cyborgs.

11:00 **ALD RUTHENIUM OXIDE-CARBON NANOTUBE ELECTRODES FOR SUPERCAPACITOR APPLICATIONS** 167
R. Warren[1], F. Sammoura[1,2], A. Kozinda[1], and L. Lin[1]
[1]University of California, Berkeley, USA and [2]Masdar Institute of Science and Technology, UAE

This work presents the first demonstration of atomic layer deposition (ALD) ruthenium oxide (RuO_2) and its conformal coating onto vertically aligned carbon nanotube (CNT) forest as supercapacitor electrodes. The ALD method allows precise control over the RuO_2 layer thickness and composition without the use of binder molecules. The ALD RuO_2 coated CNTs achieve a specific capacitance of 100 mF/cm^2 and retain their high-performance over repeated cycling.

11:15 **SUB 3-MICRON GAP MICROPLASMA FET WITH 50 V TURN-ON VOLTAGE** 171
P. Pai and M. Tabib-Azar
University of Utah, USA

We report the smallest microplasma transistor reported till date that operates with a low turn-on voltage of 50V dc. The device achieves more than 3x reduction in the turn-on voltage and 100x reduction in size compared to devices reported by other groups in the past. Earlier work reported by our group used plasma from an external source to operate the transistor. Our recent work successfully generated direct current plasma within the device with a turn-on voltage of 180V. This paper reports gate field-effect characterization results performed under dc and rf excitation and draws a comparison.

11:30 **Lunch on Own**

13:00 **Poster/Oral Session III**

Session X– Microdevices for Cell Manipulation

Session Chairs:
I. Park, *Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA*
Y. Sun, *University of Toronto, CANADA*

15:00 **FORMATION OF CROSS-SHAPED ESCHERICHIA COLI** 175
K. Hirayama, Y.J. Heo, and S. Takeuchi
University of Tokyo, JAPAN

We develop a method to regulate the shapes of bacteria by confining a single cell of bacteria into micro chamber. Escherichia coli has a cell wall structure which determines the rod-shape. We removed the cell wall of E. coli and then confined the spheroplasts into cross-shaped microchambers. If the bacteria re-synthesize its cell wall within the microchamber, we could obtain the cross-shaped bacteria. By analyzing the behavior of proteins and the cross-shaped bacteria, we believe that we could contribute to the comprehensive understanding of the shape regulation mechanism of E. coli.

15:15 **SINGLE-CELL 3D BIO-MEMS ENVIRONMENT WITH ENGINEERED GEOMETRY AND PHYSIOLOGICALLY RELEVANT STIFFNESSES** 177
M. Marelli[1], N. Gadhari[2], G. Boero[1], M. Chiquet[2], and J. Brugger[1]
[1]Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND and
[2]University of Bern, SWITZERLAND

We present a 3D microenvionment for on-chip cell culture, made of stress-bent cantilevers and designed to mimic essential physical properties of the in vivo environment, at the single-cell scale and with a high degree of parallelization. In particular, we report on a combinatorial fabrication approach bringing to the realization of a palette of devices with constant sizes (fitting a single-cell), but with stiffnesses spanning two orders of magnitude and matching physiologically relevant values.

15:30 **INTEGRATED MICRO CULTURE DEVICE FOR FULLY AUTOMATED CLOSED CULTURE EXPERIMENT OF EMBRYONIC BODY** 181
A. Yasukawa[1], T. Nishijima[2], M. Ikeuchi[1], and K. Ikuta[1]
[1]University of Tokyo, JAPAN and [2]Nagoya University, JAPAN

This paper reports formation, differentiation and analysis of embryonic bodies (EBs) from human iPS cells in a palm-size device "PASMA (Pressure Actuated Shapable Microwell Array)". By incorporating a transparent heat film and CO2 concentration adjusting system, PASMA realized miniaturization of the whole process of EB experiment in one chip. Moreover, the fully automated closed culture system can eliminate the risks of contamination due to manual operation. EBs from human iPS cells were successfully fabricated using this system.

15:45 **MECHANICAL CELL PAIRING SYSTEM BY SLIDING PARYLENE RAILS** 185
Y. Abe[1,2], K. Kamiya[1,3], T. Osaki[1,4], R. Kawano[1], N. Miki[1,2], and S. Takeuchi[1,4]
[1]Kanagawa Academy of Science and Technology, JAPAN, [2]Keio University, JAPAN,
[3]Japan Science and Technology Agency (JST), JAPAN and [4]University of Tokyo, JAPAN

This paper proposes a cell pairing system that is capable of defining the number and the position of trapped cells by mechanically sliding the parylene rail films (PRF). This system allows us to control the number as well as the order of lined-up cells. We successfully demonstrated lining up of three different cells in a designated order. The proposed system is readily applicable to study the cell-cell interactions using the single cell pairing.

16:00 **Break & Exhibit Inspection**

Session XI– Bio-Inspired Microactuators

Session Chairs:
Y. Yamanishi, *Shibaura Institute of Technology, JAPAN*
T.-H. Wang, *The Johns Hopkins University, USA*

16:30 **TWO-DIMENSIONALLY STEERING MICROSWIMMER PROPELLED BY OSCILLATING BUBBLES** 188
J. Feng and S.K. Cho
University of Pittsburgh, USA

An acoustically excited and oscillated bubble can generate a propelling force in micro scale. We develop a simple and efficient method that allows a bubble-propelled micro swimmer to propel and steer two dimensionally as wirelessly and remotely commanded.

16:45 **A MICROFABRICATED, BIOHYBRID, SOFT ROBOTICS FLAGELLUM** 192
B.J. Williams[1], S.V. Anand[1], J. Rajagopalan[2], and M.T.A. Saif[1]
[1]University of Illinois, Urbana-Champaign, USA and [2]Arizona State University, USA

We develop a microfabricated soft robotics biohybrid swimmer utilizing the contractions of one to several cardiomyocytes to provide on-board actuation to a thin, deformable, polydimethylsiloxane (PDMS) filament. The actuated filament deforms passively in response to fluid drag, producing a time-irreversible deformation pattern and net propulsive force at low Reynolds number. We utilize an elastohydrodynamic model to determine appropriate filament parameters and realize a functional swimmer.

17:00 **EVALUATION AND OPTICAL CONTROL OF SOMATIC MUSCLE MICRO BIOACTUATOR OF CHANNELRHODOPSIN TRANSGENIC DROSOPHILA MELANOGASTER** 196

M. Hirooka[1], S.P. Beh[1], T. Asano[1], Y. Akiyama[1], T. Hoshino[2], K. Hoshino[3], H. Tsujimura[3], K. Iwabuchi[3], and K. Morishima[1]
[1]Osaka University, JAPAN, [2]University of Tokyo, JAPAN, and [3]Tokyo University of Agriculture and Technology, JAPAN

In this research, we first developed light-activated somatic muscle of transgenic Drosophila melanogaster expressing a blue light sensitive cation channel, channelrhodopsin-2, and incorporated into a micro device. We successfully demonstrated that optogonetic stimulation using light pulses was able to control the contractile activity with a given temporal pattern. The contractile force was evaluated with varying light intensities and pulse widths. These results have shown that mechanical systems powered by muscles will be controlled more accurately under our strategy.

17:15 **FERROFLUID-ASSISTED MICRO ROTARY MOTOR FOR MINIMALLY INVASIVE ENDOSCOPY APPLICATIONS** 200

B. Assadsangabi, M.H. Tee, S. Wu, and K. Takahata
University of British Columbia, CANADA

Micro-scale rotary motors have a vast range of potential applications in broad areas. One promising area is medical applications. Minimally-invasive endoscopic catheters are an excellent example. The micromotors used in these catheters, however, generally have large axial lengths (e.g., >1 cm). This paper presents the first rotary micromotor enabled by ferrofluid bearing that drastically shortens the axial length of micromotors, suitable for medical catheter applications, owing to the extremely simple and reliable bearing mechanism.

17:30 **Adjourn for the day**

18:30 - 21:30 **Conference Banquet**

Thursday, January 30

08:00 **ANNOUNCEMENTS**

Plenary IV

Session Chairs:
F. Ayazi, *Georgia Institute of Technology, USA*
CJ Kim, *University of California, Los Angeles, USA*

08:05 **COMMERCIALIZATION OF WORLD'S FIRST PIEZOMEMS RESONATORS FOR HIGH PERFORMANCE TIMING APPLICATIONS** 204
Harmeet Bhugra, S. Lee, W. Pan, M. Pai, and D. Lei
Integrated Device Technology, Inc. (IDT), USA

Session XII – Resonators & RF MEMS

Session Chairs:
A. Seshia, *Cambridge University, UK*
K. Böhringer, *University of Washington, USA*

08:45 **MEMS-RECONFIGURABLE WAVEGUIDE IRIS FOR SWITCHABLE V-BAND CAVITY RESONATORS** 206
Z. Baghchehsaraei and J. Oberhammer
KTH Royal Institute of Technology, SWEDEN

We present, for the first time, a reconfigurable waveguide iris based on a MEMS-reconfigurable surface integrated into a WR-12 rectangular waveguide (60–90 GHz, 3.099 mm × 1.549 mm). The reconfigurable surface is only 30 μm thick and incorporates 252 simultaneously switched contact points for activating or deactivating an inductive iris. The switchable irises can be utilized to implement components such as reconfigurable filters and cavity resonators. We also present for the first time a reconfigurable cavity resonator based on the novel MEMS-reconfigurable iris.

09:00 **A MICROMECHANICAL PARAMETRIC OSCILLATOR FOR FREQUENCY DIVISION AND PHASE NOISE REDUCTION** 210
T.O. Rocheleau, R. Liu, J. Naghsh Nilchi, T.L. Naing, and C.T.-C. Nguyen
University of California, Berkeley, USA

A capacitive-gap RF MEMS resonator array demonstrates a first on-chip MEMS frequency divider with 61-MHz output generated from a 121-MHz electrical drive through use of a parametric oscillation effect. This provides not only the expected 6dB reduction in close-to-carrier phase noise, but also a remarkable 23dB reduction in far-from-carrier noise due to filtering by the high-Q mechanical resonator. In contrast with traditional frequency division, the parametric oscillator here requires no active devices, adds no noise to the signal and has essentially zero power consumption, limited in principle only by MEMS resonator loss.

09:15 **TEMPERATURE-COMPENSATED PIEZOELECTRICALLY ACTUATED LAMÉ-MODE RESONATORS** 214
V.A. Thakar and M. Rais-Zadeh
University of Michigan, USA

In this work, we present a passive compensation strategy for Lamé-mode resonators using silicon dioxide refilled islands within the resonator body. With this technique we achieve compensation of the first-order TCF and further demonstrate that the turnover temperature (TOT) can be tuned across a wide range from -40°C to +120°C by optimizing the placement of oxide refilled islands.

