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MEMS 2016 Program Schedule

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Sunday, 24 January

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

Monday, 25 January

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

Invited Plenary Speaker I

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

Session I - Optics I

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

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

09:50 **STANDOFF INFRARED SPECTROSCOPY ON ENERGETIC MATERIALS USING HYDROGEL MICROCANTILEVERS** **6**
I. Chae[1], M.F. Khan[2], J. Song[3], J. Lee[3], J. Lee[3], and T. Thundat[2]
[1]Pennsylvania State University, USA, [2]University of Alberta, CANADA, and [3]Sogang University, SOUTH KOREA

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

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

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

10:20 **Break & Exhibit Inspection**

Session II - Fabrication & Materials I

10:50 **GRAPHENE WAFER TRANSFER PRINTING FOR 3D SURFACE** **13**

Y. Zhang[1,2], Y. Gui[1,2], F. Meng[1,2], L. Li[1,2], C. Gao[1,2], H. Zhu[3], and Y. Hao[1,2,4]
[1]Peking University, CHINA, [2]National Key Laboratory of Nano/Micro Fabrication Technology, CHINA, [3]Tsinghua University, CHINA, and [4]Innovation Center for MicroNanoelectronics and Integrated System, CHINA

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

11:05 **A TRANSFER-FREE WAFER-SCALE CVD GRAPHENE FABRICATION PROCESS FOR MEMS/NEMS SENSORS** **17**

S. Vollebregt[1], B. Alfano[2,3], F. Ricciardella[4], A.J.M. Giesbers[5], Y. Grachova[1], H.W. van Zeijl[1], T. Polichetti[3], and P.M. Sarro[1]
[1]Delft University of Technology, THE NETHERLANDS, [2]University of Naples, ITALY, [3]Ente Nuove Tecnologie, Energia e Ambiente (ENEA) UTTP/MDB, ITALY, [4]Italian Institute of Technology, ITALY, and [5]Philips Innovation Services, THE NETHERLANDS

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

11:20 **HIGH DYNAMIC ABLATION AND INJECTION BY ELECTRIC CAVITATION FOR WIDE RANGE OF MATERIALS** **21**

K. Takahashi[1], Y. Arakawa[1], and Y. Yamanishi[1,2]
[1]Shibaura Institute of Technology, JAPAN and
[2]Japan Science and Technology Agency (JST), JAPAN

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

11:35 **LOW TEMPERATURE DIRECT BONDING OF SINGLE CRYSTAL QUARTZ SUBSTRATES FOR HIGH PERFORMANCE OPTICAL LOW PASS FILTER USING AMORPHOUS SiO_2 INTERMEDIATE LAYERS** **25**

B. Ma, H. Kuwae, A. Okada, W. Fu, S. Shoji, and J. Mizuno
Waseda University, JAPAN

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

11:50 **HIGH ASPECT-RATIO 3D MICROSTRUCTURES VIA NEAR-FIELD ELECTROSPINNING FOR ENERGY STORAGE APPLICATIONS** **29**

G. Luo[1,2], K.S. Teh[2,3], X. Zang[2], D. Wu[2,4], Z. Wen[1], and L. Lin[2]
[1]Chongqing University, CHINA, [2]University of California, Berkeley, USA, [3]San Francisco State University, USA, and [4]Xiamen University, CHINA

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

12:05 **Lunch & Exhibit Inspection**

13:05 **Poster/Oral Session I**
Poster presentations are listed by topic category with their assigned number starting on page 16.

15:05 **Break & Exhibit Inspection**

Session III - PowerMEMS

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

Y. Lu[1], F. Cottone[1,2], S. Boisseau[3], F. Marty[1], D. Galayko[4], and P. Basset[1]
[1]Université Paris-Est, FRANCE, [2]University of Perugia, ITALY,
[3]CEA-LETI, FRANCE, and [4]UPMC-Sorbonne Universite, FRANCE

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

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

K. Kittipaisalsilpa, T. Kato, and Y. Suzuki
University of Tokyo, JAPAN

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

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

J. Park and K.-S. Yun
Sogang University, SOUTH KOREA

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

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

Z. Wu[1], X. Wang[1,2], X. Kuang[1], and L. Liu[1]
[1]Tsinghua University, CHINA and [2]Chinese Academy of Sciences

This paper reports a flexible tubular passive µDMFC for powering wrist bands at the first time. The tubular µDMFC, featured by flexible electrodes and foldable whole structure, shows excellent power density and long-term performance compared to batteries. It is believed that this µDMFC is applicable to serve as the power unit for wrist bands (typically ^{1}~^{2}0mW) or even other wearable devices.