09:30 **A MEMS AUTONOMOUS SWITCHED OSCILLATOR** 218
G.B. Torri[1,2], J. Bienstman[2], X. Rottenberg[1], H.A.C. Tilmans[2], C. Van Hoof[1,2], and R. Puers[1,2]
[1]*imec, BELGIUM and* [2]*KU Leuven, BELGIUM*

We design and measure an autonomous electrostatic MEMS oscillator that exhibits periodic and aperiodic behavior. The system consists of an electrostatic MEM, a dc voltage source, and a displacement dependent resistive circuit. The applied voltage above the pull-in and the position dependent circuit are responsible for sustaining the oscillations. Electronic and non-electronic information can be input or retrieved from the oscillator system. Applications for such device range from chaotic signals for communications, sensitive mass sensors, and signal processing.

10:00 **Poster/Oral Session IV**

Session XIII – Chemical Sensors & Systems

Session Chairs:
A. Llobera, *Centre Nacional de Microelectronica, SPAIN*
H. Moon, *University of Texas, Arlington, USA*

12:00 **SURFACE TENSION MONITORING IN A "SOFT" INTERFACE USING ELECTROWETTING ON DIELECTRIC** 222
S. Choi[1], Y. Kwon[2], E. Jeon[1], S. Kim[1], and J. Lee[1]
[1]Seoul National University, SOUTH KOREA and [2]Samsung Electronics Co., Ltd., SOUTH KOREA

We report the first demonstration of interfacial tension monitoring across two immiscible liquids using electrowetting on dielectric (EWOD). Impedance measurement during EWOD reveals the variation of surfactant concentration at the liquid-liquid interface in real time. We also show such approach can be used for label-free monitoring of DNA hybridization. Our approach opens a new horizon of EWOD used as a molecular sensing mechanism across a "soft" interface between liquids.

12:15 **MICROFLUIDIC BUBBLE-BASED GAS SENSOR** 226
A. Bulbul, H.-C. Hsieh, and H. Kim
University of Utah, USA

We report a new class of a gas sensor that utilizes the variations in bubble sizes, when different gases are introduced into a liquid flow, to identify gas types and even quantify the amounts. To verify the feasibility of the concept, the sizes of discretely formed bubbles were optically monitored and analyzed through a custom-developed MATLAB software.

12:30 **A FLEXIBLE GRAPHENE FET GAS SENSOR USING POLYMER GATE DIELECTRICS** 230
Y. Liu, J. Chang, and L. Lin
University of California, Berkeley, USA

We have successfully demonstrated a Graphene FET (GFET) gas sensor on a flexible plastic substrate for the first time with a sensitivity of $0.00428ppm^{-1}$ ($\Delta R/R_0$) for ammonia detection. Compared with the state-of-art technologies, four distinctive advancements have been achieved: (1) first demonstration of a flexible graphene FET gas sensor; (2) a new fabrication process to achieve embedded-gate GFET on a flexible substrate; (3) proof of utilizing polymeric materials of parylene and polyethylenimine (PEI) as the gate dielectrics and channel dopant for graphene FET, respectively; and (4) validation of a real-time gas sensing mechanism utilizing n-type doping of graphene induced by ammonia exposure.

12:45 **Awards Ceremony**

13:00 **Conference Adjourns**

Poster/Oral Presentations

M – Monday (13:00 - 15:00)
T – Tuesday (14:00 - 16:00)
W – Wednesday (13:00 - 15:00)
Th – Thursday (09:45 - 11:45)

Bio MEMS (Bio)

We present a novel design of continuously optically-induced electroporation (OIE) device capable of replacing culture medium and electroporation buffer in a seamless fashion. With this approach, the entire process for continuous cell electroporation could be performed automatically without human intervention. Furthermore, the survival rate of the cells could be greatly improved due to this fast, automatic procedure.

Here we present the first permeability assay platform to enable rapid characterization of shear stress effects fully spanning the physiologically relevant spectrum (1-60dyn/cm2) for endothelial cells in vitro. The structure comprised 4 parallel channels to enable independent permeability assays, and generated 15x shear stress range indicated by simulation and an integrated micro-flow sensor array. Endothelial cells exhibited decreased permeability of fluorescent tracers with shear stress, as well as increased elongation and cell alignment with increases in shear stress.

This paper presents a microfluidic device for synthetically isolating cell-targeting aptamers from a randomized single-strand DNA (ssDNA) library. The device integrates cell culturing with affinity selection of cell-binding ssDNA, which is then amplified by bead-based polymerase chain reaction (PCR). Coupling of the selection and amplification using pressure-driven flow realizes multi-round aptamer isolation on a single chip.

We develop nanowire-integrated microfluidic devices for hydrodynamic trapping and anchoring of bacterial cells and demonstrate that the mesh-like cages formed by integrating ZnO nanowires are effective in trapping and anchoring of Escherichia coli as a model bacterium. We present two anchoring modes, impaling and wedging, followed by irreversible damage or reversible deformation of the cell wall, respectively.

Cardiovascular diseases are responsible for 25-million deaths worldwide on a yearly basis. Timely diagnosis of the disease is therefore an important research area. Toward this end, C-reactive protein (CRP) is a general biomarker for inflammation and infection, and has become a good marker for evaluating risks of cardiovascular diseases. Previously, a CRP-specific aptamer (nucleic acid-based antibody, in a nutshell) with high sensitivity and specificity was used to detect CRP in microfluidic system, which was capable of performing the detection in an automated fashion while consuming tiny volumes of reagents and samples. In parallel, field-effect transistors (FET) have emerged as sensors to detect small molecules, proteins and even viruses, and have demonstrated rapid and highly sensitive detection in a compact system. In this work, an integrated device that combined the advantages of microfluidics, aptamers and FET-based sensors was developed to achieve rapid, sensitive and specific CRP detection. The developed integrated microfluidic system with FET sensor and CRP-specific aptamer can be promising for fast, sensitive and specific CRP detection.

T-006 **ASSEMBLY OF NEURAL CELL-LADEN MICROPLATES ON A MICROFABRICATED BREADBOARD** 254

S. Yoshida[1], K. Sato[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

We developed a method to form an arbitrary network of neural cell-laden microplates using a breadboard-like microelectrode array (MEA). We cultured single neural cells on perforated microplates with control of their morphologies, then mounted the plates on the micro-sockets attached on the breadboard. Through a pore punched in the center of the microplate, the electrical activities of cells would be accessible with gold electrodes patterned on the MEA.

W-007 **CD4 CELL ISOLATION FROM BLOOD USING FINGER-ACTUATED ON-CHIP MAGNETOPHORESIS FOR RAPID HIV/AIDS DIAGNOSTICS** 256

M. Glynn, D.J. Kinahan, D. Chung, and J. Ducrée
Dublin City University, IRELAND

We have developed a microfluidic based disposable device, actuated solely by finger pressure from the operator, to repeatedly pass micro quantities of blood past a magnetic based cell capture structure to allow CD4 cell based HIV diagnostics in less than 1 minute following sample application. This is aimed for deployment in resource-poor regions where HIV is endemic but diagnostics is a challenge.

Th-008 **CENTRIFUGALLY AUTOMATED SOLID-PHASE PURIFICATION OF RNA** 260

N. Dimov, J. Gaughran, D. McAuley, D. Boyle, D.J. Kinahan, and J. Ducrée
Dublin City University, IRELAND

We report for the first time on a fully centrifugally automated solid-phase purification of RNA on an integrated microfluidic disc with sequential release of on-board reagents.

M-009 **FABRICATION METHOD TO A HIGH RESOLUTION CONTROL IN THE SPACE OF CELL CULTURING ENVIRONMENT WITH MICROFLUIDIC SYSTEM** 264

T. Hiraiwa[1], T. Kimura[1], Y. Takenaka[1], R. Tanamoto[1], H. Ota[3], H. Kimura[2], Y. Taguchi[1], N. Miki[1], Y. Matsumoto[1], K. Oka[1], A. Funahashi[1], and N. Hiroi[1]
[1]Keio University, JAPAN, [2]Tokai University, JAPAN, and [3]University of California, Berkeley, USA

We develop a reusable Cell Culturing Device, designed for single cells and cellular network analysis. This is the first success of combination of Microcontact Printing (μCP) and Vacuum Device. This device has following advantages: (1) cells stay within the micropatterns more than 12hrs, (2) cell culture environment is regulated precisely using laminar flow, (3) this device is reusable for further experiments.

T-010 **INDIVIDUALLY ADDRESSABLE MULTI-CHAMBER ELECTROPORATION PLATFORM WITH DIELECTROPHORESIS-ASSISTED CELL POSITIONING** 268

S. Park and G. Yossifon
Technion–Israel Institute of Technology, ISRAEL

We developed a novel, multifunctional platform with an array for high throughput screening which integrates DEP trapping/positioning and electroporation mechanisms in a multi-chamber array where each chamber may be individually activated. As a proof of concept, platforms with an array of 40 × 2 cell microchambers were fabricated and tested to demonstrate the feasibility of integrating the two functionalities: 1) the manipulation of the particles/cells using DEP, and 2) gradient electroporation using by producing a spatial gradient of electroporation parameters to optimize electroporation efficiency.

W-011 **INTEGRATION OF HEAT-TRANSFER RESISTANCE MEASUREMENTS ONTO A DIGITAL MICROFLUIDIC PLATFORM TOWARDS THE MINIATURIZED AND AUTOMATED LABEL-FREE DETECTION OF BIOMOLECULAR INTERACTIONS** 272

E. Perez-Ruiz[1], T. Vandenryt[2], D. Witters[1], D. Decrop[1], B. van Grinsven[2], D. Spasic[1], P. Wagner[2], and J. Lammertyn[1]
[1]KU Leuven, BELGIUM and [2]University of Hasselt, BELGIUM

In this work the successful integration of heat-transfer resistance measurements with a digital microfluidic chip is shown. The integrated miniaturized platform allows the automated label-free detection of biomolecular interactions. To immobilize biomolecules on the hydrophobic chip surface, hydrophilic gold sensing patches are created by means of a novel dry lift-off technique that leaves the chip surface unaffected. In order to validate the integrated device, DNA melting analysis was performed in the set-up.

Chemical Sensors and Systems (CSS)

This study reports on integration of boron-doped diamond (BDD) microelectrodes on CMOS-based 20×20 amperometric biosensor array. The BDD electrodes are once formed on a Si wafer at 800°C, and then transferred to a 0.18 µm CMOS wafer with a benzocyclobutene (BCB) bonding interlayer. The fully-integrated device successfully detects biomolecules such as histamine owing to a wide potential window of the BDD electrode, and offers 2-dimensional real-time imaging of histamine diffusion in a solution. This type biosensor promises sensing and imaging applications of various biological materials which cannot be detected by conventional sensors.

Graphene has high sensitivity to gases, but has poor selectivity. Therefore, graphene is hard to apply to electronic nose. Because the gas absorbability of ionic liquid (IL) depends on its type, graphene FETs (GFETs) gated by different ILs have different gas responses. The response pattern of the IL-gated GFETs (ILGFETs) enables gas species detection, i.e. ILs provide gas selectivity to graphene. We assembled three ILGFETs with three kinds of ILs into an ILGFET array. The response patterns to several gases were measured to demonstrate the feasibility of graphene electronic nose.

We report the first demonstration of MEMS-based sensor array enabling multiple tests in one disposable microfluidic cartridge using plasma. The LoC (Lab-on-Chip) platform technology is versatile and demonstrated here for real-time coagulation and clot-time tests (activated Partial Thrompoblastin Time (aPTT) and Prothrombin Time (PT)). The start and the end of fibrin generation during coagulation can be clearly seen in real-time for both of the tests. Magnetic actuation and optical read-out is used. Hence no electrical connection to the MEMS chip is required. This makes the system convenient for point-of-care tests.

In this paper, we present a parallelized droplet-based platform for on-demand, combinatorial generation of nanoliter droplets. By parallelizing fission and fusion modules, throughput is increased by two orders ofmagnitude. With 32 Hz droplet generation, the projected throughput of this parallelized design is nearly 3 million sample-probe droplets per day on a single device (with 4 replicates of 750 thousand different mixtures). This translates to 240 unique sample-probe mixtures with 4 replicates per minute each.

We develop an EWOD impedance measurement system for in situ chemical reaction monitoring to maximize the advantage of microscale chemical synthesis. As a demonstration, we measure the droplet impedance on EWOD at various stages of an acid-base titration, showing its capability of detecting the equivalence point of neutralization.

Energy Harvesting and Power MEMS (EHPM)

A three-dimensional solid-state miniaturized supercapacitor based on double conformal coating of Multiwalled Carbon Nanotubes (MWCNTs) bundles is presented. Atomic Layer Deposition (ALD) is used to deposit Al_2O_3 as dielectric layer and TiN as high aspect-ratio conformal counter-electrode on 2µm long MWCNTs bundles. The devices are realized using an IC wafer-scale manufacturing process and show a remarkable volumetric capacitance density value of 12mF/cm^3 with high reproducibility (≤0.3E-12F deviation). The small footprint (100µm^2 to 625µm^2), a thickness of only 2µm, the extremely high capacitance density and the novel and easy-to-integrate fabrication process make it possible to realize high performance energy storage micro-devices.

In this work, graphene electrodes are employed to increase the power output of a microliter-scale microbial fuel cell (μMFC) for the first time. Previously, researchers have predominantly used Au/Cr electrodes in μMFCs, and have operated these fuel cells under controlled anodic conditions to attain high current densities and columbic efficiencies. At present, relatively low power outputs and open circuit potentials have limited such fuel cells from implementation in practical applications. To improve such performance, here we introduce a graphene-based μMFC (G-MFC) that utilizes graphene electrodes.

We developed a lead-free (K,Na)NbO3 (KNN) nonlinear microenergy harvester. The harvester was densely integrated with a quatrefoil-shaped proof mass and quad cantilevers using bulk micromachining. The KNN/Si composite cantilever with two-separated KNN capacitors was to effectively collect charge. Clamped-clamped beam design was also adopted for wide band operation. The experimental results showed that the wide bandwidth of 253 Hz and the highest power density of 1623 uW/cm3 among the developed piezoelectric nonlinear MEMS harvesters were achieved at the low acceleration of 6 m/s2.

This paper presents a new on-chip Li-ion capacitor featured by higher energy density than that of supercapacitor under the same level of charge/discharge rate. Activated carbon (AC), a supercapacitor material, is used as positive electrode, while graphite, an anode material of Li-ion battery, is used as negative electrode and the electrolyte used in Li-ion battery serves as electrolyte. The prototype with 100-μm-thick electrodes shows a capacity of 175μAh/cm^2 and an energy density of about 1550mJ/cm^2 under a charge/discharge current of 0.5mA/cm^2, and a cell voltage of 3.4V.

This paper presents the high performance on-chip micro supercapacitors using manganese dioxide (MnO_2) decorated into direct-prototyped porous carbon electrodes. By a new method of incorporating MnO_2 into carbon framework, both electric double layer capacitance (EDLC) and pseudocapacitance contribute to total capacity. Therefore, about 4-time increase in volumetric capacitance (0.8mF/(cm^2 μm) vs. 2.9mF/(cm^2 μm) under the scan rate of 50mV/s) is achieved. The procedure makes such devices potentially to be integrated into multi-function microsystems.

We have developed a novel in-plane MEMS electret energy harvester with overlapping-area change and gap-closing electrodes that provides large output power both at low and high vibration accelerations. An early prototype has been successfully microfabricated with the single layer silicon-on-insulator process. Soft X-ray charging is employed to establish uniform surface potential around 60 V on vertical electrets on the sidewall of the comb fingers. Up to 1.6 μW output power has been obtained, which corresponds to the effective as high as 57%.

This paper presents a novel fabrication process to pattern the charge in electret film for vibration energy harvester (VEH) Applications. Compared with previously reported techniques, PTFE electret material, which is inexpensive and has highSurface potential, is used. The line width of the charge pattern is determined by photolithography process. Experiment results show that the surface potential on the patterned charge zone of PTFE is higher than -200V when line width reaches 20um. A demoed VEH is built by using the pattern technique and tested.

Fabrication Technologies (FAB)

T-066 **GRAPHENE SYNTHESIS VIA DROPLET CVD AND ITS PHOTONIC APPLICATIONS** 486
X.N. Zang and L. Lin
University of California, Berkeley, USA

The process of "droplet CVD" for the synthesis of graphene sheets and its photonic applications have been demonstrated for the first time. Metal (Cu or Ni) droplets are naturally transformed from thin films in a high temperature furnace and utilized to grow graphene sheets via the chemical vapor deposition (CVD) process. As such, this new class of fabrication process could open up various graphene-based device/system applications, including photonic sensors."

W-067 **HIGH ASPECT RATIO, LARGE AREA SILICON-BASED GRATINGS FOR X-RAY PHASE CONTRAST IMAGING** 490
J.J. Baborowski, V. Revol, C. Kotler, R. Kaufman, P. Niedermann, F. Cardot, A. Dommann, A. Neels, and M. Despont
CSEM SA, SWITZERLAND

The presented work reports on the latest developments in the manufacturing of high aspect ratio silicon-based gratings used for X-ray phase contrast imaging (XPCI. XPCI reveals subtle changes in the microstructure of the samples, such as micro-cracks in composite materials or micro-calcifications in breast tissues. In fields as diverse as medicine, non-destructive testing or security, the gained information of this technique allows early diagnostic or detection of defects, tumors or explosives. The range of opportunities offered by depends highly on the achievable gratings parameters, such as periodicity, depth, duty cycle and aspect ratio. We have developed large (100x100mm2) Au-Si-Au-Air gratings with a periodicity of down to 2 µm and a depth of up to 100 µm with extremely low defect density (<1 defect/cm2). The fabricated gratings have been implemented on a XPCI set-up and used to demonstrate unprecedented imaging quality in material quality control.

Th-068 **HIGH RESOLUTION MICRO ULTRASONIC MACHINING (HR-µUSM) FOR POST-FABRICATION TRIMMING OF FUSED SILICA 3-D MICROSTRUCTURES** 494
A. Viswanath, T. Li, and Y.B. Gianchandani
University of Michigan, USA

Post-fabrication trimming is interesting for devices such as inertial sensors, timing references, and mass-balance resonators to adjust stiffness, mass, and potentially damping. The trimming process should be capable of micro machining brittle materials, without inducing stress or subsurface cracks. We have developed and evaluated a subtractive trimming technique based on micro ultrasonic machining (µUSM), for high-resolution trimming of complex 3D microstructures made from fused silica. Machining rates as low as 10 nm/sec and surface roughness as low as 30 nm have been achieved.

M-069 **FABRICATION OF CARBON NANOFIBROUS MICROELECTRODE ARRAY (CNF-MEA) USING NANOFIBER IMMERSION PHOTOLITHOGRAPHY** 498
P.F. Jao[1], E. Franca[1], S.P. Fang[1], J. Yoon[1], K. Cho[1,3], D.E. Senior[2], G.J. Kim[1], B. Wheeler[1], and Y.K. Yoon[1]
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Microelectrode arrays are used for stimulating and receiving neural electrical signals in vitro neural study. This work demonstrates the fabrication process of nanofibrous 3D microelectrodes using immersion lithography. Oil immersion negates the diffraction effects intrinsic in the photopatterning of electrospun nanofibers to give higher aspect ratio. Nanofiber electrode resistivity is characterized and its performance compared to that of carbon thin film. In vitro testing of electrodes are performed using E18 cortical neurons and cell density and cell viability analyzed.

T-070 **INDUCTIVELY COUPLED PLASMA ETCHING OF BULK TUNGSTEN FOR MEMS APPLICATIONS** 502
L. Song, N. Li, S. Zhang, J. Luo, J. Hu, Y. Zhang, S. Chen, and J. Chen
Peking University, CHINA

Tungsten based MEMS devices have the potential to be used for many applications, such as tools for micro electrical discharge machining and ultrasonic machining, or mold for inject molding. For the first time, bulk tungsten ICP etching was developed and characterized, which is capable of producing high aspect ratio (>13) structures with feature size below 3µm. Etching depth of 230µm has been achieved at an etch rate up-to 2.2µm/min. This technology offers big opportunities for MEMS applications.

W-071 **LARGE ARRAYS OF INKJET-PRINTED MEMS MICROBRIDGES ON FOIL** 506
F. Molina-Lopez, D. Briand, and N.F. de Rooij
Ecole Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This works describes the fabrication of an array of printed MEMS microbridges on polymeric foil in only four easy steps.Each functional material was deposited exclusively by inkjet-printing technique, compatible with large-area fabrication. Thearray consists of 60 to 80 individual microbridges, occupying an area of 2 mm x 2 mm, and displaying a total capacitancevalue of 1 - 1.7 pF when connected in parallel.

T-078 **PRINTING AND ENCAPSULATION OF ELECTRICAL CONDUCTORS ON POLYLACTIC ACID (PLA) FOR SENSING APPLICATIONS** 532
A. Vásquez Quintero, N. Frolet, D. Märki, G. Mattana, A. Marette, D. Briand, and N.F. de Rooij
Ecole Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This paper presents the printing of resistive and capacitive devices for temperature and humidity sensing applications, respectively, on biodegradable polylactic acid (PLA) substrates. Inkjet and gravure printing were assessed as direct silver-based nanoparticles inks transfer methods. Flash photonic ink sintering methodologies were optimized due to the low PLA glass transition temperature (58 °C) and maintain its mechanical integrity. An encapsulation method for electrical conductive structures is proposed by means of laminating PLA sheets at relatively low temperatures (< 60 °C). These fabricated structures are now exposed for long periods (months) in compost and high humidity environments to evaluate their degradation.