Session IV - Resonators I

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

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

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

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

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

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

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

N. Sarkar[1,2], G. Lee[1,2], D. Strathearn[1,2], M. Olfat[1,2], and R.R. Mansour[1,2]
[1]University of Waterloo, CANADA and [2]ICSPI Corp., CANADA

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

17:20 **ALL-ELECTRICAL READOUT OF ATOMICALLY THIN MoS_2 NANOELECTROMECHANICAL RESONATORS IN THE VHF BAND** **59**

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

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

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

I. Ouerghi[1], M. Sansa[1], L. Duraffourg[1], K. Benedetto[1], P. Besombes[1], K. Huet[2], F. Mazzamuto[2], I. Toque-Tresonne[2], C. Ladner[1], S. Kerdiles[1], W. Ludurczak[1], and T. Ernst[1]
[1]CEA-LETI, FRANCE and [2]SCREEN-LASSE, FRANCE

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

17:50 **Adjourn for the Day**

Tuesday, 26 January

Invited Plenary Speaker II

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

Session V - Actuators

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

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

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

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

09:45 **INTEGRATED SMA-BASED NEMS ACTUATOR FOR OPTICAL SWITCHING** **79**
F. Lambrecht[1], I. Aseguinolaza[2], V. Chernenko[2,3], and M. Kohl[1]
[1]Karlsruhe Institute of Technology (KIT), GERMANY, [2]University of the Basque Country, SPAIN, and [3]Ikerbasque, Basque Foundation of Science, SPAIN

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

10:00 **SMART SELF-CLEANING COVER GLASS FOR AUTOMOTIVE MINIATURE CAMERAS** **83**
K.Y. Lee[1], J. Hong[2], D.S. Jang[1], S.J. Hong[1], S.J. Le[2], and S.K. Chung[1]
[1]Myongji University, SOUTH KOREA and
[2]Pohang University of Science and Technology (POSTECH), SOUTH KOREA

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

10:15 **Break & Exhibit Inspection**

Session VI - Resonators II

10:45 **A HIGH-SENSITIVE RESONANT ELECTROMETER BASED ON MODE LOCALIZATION OF THE WEAKLY COUPLED RESONATORS** **87**

H. Zhang, W. Yuan, J. Huang, B. Li, and H. Chang
Northwestern Polytechnical University, CHINA

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

11:00 **OVENIZED DUAL-MODE CLOCK (ODMC) BASED ON HIGHLY DOPED SINGLE CRYSTAL SILICON RESONATORS** **91**

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

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

11:15 **AMPLITUDE MOTION STABILIZATION IN DRIVE RESONATORS LIMITED BY AN AUTOMATIC FEATHER CONTACT MECHANISM** **95**

F. Giacci, A. Bianchi, S. Dellea, A.F. Longoni, and G. Langfelder
Politecnico di Milano, ITALY

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

11:30 **LOW POWER DAMPING CONTROL OF A RESONANT SENSOR USING BACK ACTION IN SILICON NANOWIRES** **99**

G. Lehée[1,2], F. Souchon[3,4], J.-C. Riou[1], A. Bosseboeuf[2], and G. Jourdan[3,4]
[1]SAGEM Defense Security, FRANCE, [2]Université Paris-Sud, FRANCE,
[3]University Grenoble Alpes, FRANCE, and [4]CEA-LETI, FRANCE

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

11:45 **OFF-RESONANCE OPERATION OF A MEMS LORENTZ FORCE MAGNETOMETER WITH IMPROVED THERMAL STABILITY OF THE SCALE FACTOR** **103**

S. Sonmezoglu and D.A. Horsley
University of California, Davis, USA

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

12:00 **MEMS 2017 Announcement**

12:15 **Lunch & Exhibit Inspection**

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

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

15:15 Break & Exhibit Inspection

Session VII - Acoustics

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

X. Jiang[1], H.-Y. Tang[1], Y. Lu[2], X. Li[1], J.M. Tsai[3], E.J. Ng[3], M.J. Daneman[3], M. Lim[3], F. Assaderaghi[3], B.E. Boser[1], and D.A. Horsley[2]
[1]University of California, Berkeley, USA, [2]University of California, Davis, USA, and [3]Invensense Inc., USA