W-079 **RAPID PROTOTYPING OF RESISTIVE MEMS SENSING DEVICES ON PAPER SUBSTRATES** 536
T. Meiss[1], R. Werthschützky[1], and B. Stoeber[2]
[1]Technische Universität Darmstadt, GERMANY and [2]University of British Columbia, CANADA

We have developed an inexpensive inkjet printing process to rapidly fabricate resistive sensor devices on paper substrates. Since we use a commercial inexpensive inkjet printer and the design can be modified and tested within minutes, the process is especially useful to easily develop and test MEMS sensor models. Additional applications encompass disposable medical sensors, sensors for paper packaging, as well as very low cost strain sensing.

Th-080 **REAL-TIME DYNAMICALLY RECONFIGURABLE LIQUID METAL BASED PHOTOLITHOGRAPHY** 540
D. Kim[1], J.H. Yoo[1], W. Choi[1], K. Yoo[2], and J.B. Lee[1]
[1]University of Texas at Dallas, USA and [2]Hanbat National University, SOUTH KOREA

We report real-time dynamically reconfigurable photolithography technique using liquid metal Galinstan as UV opaque material and PDMS as UV transparent material. We demonstrated dynamically reconfigured on-demand patterning of single digit numbers in positive photoresists along with various patterns with minimum feature size of 10 µm. To the best of our knowledge, this is the first demonstration of true real-time reconfigurable photolithography in UV wavelengths.

M-081 **RELEASE AND TRANSFER OF LARGE-AREA ULTRA-THIN PDMS** 544
J. Gao, D. Guo, S. Santhanam, Y.J. Yu, A.J.H. McGaughey, S.C. Yao, and G.K. Fedder
Carnegie Mellon University, USA

This paper reports on a successful fabrication of ultra-thin 10µm PDMS films with embedded Au electrodes, as well as the releasing and transferring of large area films. The motivation for this work is in development of a miniature pump actuator for moving working fluid in an electrocaloric microcooler. It opens a promising route for fabricating ultra-thin and compliant MEMS and electronic devices.

T-082 **SOLID STATE MEMS DEVICES ON FLEXIBLE AND SEMI-TRANSPARENT SILICON (100) PLATFORM** 548
S.M. Ahmed, A.M. Hussain, J.P. Rojas, and M.M. Hussain
King Abdullah University of Science and Technology, SAUDI ARABIA

We report fabrication of MEMS thermal actuators on flexible and semi-transparent bulk silicon <100> substrate. The fabricated thermal actuators exhibit similar performance before and after bending. We fabricate the devices first and then release the top portion of the silicon (≈ 19 µm) which is flexible and semi-transparent. Then we perform chemical mechanical polishing to reuse the remaining wafer. Prior demonstrations on flexible MEMS devices had limited thermal budget (<150 °C) compatibility and they did not have cost-saving wafer recycling process.

W-083 **WAFER-SCALE FABRICATION OF HIGHLY INTEGRATED RUBIDIUM VAPOR CELLS** 552
T. Overstolz, J. Haesler, G. Bergonzi. A. Pezous, P.-A. Clerc, S. Ischer, J. Kaufmann, and M. Despont
CSEM SA, SWITZERLAND

CSEM is developing a highly integrated chip scale atomic clock based on coherent population trapping (CPT) of 87-Rb atoms which are confined in a vapor cell. The vapor cells are batch fabricated, based on pipetting dissolved RbN3 into cell cavities etched into a silicon wafer, closing the cavities by anodic bonding, and UV decomposition of recrystallized RbN3 deposits into Rb and N2. The vapour cells are equipped with resistive heaters, temperature sensors, and Helmholtz coils integrated on both sides of the cell windows.

Th-084 **WAFER-SCALE FLEXIBLE GRAPHENE LOUDSPEAKERS** 556
H. Tian, Y.L. Cui, Y. Yang, D. Xie, and T.L. Ren
Tsinghua University, CHINA

Wafer-scale flexible graphene loudspeakers are fabricated in one-step laser scribing technology. Current fabrication process for graphene devices is mainly based on CVD graphene, which needs several hours' graphene growth, transfer and patterning. By using this new laser scribing technology, wafer-scale graphene patterns can be obtained in 25 minutes. The loudspeaker is demonstrated to be high performance with wide-band sound generation from 1~50 kHz. Our results show that the laser scribed graphene could be widely used in integrating wafer-scale graphene-based electroacoustic devices.

Industry

A low-cost and wide mirror area polymer MEMS scanner for on-demand light distribution was fabricated by combined process of the injection molding and layer transfer of screen-printed patterns on a film. This fabrication process realizes low cost polymer MEMS. It is expected that the low-cost MEMS can be a killer application for new industry field.

We describe the design, fabrication and performance of a MEMS pump that is actuated electromagnetically and is capable of pumping very high viscosity liquids. Valve motion relative to that of the pumping piston is described in detail.

We present a comprehensive approach to address the issue of the mechanical reliability of MEMS piezoelectric vibration harvesters. These harvesters generate sufficient electrical power for powering a tire pressure monitoring system. However, their reliability, particularly in terms of shock resilience, has to be optimized for in-tire applications. This paper showcases experimentally verified improvements of the mechanical reliability, which is achieved by optimizing both the package design and the wafer processing.

We have developed a scalable low-cost microbolometer which can be used for automotive nightvision as well as consumer applications with a broad variety of requirements regarding image resolution and sensitivity. In contrast to state-of-the-art microbolometers which are based on a standard CMOS ASIC process with CMOS-compatible MEMS post-processing on the same wafer, we use a MEMS wafer with the microbolometer pixels and a standard CMOS wafer with the read-out ASIC which are mechanically, electrically and hermetically connected. This concept allows for significant cost reduction since the two dedicated technologies for the MEMS and the ASIC can be optimized and fabricated independently and because the ASIC chip can serve as a hermetic package for the MEMS.

Materials and Device Characterization (MDC)

We present a high-efficiency 2D photonic crystal based solar thermophotovoltaic (STPV) device operating at high temperatures (~1300 K) under moderate solar concentration (~100 Suns). These results were only possible by tailoring the spectral properties of the absorber-emitter through surface nanostructuring of tantalum and minimizing parasitic thermal losses through an innovative vacuum-enclosed experimental setup.

We will show a technique, based on plain optical microscopy and curve fitting, for measuring in-plane displacements in MEMS applications. We modeled and experimentally verified how the measurement accuracy is influenced by quantization noise, photon shot noise, optical magnification, camera resolution and pixel binning. We found that when the noise figure was dominated by shot noise, the measurement error was lowered into the deep-subnanometer range.

W-091 **CHARACTERIZATION OF IMPROVED CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS (CMUTS) USING ALD HIGH-K DIELECTRIC ISOLATION** 584
T. Xu, C. Tekes, and F.L. Degertekin
Georgia Institute of Technology, USA

We show the advantages of high-k dielectric, ALD HfO2 over traditional PECVD silicon nitride isolation for Capacitive Micromachined Ultrasonic Transducers (CMUTs) fabricated by a low temperature, CMOS compatible, sacrificial release method. ALD HfO2 dielectric properties are characterized to optimize CMUT design in transmit and receive mode. Performances of the two different dielectric isolation devices are evaluated through parallel plate modeling and experimentally measured pressure outputs and receive sensitivities.

Th-092 **CHARACTERIZATION OF STICTION FORCES IN ULTRA-CLEAN ENCAPSULATED MEMS DEVICES** 588
D.B. Heinz, V.A. Hong, E.J. Ng, C.H. Ahn, Y. Yang, and T.W. Kenny
Stanford University, USA

We show that stiction in contact between encapsulated MEMS devices and the surrounding sidewalls generally results in a reversible adhesion with a consistent adhesion force. This force is small enough (25 μN) to be overcome by the restoring force of the springs in inertial sensors with resonant frequency above 4 kHz. Therefore, it should be possible to design and build stiction-free inertial sensors in this process – a significant advantage over approaches that rely on deposition, tuning and maintenance of chemical coatings for inertial sensors.

M-093 **COMPOSITE OF THERMALLY RESPONSIVE SOLUTION AND LUBRICATING MICRO BEADS AS SEALING MATERIAL FOR PISTON-CYLINDER ACTUATOR** 592
T. Chishiro, S. Honda, and S. Konishi
Ritsumeikan University, JAPAN

This paper proposes a novel sealing technique for miniaturized piston-cylinder actuator. The sliding part of a piston actuator requires both high sealing and excellent lubrication. This paper will show a smart sealing material composed of thermally responsive solution and lubricating micro beads. Micro beads are expected to contribute to provide lubricant between a sliding part and an inner wall when thermally responsive solution gels by heating. We will present the concept, design, and characterization of proposed sealing technique for a piston actuator.

T-094 **CONTINUOUS DYNAMIC TIMING MEASUREMENTS TO MONITOR SPRING AND SURFACE FORCES IN MEMS SWITCH RELIABILITY** 596
C. Kosla[1], P. Fitzgerald[2], and M. Hill[1]
[1]Cork Institute of Technology, IRELAND and [2]Analog Devices, IRELAND

We demonstrate an automatic reliability detection/prediction system for industry manufactured MEMS switches based on dynamic time measurements, allowing for non-invasive and continuous device monitoring. The developed method highlights the influence of both restoring and surface forces evolution on switch reliability and for the first time allows identification of an imminent device failure due to its continuous monitoring. Additionally we present the scalability of this approach by testing it on different switch types and on a large number of samples.

W-095 **DIRECT MEASUREMENT OF SHEAR PIEZORESISTANCE COEFFICIENT ON SINGLE CRYSTAL SILICON NANOWIRE BY ASYMMETRICAL FOUR-POINT BENDING TEST** 600
T. Kimura, N. Saito, T. Takeshita, K. Sugano, and Y. Isono
Kobe University, JAPAN

This research evaluated the shear piezoresistance property of p-type single crystal silicon nanowire (SiNW) by the asymmetrical four-point bending (AFPB) testing proposed by the authors. We fabricated the p-type SiNW on the AFPB specimen with "V" shaped notches made of single crystal silicon. Bending the specimen by the asymmetrical four point-supports, simple shear stress can be produced at the center of the specimen. Consequently, we have succeeded in evaluating the shear piezoresistance coefficient of SiNW directly."

Th-096 **DISSOLVABLE MATERIAL FOR HIGH-ASPECT-RATIO FLEXIBLE SILICON-MICROWIRE PENETRATIONS** 604
S. Yagi, S. Yamagiwa, T. Imashioya, H. Oi, Y. Kubota, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

For realization of low invasive electrode penetrations into biological tissue, here we improved the penetration capability of high-aspect-ratio flexible silicon-micorwires by coating a dissolving material of silk fibroin. The silk fibroin was coated over vertically vapor-liquid-solid (VLS) grown silicon-microwires. The 420-μm-long silicon-wire with a ~200-μm-thick silk film exited the stiffness of 4.03 N/m, which is 72% improved value compared to that of the silicon-wires without silk (2.34 N/m). The effects of the silk support on the wire penetration were observed by demonstrating the gelatin penetrations. These results suggest that the numerous high-aspect-ratio flexible bioprobes can be penetrated by using the silk support.