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

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

Y.-H. Song and S. Gong
University of Illinois, Urbana-Champaign, USA

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

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

O. Rozen[1], S.T. Block[1], X. Mo[1], W. Bland[1], P. Hurst[1], J.M. Tsai[2], M. Daneman[2], R. Amirtharajah[1], and D.A. Horsley[1]
[1]University of California, Davis, USA and [2]InvenSense Inc., USA

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

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

A. Gao, Y. Yang, and S. Gong
University of Illinois, Urbana-Champaign, USA

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

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

A. Ansari and M. Rais-Zadeh
University of Michigan, USA

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

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

D. Feng[1,2], W.L. Jiang[1,2], D.H. Xu[1], B. Xiong[1], and Y.L. Wang[1]
[1]Chinese Academy of Sciences, CHINA and
[2]University of the Chinese Academy of Sciences, CHINA

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

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

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

Session VIII - Microfluidics I

17:30 **IN-SITU GENERATION OF HIGHLY STABLE, SUB 10-nm OXYGEN NANOBUBBLES IN LIQUID ENVIRONMENTAL TEM** **133**
P. Kundu, S.-Y. Liu, F.-R. Chen, and F.-G. Tseng
National Tsing Hua University, TAIWAN

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

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

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

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

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

18:15 **Adjourn for the Day**

Wednesday, 27 January

Invited Plenary Speaker III

Session IX - Medical Microsystems

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

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

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

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

10:15 **Break & Exhibit Inspection**

Session X - Pressure Sensors I

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

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

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

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

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

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

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

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

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

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

12:15 **Lunch & Exhibit Inspection**

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

15:00 **Break & Exhibit Inspection**

Session XIa - Microfluidics II

15:30 **IN-LINE DNA PRECONCENTRATION, SIZE SEPARATION, AND SINGLE MOLECULE DETECTION WITHOUT APPLIED ELECTRIC FIELDS** **181**

S.M. Friedrich[1], J.M. Burke[2], K.J. Liu[2], and T.-H. Wang[1]
[1]Johns Hopkins University, USA and [2]Circulomics, Inc., USA

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

15:45 **NANO-PYRAMID ARRAYS FOR NANO-PARTICLE TRAPPING** **185**

X. Sun, H.-W. Veltkamp, E.J.W. Berenschot, H.J.G.E. Gardeniers, and N.R. Tas
MESA+, University of Twente, THE NETHERLANDS

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

16:00 **LOW-COST TEMPERATURE-COMPENSATED THERMORESISTIVE MICRO CALORIMETRIC FLOW SENSOR BY USING 0.35µm CMOS MEMS TECHNOLOGY** **189**

W. Xu[1], B. Gao[1,2], S. Ma[1,2], A. Zhang[2], Y. Chiu[3], and Y.-K. Lee[1]
[1]Hong Kong University of Science and Technology, HONG KONG,
[2]Xi'an Jiaotong University, CHINA, and [3]National Chiao Tung University, TAIWAN

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

16:15 **TOWARDS NANOGRAM PER SECOND CORIOLIS MASS FLOW SENSING** **193**

J. Groenesteijn[1], R.G.P. Sanders[1], R.J. Wiegerink[1], and J.C. Lötters[1,2]
[1]MESA+, University of Twente, THE NETHERLANDS and
[2]Bronkhorst High-Tech BV, THE NETHERLANDS

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

Session XIb - Fabrication & Materials II

15:30 **NON-SPHERICAL LIPOSOME FORMATION USING 3D-LASER-PRINTED MICRO-CUBE STRUCTURES** **197**

K. Inoue[1,3], K. Kamiya[1,4], T. Osaki[1,2], N. Miki[1,3], and S. Takeuchi[1,2]
[1]Kanagawa Academy of Science and Technology, JAPAN,
[2]University of Tokyo, JAPAN,
[3]Keio University, JAPAN, and
[4]Japan Science and Technology Agency (JST), JAPAN

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

15:45 **VIBRATION-TRIGGERED SELF-ASSEMBLY OF CAGED DROPLETS TO CONSTRUCT A DROPLET INTERFACE BILAYER NETWORK** **200**

H. Yasuga[1], T. Osaki[1], K. Kamiya[1], R. Kawano[1], N. Miki[1,2], and S. Takeuchi[1]
[1]*University of Tokyo, JAPAN,* [2]*Keio University, JAPAN, and*
[3]*Tokyo University of Agriculture and Technology, JAPAN*