M-097 **DOME-DISC: DIFFRACTIVE OPTICS METROLOGY ENABLED DITHERING INERTIAL SENSOR CALIBRATION** 608

S. Nadig[1], S. Ardanuç[1], B. Clark[2], and A. Lal[1]
[1]Cornell University, USA and [2]Analog Devices Inc., USA

We demonstrate ~100-ppm accurate scale-factor and bias calibration of a commercial gyroscope, in which the typical un-calibrated scale factor variations are 100,000-ppm. In this paper, we present a Diffractive Optical Metrology Enabled Dithering Inertial Sensor Calibration consisting of a novel piezoelectric dither stage, the motion of which is measured by imaging the diffraction pattern off the stage of a long-term stable wavelength laser. The architecture presented here illustrates how atomically stable lasers and CMOS imagers can be combined to form a miniature atomically stable self-calibrated inertial sensor platform.

T-098 **ELECTRICAL CHARACTERIZATION OF ALD COATED SILICON DIOXIDE MICRO-HEMISPHERICAL SHELL RESONATORS** 612

P. Shao, V. Tavassoli, C.-S. Liu, L.D. Sorenson, and F. Ayazi
Georgia Institute of Technology, USA

A micro-hemispherical shell resonator (μHSR) is the beating heart of a micro-scale hemispherical resonator gyroscope (μHRG). Small damping and high symmetry are two essential requirements for μHRGs. Damping can be quantified bymechanical quality factor (Q) of the resonance, and structural symmetry can be quantified by the frequency split between two degenerate resonance modes. This paper reports on important electrical characterizations of Q and frequency split of ALD coated thermally-grown silicon-dioxide μHSRs, and analysis on how the performance will change with fabrication and measurement parameters.

W-099 **FABRICATION AND DEGRADATION CHARACTERISTIC OF SPUTTERED IRIDIUM OXIDE NEURAL MICROELECTRODES FOR FES APPLICATION** 616

X.-Y. Kang, J.-Q. Liu, H.-C. Tian, J.-C. Du, B. Yang, H.-Y. Zhu, Y. NuLi, and C.-S. Yang
Shanghai Jiao Tong University, CHINA

We have fabricated reactively sputtered iridium oxide film (SIROF) microelectrodes under different oxygen flows and the stimulus-evoked degradation properties are also tested. The SIROF microelectrodes prepared under 25 sccm oxygen flow shows the least degradation from continuous electrical stimulation. That the charge storage capacity (CSC) is only 9.6 % lost and the 1 kHz impedance is only 4.23% increase. Hence, the 25 sccm one can be an ideal microelectrode modification material for electrical stimulation with the least degradation.

Th-100 **FABRICATION AND TESTING OF PIEZOELECTRIC HYBRID PAPER FOR MEMS APPLICATIONS** 620

S.K. Mahadeva, K. Walus, and B. Stoeber
University of British Columbia, CANADA

We have developed a new inexpensive functional paper based material that can be used as a piezoelectric substrate for sensing applications. In our simple method, nanostructured BaTiO3 is embedded onto the fibers prior to forming paper sheet, which involves immersion of wood fibers in aqueous solution of poly(diallyldimethylammonium chloride) PDDA and poly(sodium 4-styrenesulfonate) and once again in PDDA, and results in the creation of a positively charged surface on wood fiber. The treated wood fibers are then immersed in a BaTiO3 suspension, leading to the electrostatic binding of BaTiO3. The hybrid paper showed the highest d33 of 4.8±0.4 pC/N.

M-101 **GRAPHENE WOVEN FABRIC AS HIGH-RESOLUTION SENSING ELEMENT OF CONTACT-LENS TONOMETER** 624

Y. Zhang[1], T. Man[1], X. Li[2], H. Zhu[2], and Z. Li[1]
[1]Peking University, CHINA and [2]Tsinghua University, CHINA

In our work, the graphene woven fabrics (GWFs), the combination of highly sensitive strain sensing and transparency, is investigated as the sensing element of the contact-lens tonometer, which enables precisely monitor IOP. The relationship between the current changes when keeping the voltage constant and effective IOP increasing has been obtained.

T-102 **INCREASED THERMAL CONDUCTIVITY POLYCRYSTALLINE DIAMOND FOR LOW-DISSIPATION MICROMECHANICAL RESONATORS** 628

H. Najar[1], A. Thron[1], C. Yang[2], S. Fung[1], K. van Benthem[1], L. Lin[2], and D.A. Horsley[1]
[1]University of California, Davis, USA, and [2]University of California, Berkeley, USA

We report an investigation of microcrystalline diamond (MCD) films deposited under different conditions to increase thermal conductivity and therefore mechanical Q in MEMS resonators. Here, through a study of different deposition conditions, we demonstrate a three-fold increase in thermal conductivity (i.e. k = 100W/mK) and therefore Q-TED. We further present a study of the unique microstructure of hot filament CVD diamond films and relate growth conditions to observed microstructural defects.

Magnesium (Mg) and magnesium alloys have drawn great attention as biodegradable materials. It means that magnesium could be an interesting dual "sacrificial and biodegradable MEMS material". This work then reports the first etching tests of the dual properties of ebeam-deposited thin-film Mg (i.e., 0.3 and 1.0 micron thick). Here we have tested etchants including diluted hydrochloric acid, saline, and culture medium. Data are fitted by "First-and-Second order" model. The initial results do show that thin-film Mg indeed is a promising dual sacrificial and biodegradable material."

We propose an innovative and simple three-dimensional (3-D) reshaping (plastic deformation) technique in MEMS devices by solely electrical control with ultrafine tuning resolution. While voltage input induces stress on the device, Joule heating is applied to make plastic deformation in the device, where the tuning resolution was demonstrated at a sub-100nm level. The proposed technique is expected to be favorably used in many integrated MEMS devices where reshaping feature is required avoiding any external instruments.

We report a tunable THz filter based on random access metamaterial with liquid metal droplet, which is tuned by controlled electrowetting effects. The random access metamaterial consists of micro droplets formed by lotus effect. In experiment, it measures a near 0.01-THz frequency shift of the dipole resonance spectrum induced by changing of the droplets shape via electrowetting effect. The random access metamaterial is flexible in tuning and easy in fabrication, which has potential application on tunable filters, controllable beam steering and flat lens.

We report the study of underwater wetting transition of superhydrophobic (SHPo) surfaces from dewetted (Cassie) to wetted (Wenzel) state through direct and continuous meniscus visualization. The result confirmed two meniscus states of pinning and wetting, the latter leading to the Wenzel state. Furthermore, the result revealed that the Cassie state can (or cannot) be indefinite if (or unless) the water is saturated with air and the hydrostatic pressure is low enough.

Mechanical Sensors and Systems (MECH)

This paper reports the development and performance of a 3D hemispherical micro glass-shell resonator with integrated electrostatic excitation and capacitive detection transducers. This paper presents the first performance results of the 3D shell resonator with integrated micro fabricated excitation and sensing units that produced the first vibration mode of resonance at 5.843 kHz with a quality factor of 730 at atmosphere with the time decay constant of 39.78ms.

We design and manufacturing a new CMOS-MEMS Pirani vacuum gauge with complementary bump heat-sink and cavity heater. By using the bump heat-sink and cavity heater design, the active area of heat-sink and heater can be increased without changing device footprint size. In addition, the cavity in heater reduces the thermal mass for low power operation. The proposed design have larger dynamic range, higher sensitivity and lower power consumption as compare to the typical type.

Medical Microsystems (MEDM)

We demonstrate a parametrically-excited 2D microscanner for a miniature dual axes confocal fluorescence endomicroscope. The scanner has a compact and robust gimbal structure which can perform resonant scanning with large tilting angle at high speed. A single-wafer based SOI process has been developed for improving the quality and the yield of the device. Ex vivo imaging on mouse colon is performed using the fabricated endomicroscope, and the near infrared fluorescence en-face image of dysplasia crypts over a large field-of-view of 800μm×400μm with subcellular resolution is obtained.

This work presents a capacitive immunosensor using on-chip electrolytic pumping and magnetic washing techniques. The proposed device possesses the advantages such as simple operation, low power consumption, and portability. The proposed device was fabricated using typical micromachining process, and is suitable for mass-production. We also demonstrated the detection of N-Terminal pro-brain-Type natriuretic peptide (NT-proBNP) using the fabricated device integrated with a CMOS capacitance sensing chip. The proposed device potentially can be used as a portable system for point-of-care applications.

We develop a wireless-enabled, flexible optrode array with multichannel micro-LEDs for selective optical stimulation of cortical neurons and simultaneous recording of light-evoked neural activity. The array integrates wirelessly addressable micro-LED chips with slanted polymer waveguides for precise light delivery to multiple cortical layers simultaneously. A droplet backside exposure (DBE) method was developed to monolithically fabricate varying-length optrodes on a single polymer platform.

We reports a flexible microneedle array electroporation chip for in vivo nucleic acid delivery. Silicon MNA is proposed to penetrate the high-resistant stratum corneum, while flexible parylene substrate is used to fit the natural shape of electroporated objects. Using the proposed chip, we successfully achieved plasmid DNA expression and siRNA delivery in living tissue with low voltage (30-40V), neither physical nor biological harm to skin was observed.

Helicobacter pylori play a crucial role in gastric diseases. The incidence rate of duodenal ulcer and gastric ulcer from H. pylori infected patients were found to be about 90-100% and 60-100%.Recently, some point mutations were found in gyrase genes against Quinolones. In this study a new method was therefore developed to perform molecular diagnostic techniques of SNP-PCR on an integrated microfluidic system to detect the Quinolones resistance of H. pylori.

The mechanical and electrochemical properties and sensing performance of untreated and annealed Parylene-platinum electrochemical impedance-based force sensors were compared. Annealing reduced the height and increased the stiffness of the Parylene structure, and smoothed electrode surfaces, affecting sensor performance. Our results indicate that annealing effects cannot be ignored for Parylene-metal device systems and that mechanical and electrochemical properties and performance must be determined after heat treatment, such as annealing and sterilization.

W-159 **MICRO-ELECTRODE ARRAYS FOR MULTI-CHANNEL MOTOR UNIT EMG RECORDING** 857
S. Yamagiwa, H. Sawahata, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

We report an array of micro-electrodes, which can record motor unit (MU) electromyogram (EMG) signals. As a basic structure of the electrode, we prepared 200-µm-square Si-pyramids with the height of 200 µm by Tetramethylammonium hydroxide (TMAH), resulting in robust MU-EMG recordings without conductive gel. Platinum (Pt) was used as an electrode material and parylene-C was deposited as an insulator. Fabricated µEMG electrodes connected to a recording system clearly detected MU-EMG action potentials from a human forearm. In addition, different MU-EMG signals between µEMG electrodes were detected by crooking fingers. These results indicate that the µEMG array device becomes a powerful tool for medical applications including myoelectric prosthetic technologies.

Th-160 **MICRO-WING AND PORE DESIGN IN AN IMPLANTABLE FPC-BASED NEURAL STIMULATION PROBE FOR MINIMALLY INVASIVE SURGERY** 861
Y.-H. Wang[1], D. Tsai[1,2], B.-A. Chen[1], Y.-Y. Chen[1], C.-C. Huang[1], P.-C. Huang[1], C.-Y. Lin[1], J. Yu[1], W.-P. Shih[1], C.-W. Lin[1], and H.-J. Sheen[1]
[1]National Taiwan University, TAIWAN and [2]University of California, San Diego, CA

A bipolar porous probe for an implantable nerve stimulation treatment utilizing minimally invasive surgery is presented. The flexible printed circuit (FPC) probe features micro-wings, which can increase fixation after implantation, and contains porous structures for cell growth to promote permanence in the body. Two recording pairs detect whether or not cells grow into the pores, and one pair of stimulating pads stimulates the target nerve. This probe is composed of two SU-8 layers and one FPC layer, to form a 3-D porous structure.

M-161 **NANOELECTROPORATION AND CONTROLLABLE INTRACELLULAR DELIVERY INTO LOCALIZED SINGLE CELL WITH HIGH TRANSFECTION AND CELL VIABILITY** 865
T.S. Santra, J. Borana, P.-C. Wang and F.-G. Tseng
National Tsing Hua University (NTHU), TAIWAN

Here we demonstrate controllable nano-electroporation platform for HeLa and human Caucasian Gastric Adenocarcinoma (AGS) cell to achieve high efficient bimolecular delivery with high cell viability.

T-162 **OPTO-MECHANICAL MICROBRIDLES FOR THE DETERMINATION OF STRUCTURAL AND FUNCTIONAL PROPERTIES OF SMALL RESISTANCE ARTERIES** 869
R. Rodríguez-Rodríguez[1], J.A. Plaza[2], V. Matchkov[3], U. Simonsen[3], M.D. Herrera[1], S. Büttgenbach[4], A. Llobera[2], and X. Munoz-Berbel[2]
[1]University of Seville, SPAIN, [2]Centro Nacional de Microelectrónica (CNM), SPAIN, [3]University of Aarhus, DENMARK, and [4]Technische Universität Braunschweig, GERMANY

We develop and optimize an opto-mechanical system for monitoring diameter of arterial segments in vitro.

W-163 **PDMS MICROCHANNEL SCAFFOLDS FOR NEURAL INTERFACES WITH THE PERIPHERAL NERVOUS SYSTEM** 873
Y. Choi[1], S. Park[2], Y. Chung[3], R.K. Gore[4], A.W. English[4], and R.V. Bellamkonda[2]
[1]University of Texas – Pan American, USA, [2]Georgia Institute of Technology, USA, [3]University of Rhode Island, USA, and [4]Emory University, USA

Neural interfaces with the peripheral nervous system have been developed to provide a direct communication pathway between peripheral nerves and prosthetic limbs. This paper reports a regenerated peripheral nervous system which can control the reinnervated muscles and interpret neurological signals. The acquired bioelectrical signals can be used for the interpretation of mind which will be used to monitor prosthetic limbs. Transected nerves were regenerated through PDMS scaffolds and transferred signals through embedded microwires and acquisition systems.

Th-164 **SELECTIVE RF HEATING OF RESONANT STENT TOWARD WIRELESS ENDOHYPERTHERMIA FOR RESTENOSIS INHIBITION** 877
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Stents have served as a critical device for minimally invasive treatment of cardiovascular disease, the leading cause of death in North America. Artery renarrowing (known as restenosis) often occurs after stent implantation due to excess growth of vessel tissue, blood clot(thrombus) formation, and/or other factors. This paper presents, for the first time, a novel active stent that serves as a resonant heater with high frequency selectivity controlled using external RF fields, offering a new therapeutic path to wireless endohyperthermia for in-stent restenosis.

We present an endoscopic probe with forward-looking piezoelectric fiber scanner for confocal optical imaging with a very short length of 13.1 mm. The system is based on Si bench technology with integrated fluidics for realizing tunable liquid-filled membrane-lenses. The tunability in focal length allows confocal depth scanning up to 100 µm without any movable optics or stages. The lateral and axial resolution were demonstrated to be 2 µm and 20 µm, respectively.

We developed a microknife for cellular scalce surgery.The work includes modeling, fabrication, measurement and actual cell-cutting. The result showed that developed knife can cut cell monolayer successfully with 2 micro cut line width by utilizing the ultra-sharp edge and ultrasound assiat.

We report a visualization platform comprised of an ultra-thin silicone membrane to differentiate between the biophysical properties of cancerous and healthy cells. Cancerous cells adhere to and spread on the membrane inducing deformation, termed 'membrane wrinkling', while healthy cells do not generate wrinkle patterns on the membrane. Quantitative measurement of wrinkling represents a powerful, non-invasive diagnostic tool for common cancers such as bladder cancer.

We present a novel implantable X-ray-addressable MEMS Blood Pressure sensor, the X-BP, for the non-invasive and cost-effective surveillance of coronary in-stent restenosis. We successfully fabricated and tested the X-BP sensor and its pressure response curve. We placed the X-BP sensor in a coronary stent and prove adequate visibility in a clinically realistic scenario.

Micro-Actuators (ACT)

This paper presents a novel actuator for energy harvesting from ambient acoustic noise using acoustically oscillating droplets. When a water droplet sitting on a piezocantilever is excited by an acoustic wave around its natural frequency, it oscillates and simultaneously bends the piezocantilever by the reaction of the droplet oscillation, resulting in electric power generation from the piezocantilever. The envisioned energy harvesting system can extract mechanical power from acoustic noise in a wide range of frequencies using liquid droplets in different sizes and natural frequencies and convert the mechanical power to electrical power for wireless electronic devices. This new type of actuation technique is a simple but useful tool not only for the energy harvesting system but also potential acoustic wave sensors and actuators.

This paper presents a novel on-chip micromanipulation method using a microbubble actuated by optical and acoustical excitation for single cell manipulation and characterization in a microfluidic chip, along with the experimental verification of bubble manipulation (generating and transporting operations) and micro-object manipulation (capturing, carrying, and releasing operations).

To prevent the adhesion of particles at surfaces by transporting them along the surface this paper reports on a pneumatically actuated new type of biomimetic particle transporter. Rows of flaps are positioned asymmetrically on movable membranes. Each flap row can be deflected separately by an induced pneumatic force. This membrane movement converts to a large deflection of the flaps in x-direction (lateral). Due to the high aspect ratio of the flaps the angle rotation results in a fluid movement parallel to the surface which prevents the particle deposition.

This paper discusses characterization of the surface textures created by MEMS tactile display with a large displacement MEMS actuator array. The actuator consists of piezoelectric actuators and a hydraulic displacement amplification mechanism to achieve large enough displacement to stimulate human tactile receptors. In our prior work, we successfully displayed smooth and rough surfaces using MEMS tactile display by controlling the vibration frequency and the driving voltage of the actuators. In this paper, we propose “sample comparison method" to further characterize the virtually created surface textures, where microfabricated tactile samples are used. In this method, by requesting the subjects to select samples that they felt most similar to the displayed surfaces, the control parameters of the MEMS tactile display were successfully correlated with the surface properties of the samples.

Micro-Fluidic Components and Systems (µFLUIDIC)

Our work reports on a passive compact flow regulator designed to maintain a steady flow during breath diagnostics using a novel flow regulation principle. The fabricated prototype consists of two 3D-printed plastic parts with an integrated cantilever aligned in the direction of the flow, to control comparatively large air flows in the 50 ml/s regime suitable for asthma diagnostics.

We have developed and implemented a simple three-dimensional (3D) particle tracking method for use in particle focusing applications. Using conventional fluorescence microscopy and a multi-step image post-processing algorithm based on particle defocusing principles, this technique was experimentally verified with results comparable to theoretical predictions of (1) gravitational settling and (2) inertial focusing. Our technique determines particle positions to micron accuracy in microfluidic systems for Re < 100.

The fundamental difficulty in single cell co-culture is to provide a controlled microenvironment. The cell culture chamber must be isolated for secreted cytokines to be accumulated inside the chamber over time. However, in an isolated environment nutrition factors will deplete. It is important to find a way to continuously supply nutrition factors while isolating cells sectional view of the proposed co-culture chip and its operation. We placed a semi-permeable membrane between the cell culture chamber and the media exchange channel. Nutrition can be supplied to the cells through the membrane, but the secreted cytokines are accumulated inside the chamber because their molecule sizes are too large to escape. The preliminary result demonstrated the capability of studying interaction between two cells and its potential to investigate modeling of more complicated cell niches.

We report the design and fabrication of vacuum assisted microfluidic trapping device for the capture of single cell such as an oocyte. We also suggest an application of such device for an intracellular monitoring of a cell that has an interaction with external environments. Real time monitoring is enabled through the fabrication on a silicon-on-glass substrate, offering excellent optical imaging window. We demonstrate the single cell capture event and monitoring of chromosome activity. This result will provide a powerful tool for investigating the physiological and pathological cellular functions.

We have investigated the unique effect of transient flow rate on inertial particle focusing in microfluidic systems. A comparative analysis was conducted using both constant and transient flow rates on polystyrene (PS) beads in various channel geometries. Results show that particle focusing equilibrium positions are affected by the use of a transient (changing) flow rate. Transient inertial flows provide a new degree of freedom for manipulation of particle positioning in microfluidic channels.

Nano-Electro-Mechanical Devices and Systems (NANO)

This work compares through both theory and experiment the effect of cavity shape and size on the sensitivity of piezoresistive pressure sensors based on suspended graphene membranes. Further, the paper analyzes the effect of both biaxial and uniaxial strain on the membranes.

A micro/nanofluidic device including linearly-arranged gold nanoparticles embedded into nanochannels was developed for highly-sensitive Surface-Enhanced Raman Spectroscopy (SERS) analysis. The nanochannels array was fabricated by a “photo" lithography-based process without costly and time-consuming process such as EB lithography. Then particles with diameters of 100 nm are arranged into the nanochannels by a nanotrench-guided self-assembly process. The device was successfully fabricated and it was active for SERS analysis with 4,4’-bypiridine as a target molecule."

We present a sensing platform based on high-stability low-power n-channel fully depleted FinFETs on Si-bulk. Efficient chemical and biological label-free sensing has been demonstrated, paving the way towards non-invasive simultaneous monitoring of human physiological signals such as pH and proteins. In contrast to other SiNW-based sensors, the use of scalable high-k dielectric FinFETs for both applications is in accordance with the material constraints which come along Moore’s Law of scaling.

We report frequency-dependent bidirectional AC electroosmotic flow (AC-EOF) in a nanochannel with double layer overlap. Simulations confirm the observed bidirectionality. By this frequency-dependent bidirectional pumping, nanochannel AC-EOF behaves in fundamentally different way than microchannel AC-EOF. The results are of importance for the understanding of ion and liquid transport in nanoconfinement.

This work reports on the first experimental demonstration of a self-oscillator based on a single crystal silicon NEMS resonator monolithically co-integrated with a simple electronic circuitry manufactured with a very low-cost 0.35µm CMOS technology. This NEMS-CMOS self-oscillator pixel is as small as 50x70 μm^2 (pads excluded).

T-214 **A GRAPHENE NANOSENSOR FOR DETECTION OF SMALL MOLECULES** 1075

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We developed a graphene field effect transistor (GFET) biosensor for detection of an important small molecular hormone DHEA-S. In view of the low charged small biomolecules can't excite sufficient electrical response of GFET, we proposed a competitive dehybridization strategy based on the aptamer-target specific association. We experimentally demonstrated that on the graphene surface, aptamer dehybridization caused by DHEA-S specific association provides strong response of GFET. And the concentration of target DHEA-S can be quantitatively detected by observing the "half time period" of aptamer dehybridization kinetic process.

W-215 **INTERROGATING CONTACT-MODE SILICON CARBIDE (SiC) NANOELECTROMECHANICAL SWITCHING DYNAMICS BY ULTRASENSITIVE LASER INTERFEROMETRY** 1079

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We report the experimental demonstration of probing the dynamics of nanoscale contacts in robust nanoelectromechanical switches based on silicon carbide (SiC) nanocantilevers. For the first time, we measure the dynamical behavior of contact-mode SiC nanoelectromechanical switches, in both frequency- and time-domain, by directly probing the tips of the SiC nanocantilevers, using ultrasensitive laser interferometric techniques.

Th-216 **MATRIX INDEPENDENT LABEL-FREE NANOELECTRONIC BIOSENSOR** 1083

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We fabricated a novel, label free and real time electrical impedance biosensor, referred to as the nanoneedle biosensor. The nanoneedle is an ultrasensitive and localized device, which has the ability to directly measure biomolecular binding as a function of time (real-time). The utility of this sensor in affinity biosensing was demonstrated. As a practical example with clinical relevance, we demonstrated the detection of Vascular Endothelial Growth Factor (VEGF) for cancer diagnosis. Our demonstration of label-free and real-time detection of VEGF with this sensor can be envisioned to allow for one-step point-of-care cancer diagnosis. This work provides a strong starting point for a new class of electronic biosensing devices with the capability of rapid direct large-scale integration.

M-217 **MECHANICAL PROPERTIES OF FEW LAYER GRAPHENE CANTILEVER** 1087

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We report the spring constant measurement of few-layer (1-, 2-, and 3-layer) graphene (FLG) cantilevers by optical heterodyne interferometry. We fabricated FLG cantilever with a weight of diamond-like carbon using focused ion beam. The effective spring constants were obtained from the measured resonant frequency and the mass of the weight, and were calculated to be about 2.7×10^{-3} N/m. This result indicates FLG cantilever structure is more rigid than that predicted from the literature data.

T-218 **NANO-OPTO-MECHANICAL MEMORY BASED ON OPTICAL GRADIENT FORCE INDUCED BISTABILITY** 1091

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A bistable nano-opto-mechanical memory is designed, fabricated and experimentally demonstrated.Fabricated with CMOS compatible process, this optical memory can be easily packaged and integrated with otherphotonic devices. The nano-size of the memory enable for large scale integration, high speed operation and low powerconsumption. It has other potential applications such as optical switch, logic gate and actuator.

W-219 **SUBMICRON THREE-TERMINAL SIGE-BASED ELECTROMECHANICAL OHMIC RELAY** 1095

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We demonstrate functional cantilever switches based on a CMOS-compatible low-T(400ºC) CVD SiGe process flow. Devices with dimensions in the micrometer range, thickness and gap smaller than 100nm were successfully fabricated and electrically characterized. Typical switches characteristics such as high I_{on}/I_{off} ratio, sharp sub-threshold slope and zero off-state leakage current were observed. A minimum of 1000 cycles device lifetime was demonstrated. The maximum current which can flow through the device without causing stiction due Joule-heating was investigated.

We report on the design, fabrication, characterization, and scaling analysis of novel NEMS relays that use, for the first time, buckling piezoelectric actuators. The fabricated switches exhibit low actuation voltage (< 2 V) and reduced threshold voltage (~110 mV). Also, hysteresis in the switching process was observed and limits the minimum swing voltage to ~250 mV. A scaling analysis highlights the possibility of achieving milliVolt switching at aggressively scaled device footprints.

We propose and experimentally investigate nanoelectromechanical switches that operate via electromechanical modulation of tunneling current through compressible molecular films. This approach utilizes self-assembled molecular layers to define few nanometer-thick switching gaps, and has the potential to enable low-voltage operation while simultaneously mitigating device failure due to stiction.

We developed an experimental system which enables kinesin driven transport on arrayed microtubules in enclosed micro channels. To avoid an expected difficulty of exchanging solution, surface fabricated micro tracks were encapsulated after reagents introduction using flow cells with deformable PDMS chip at its top. After enclosed micro channels were formed, directed transport and continuous accumulation of fluorescent labeled kinesin molecules were observed. These results indicate a possibility of application as in vitro model of intracellular transport as seen in axons.

We present a novel scanning resistive probe aimed for thermal imaging and localized thermal analysis. The probe features an AFM cantilever with a sharp pyramidal tip. Metal nanowires are integrated at the inner edges of the pyramidal tip forming an electrical cross-junction at the apex. The cross-junction can be utilized both as a local temperature sensor and a heater.

Packaging Technologies (PCK)

We explore a capillary liquid solder through-hole filling method, which utilizes liquid bridge pinch-off effect. The filling is completed by first pushing solder into via holes from a solder pool through nozzle orifices, and then followed by cutting the solder pillars in the via holes off from the solder pool in the nozzle orifices. The whole TSV filling process can be completed by a cycle of pressure change. In addition, 'wafer sandwich' structure is utilized to neutralize pressure differential, which causes wafer breakage.

We develop, characterize and model a new bonding technique based on Pours Silicon (PS) technology. PS allows strong permanent bonding between needle like surfaces as well as multiple bonding and un-bonding of chips similar to Velcro principle. This approach provides low temperature Si-Si direct bonding, a fully CMOS compatible approach suitable in system integration using the Si-motherboard concept.

This paper presents the implementation of transience silicon microchips through post-processing microfabrication and micropackaging steps that transform almost any electronic, optical or MEMS substrate chips into transient ones. When transience is activated the chip mechanically shatters, and it is literally reduced to a heap of silicon dust. The massive cleavage action is achieved by the triggered release of mechanical energy stored within the silicon substrate in expandable microparticles.

This paper studies a new long-term packaging scheme for implant electronics using glass encapsulation featuring a controlled failure mode from fast diffusion to slow undercut. The experimental results show that this packagingscheme can easily survive for more than 10 years by accelerated “active" lifetime soaking test (i.e. with electric field applied) in 0.9 wt.% saline solution. This method provides advantages of easy employment, controllable long life time, and enhanced heat dissipation."

We proposed low-temperature Au-Au bonding using nanoporous Au-Ag powders as an electrical connective adhesion between bump interconnects. The nano-porous powders were formed by de-alloying Au-Ag alloy sheet with Au:Ag. The influence of the annealing temperature on the porous structures was investigated. Selective formation of the powders on bumps was achieved by stamping. Bonding strength of about 2.4 MPa was achieved by using nanoporous Au-Ag powders at 150 °C. This result indicates that the proposed powder is a useful material for low-temperature Au-Au bonding.

This study presents a large-area multi-devices integration scheme using stretchable electroplating copper spring. Advantages of this approach: (1) using the existing process technologies and materials for semiconductor in large-area applications; (2) stretchable electroplating-copper spring with large maximum strain acts as mechanically and electrically connection; (3) Si-node acts as a hub for devices implementation and integration; and (4) the chip-network can apply to curved surfaces. The proposed expand network using stretchable spring integrated multi devices has been implemented and tested.

We presents a solid-state ISFET flow meter fabricated with an innovative planar packaging process. The developed method provides a simple yet efficient method to integrate CMOS IC chip with microfluidic systems and the whole packaging process can be achieved in 40 min. The sealed ISFET chip is used for measuring the flow rate of non-ionic solutions including acetone, ethanol and glycerol of slow flow rate. And the flow rate measurement exhibited good reproducibility in the flow rate ranging from 66 to 1700 μm/s.

Physical MEMS (PHYS)

A tunable laser based on nano-opto-mechanical system is presented in this paper. A novel tuning approach is demonstrated which applies optical force to adjust the cavity mode via controlling the mechanical displacement of the silicon waveguide. In the experiments, a 24-nm wavelength tuning is realized due to a deflection of 14-nm. The optomechanical wavelength tuning coefficient is 214 GHz/nm. The demonstrated device has potential applications for optical communication system, pulse trapping/release, and chemical sensing, with easy on-chip integration on a silicon platform.

This paper presents a tunable optical iris based on electromagnetic actuation for a high-performance mini/micro camera. In optics, an iris, an aperture stop, is placed in the light path of a lens or objective and regulates the amount of light that passes through the lens by controlling the size of the aperture, an opening at it center. The iris not only controls light flux, field of view, depth of field (DOF), but also blocks scattered light and improves image quality by limiting spherical aberration. Hence, the iris is an indispensable element in most optical systems. However, the conventional mechanical iris, consisting of movable sliding blades, requires a complicated sliding rotary mechanism that has to be operated by bulky motors and is therefore difficult to miniaturize. We develop a variable optical iris operated by electromagnetic actuation. According to electromagnetic induction, when an electrical current flows in an electric coil, a magnetic field is generated in its surroundings. In this work, the magnetic field is used to actuate or pull an optically opaque ferrofluid initially filled inside the sub-channel of the iris to the center of the main channel, resulting in controlling the diameter of an aperture.

We developed a device for measuring thermal diffusivity dependency of the contacted surface layer non-destructively. The device was based on the principle that temperature phase delay between a heater and a resistance temperature detector (RTD) is affected by thermal diffusivity of the contacted surface layer. The device consisted of an Au wire, as oscillating heat source and a piezoresistance as a RTD. We exerted the simulation and the experiment for the device, and found that the phase delay decreased as thermal diffusivity increased.

We develop a single-axis mechanical micro mirror array used for gridless wavelength selective switch (WSS). The mirrors are driven by lead zirconate titanate (PZT) unimorph actuators, which is adequate for low-voltage actuation and low interference with adjacent mirrors in operation. In addition, the mirror tilt angle is feedback controlled using comb-shaped capacitance in order to realize high control resolution. We fabricated a prototype of the mirror array, and evaluated its basic performance.

We for the first time demonstrates the graphene-diamond-metal (GDM) vertical sandwich structure as a thin film UV detector. New scientific and engineering breakthroughs are: (1) first experimental investigation of the carbon-based sp2-sp3 junctions; (2) a peel-and-stick fabrication process to make flexible diamond films; and (3) first GDM vertical UV sensors. As such, the proposed detector/architecture can open up a new class of scheme to build diamond-based optoelectronic systems.

We develop close-packed liquid-filled tunable microlens arrays for optical devices such as integral imaging systems. These lenses are simply composed of poly(dimethylsiloxane)(PDMS) microchannels and applied pressure deforms the top membrane of microchannels to become convex lenses. These lenses have three advantages: (i)Uniform deformation by pressure-driven actuation, (ii)Adjustable optical characteristics without patterned electrode, (iii)High-density integration of tunable microlenses. We fabricated three types of lenses based on closed-packed structure and showed that the Spiderweb type packing is the most suitable for closer packing.

We demonstrate a compact tunable hyperchromatic lens system for imaging an object with highly resolved spectral information. This hybrid device is composed of a diffractive optical element, a tunable concave liquid-filled membrane lens, and an integrated magnetic actuator for hydraulically tuning the focal length of the refractive lens. The lens system can generate a hyperspectral datacube in the visible wavelength range, 400 – 730 nm, proved here with a spectral sampling interval of 2.4 nm.

Th-244 **A MULTI-MATERIAL Q-BOOSTED LOW PHASE NOISE OPTOMECHANICAL OSCILLATOR** 1193

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We present a multi material Radiation Pressure driven Optomechanical Oscillator (RP-OMO) with simultaneously high mechanical Qm >22,000 and optical Qo >190,000 achieving best-to-date phase noise performance of -125 dBc/Hz at 5 kHz offset from its 52-MHz carrier, which is 12 dB better than the previous best RP-OMO constructed of silicon nitride alone. The device not only reduces phase noise, but does so with a lower input laser power of only 3.6 mW. The key to achieving this performance is the addition of polysilicon material as an inner ring that boosts the overall mechanical Qm of the total structure. The addition of polysilicon further provides a mechanism for voltage-controlled electrical stiffness tuning of the oscillation frequency.

M-245 **NOVEL TUNABLE OPTICAL MODULATION LENS USING MAGNETHORHEOLOGICAL EFFECT** 1197

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This study extends the fluid dispensing and sealing technology to realize a novel MR-fluid lens (MR-fluid: liquid polymer with magnetic particles) for light intensity modulation. Merits of the device: Optical transmittance of lens is controlled by (1) weight fraction of magnetic powder, and (2) orientation of columnar particles controlled by magnetic field. In applications, the MR-fluid lens is realized on glass substrate and suspended MEMS structures. The light intensity modulation of MR-fluid lens (diameter: 2000μm) by magnetic field is demonstrated. Measurements show the NdFeB- liquid polymer (10wt%) has a 40% dark area change and 290% laser transmittance difference after applying magnetic field.

T-246 **OPTICAL CONTROL AND TUNING OF THERMAL-PIEZORESISTIVE SELF-SUSTAINED OSCILLATORS** 1201

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We experimentally demonstrate the ability to frequency tune and provide on/off control of electrically driven thermal-piezoresistive self-sustained oscillators through the direct application of HeNe laser illumination at the device surface. These phenomena, which are unique to this class of oscillator, are explained by photoexcitation of charge carriers in the device's single crystal silicon structure inducing changes to the effective electrical resistivity and piezoresistivity.

W-247 **PHOTOTHERMAL PROBING OF PLASMONIC HOTSPOTS WITH NANOMECHANICAL RESONATOR** 1205

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We present a novel technique to probe and image plasmonic structures with nanoscale resolution by measuring the photothermally induced frequency detuning of highly temperature sensitive nanomechanical resonators. We employ the high temperature sensitivity of a nanomechanical string resonator to directly probe the heating pattern produced by a gold nanoslit illuminated by a scanning laser beam. The experimental approach allows a sensitive heat mapping of single localized surface plasmons, thereby helping to shed light on the underlying thermal effects in hotspots.

Th-248 **RADIATION-PRESSURE ENHANCED OPTO-ACOUSTIC OSCILLATOR** 1209

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Cornell University, USA

We present a driving scheme for integrated chip-scale opto-acoustic oscillators (OAO) in silicon with improved phase noise performance. Through simultaneous incorporation of radiation-pressure (RP) and RF feedback oscillating mechanisms, we have demonstrated a silicon RP enhanced OAO with a 10dB close-to-carrier phase noise improvement and thereby 10dB improvement in the oscillator's figure of merit.

M-249 **THERMOPILE INFRARED ARRAY SENSOR FOR HUMAN DETECTOR APPLICATION** 1213

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OMRON Corporation, JAPAN

This paper reports the design of thermopile infrared sensor for human detector application. Sensitivity and response time of thermopile infrared sensor element are important for human detector application. In order to fulfill the specification, we developed S-shaped structure for thermopile infrared sensor element and fabrication process of chip scale vacuum package for mass production of the thermopile infrared sensors. As the result, 140V/W sensitivity and 17msec response time of the thermopile infrared sensor element are achieved.

We present a method for fabricating organic optical microcavities using a transfer-printed composite membrane which can be electrostatically actuated for dynamic tuning of the cavity emission spectra. Electrical actuation and optical characterization of a completed device show cavity mode tuning greater than 20 nm. The device structure and transfer technique is easily applicable to large area fabrication of electrostatically tunable organic lasers, and potentially allows single-point contactless-readout for large area pressure sensor arrays.

We propose a tunable metamaterial actuated by pneumatic force. The tunable metamaterial has a double of sprit-ring-resonators (SRRs) whose gap between each other is controllable in sub-micron-order. Results of a terahertz (THz) spectroscopy confirmed that controlling gap in sub-micron-order or a few micron order was suitable for tuning resonant frequency of a metamaterial compared with that in 10 micron-order.

A 256×256 bimaterial cantilever focal plane array (FPA), which is able to work in the three infrared atmospheric windows simultaneously, is fabricated and characterized. The FPA employs a silicon-framed structure by selectively etching away the substrate with Deep Reactive Ion Etching technique, and can be conveniently readout by an optical system. By combining the Chromium nano-films with silicon nitride as the multi-band IR absorber, the images of short wavelength, middle wavelength and long wavelength infrared are captured successfully with the same FPA.

We developed the very low power consumption MEMS scanner that utilizes the electrostatic field generated by alkali-ion electret. The alkali-ion electret formed on comb electrodes of the scanner provides built-in potential for the electro-static actuator so that no bias voltage is necessary. The power consumption of prototype MEMS scanner was 0.57 μW (bias voltage: DC 0 V, driving voltage: AC 9 V_{pp}, deflection angle: 12°, resonance frequency: 1.4 kHz).

RF MEMS (RF)

This paper firstly reports on a low-loss RF MEMS switch that contains a reflowed glass structure beneath a contact metal. The reflowed glass structure is employed to reduce the electromagnetic wave loss brought about by the conductive silicon bulk underneath the contact metal. RF MEMS switch totally made of silicon is used as a reference model and the insertion loss is reduced as much as 0.26 dB for the proposed model in the frequency range of 5 to 30 GHz.

A novel RF-MEMS filter configuration around 700 MHz is proposed. It is based on a differential read-out of two in-phase actuated contour-mode resonators with slightly different resonance frequencies. The resonators are actuated independently in-phase and the outputs of the resonators are subtracted. This method is effective for improving the stopband rejection by canceling the feed-through signal. The BPF is presented using 50Ω termination with bandwidth of approximately 28.6 MHz and 35 dB stopband rejection. The ultimate rejection of the filter is improved by more than 20 dB compared to the individual resonators.

AlN disk resonators having suspended (non-contacting) electrodes are demonstrated to have quality factors as high as 8,850 at 300 MHz, show no spurious modes, have single disk motional impedances of 3.0kOhm, and to possess an electrode collapse based off/on switching capability that operates via the application and subsequent removal of a strong bias voltage.

We developed a new method for lowering the phase noise of oscillators where the intrinsic resonator frequency fluctuations represent the dominant noise source. We called this technique "parametric filtering".This method has been applied to a 227 MHz aluminum nitride contour-mode MEMS resonator that shows high level of intrinsic noise which limits the oscillator phase noise. By using this new approach we have obtained an improvement of more than 20 db and 26 db respectively at 1 khz and 10 khz offset. This resulted in the lowest phase noise level ever measured for any MEMS based oscillator.

The use of a Pt-silicide-based contact interface has greatly reduced impact-induced energy loss in comb-driven resonant micromechanical switches (a.k.a., resoswitches) to the point where squegging phenomena (whereby impacts do not occur on every cycle) are eliminated, so no longer constrain the clock frequency of recently demonstrated mechanical charge pumps. This opens the application range of such charge pumps to higher power converters capable of delivering currents much higher than those of previously demonstrated version, which targeted low current-draw MEMS dc-biasing applications.

We show that an electrically isolated silicon resonator within an epi-seal polysilicon encapsulation can retain a charge for prolonged periods of time with no noticeable leakage, even at elevated temperature. The charge is applied using a silicon contact switch that operates within the epi-seal cavity to isolate the resonator from the environment.

We report on the use of pull-in electrodes for achieving narrower gaps than lithography/etch capabilities. Resonant devices with sub-ppm stability are demonstrated within the epi-seal polysilicon encapsulation process using pulled-in electrodes. The pull-in effect is reversible and can be made permanent by welding.

Presented is a ~27MHz oscillator incorporating a thin-film piezoelectric-on-silicon (TPoS) resonator with a phase noise (PN) of -139 dBc/Hz at 1kHz and -157 dBc/Hz at 1MHz from the carrier. The close-to-carrier PN is equivalent to -148 dBc/Hz when normalized to 10MHz and is the lowest reported to date for MEMS oscillators. Additionally, it is experimentally proven that the PN significantly improves when the resonator is driven at or beyond the bifurcation point in the closed-loop oscillator circuit.

We developed a variable capacitor with mechanical switching mechanism and reversible mechanical latching system to enhance tuning ratio and reduce power consumption. The switching mechanism could connect four sets of capacitors arranged in parallel sequentially by controlling the displacement of a microactuator for abrupt and coarse tuning of total capacitance. Continuous and fine tuning was also achieved by gap-closing mode of comb-finger type capacitors. The resultant maximum tuning ratio was 5.71 by combining coarse and fine tuning.