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

16:00 **PATTERNED SOFT-MICROPOLYHEDRA BY SELF-FOLDING AND MOLDING** **203**

S. Pandey, C. Yoon, Z. Zhang, H.R. Kwag, J. Hong, and D.H. Gracias
Johns Hopkins University, USA

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

16:15 **MICROFLUIDIC FABRICATION OF HYDROGEL-FIBER-BASED 3D CONSTRUCTS UTILIZING LIQUID ROPE-COIL EFFECT** **207**

M. Nie[1] and S. Takeuchi[1,2]
[1]*University of Tokyo, JAPAN and* [2]*Japan Science and Technology Agency (JST), JAPAN*

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

Session XIIa - Pressure Sensors II

16:30 **ACHIEVING CLINICALLY VIABLE 12-CM READOUT DISTANCE FROM MICROMACHINED IMPLANTABLE INTRAOCULAR PRESSURE SENSOR USING A STANDARD CLINICAL SLIT LAMP** **210**

J.O. Lee[1], H. Park[1], O. Chen[1], A. Balakrishna[1], J. Du[2], D.W. Sretavan[2], and H. Choo[1]
[1]*California Institute of Technology, USA and*
[2]*University of California, San Francisco, USA*

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

16:45 **A NOVEL *TUB* (THIN-FILM UNDER BULK) PROCESS FOR HIGH-PERFORMANCE PRESSURE SENSORS OF SUB-KPA MEASURE-RANGE** **214**

H. Zou[1,2], J. Wang[1], and X. Li[1,2]
[1]*Chinese Academy of Sciences, CHINA and*
[2]*University of the Chinese Academy of Sciences, CHINA*

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

17:00 **WIRELESS MAGNETOSTRICTIVE TYPE INDUCTIVE SENSING CMOS-MEMS PRESSURE SENSORS** **218**

H.-C. Chang, S.-C. Liao, C.-L. Cheng, J.-H. Wen, H.-S. Hsieh, C.-H. Lai, and W. Fang
National Tsing Hua University, TAIWAN

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

17:15 **A NOVEL PRESSURE SENSOR WITH BUILT-IN OVERPRESSURE PROTECTION UTILIZING THREE-DIMENTIONAL ETCHING AND WAFER-LEVEL STACKING TECHNOLOGY** **222**

T. Tokuda, Y. Seto, and M. Yoneda
Azbil Corporation, JAPAN

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

Session XIIb - Optics II

16:30 **METAL-DIELECTRIC-METAL PLASMONIC NANOHELMS AS BROAD-COLOR-GAMUT TUNABLE PIXELS FOR VIVID DISPLAY** **226**

J.R. Fan and W.G. Wu
Peking University, CHINA

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

16:45 **DYNAMIC METASURFACE FOR BROADBAND ELECTROMAGNETIC MODULATOR IN REFLECTION** **230**

P.C. Wu[1], H. Cai[2], Y.D. Gu[2], W.M. Zhu[1], W. Zhang[1], Z.C. Yang[3], Y.F. Jin[3], Y.L. Hao[3], D.-L. Kwong[2], D.P. Tsai[4], and A.-Q. Liu[1]
*[1]Nanyang Technological University, SINGAPORE, [2]Agency for Science, Technology and Research (A*STAR), SINGAPORE, [3]Peking University, CHINA, [4]Academia Sinica, TAIWAN, and [5]National Taiwan University, TAIWAN*

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

17:00 **FRACTAL ENGINEERED VOIDS FOR NON-RESONANT NANO-PLASMONIC DETECTION OF WEAK MOLECULAR FINGERPRINT AT MID IR** **234**

D. Hasan, J. Wang, and C. Lee
National University of Singapore, SINGAPORE

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

17:15 **NANO-OPTOMECHANICAL DISK RESONATORS OPERATING IN LIQUIDS FOR SENSING APPLICATIONS** **238**

E. Gil-Santos[1], C. Baker[1], D.T. Nguyen[1], W. Hease[1], C. Gomez[2], A. Lemaître[2], S. Ducci[1], G. Leo[1], and I. Favero[1]
[1]Université Paris Diderot, FRANCE and [2]CNRS, FRANCE

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

17:30 **Adjourn for the Day**

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

Thursday, 28 January

Invited Plenary Speaker IV

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

Session XIII - Inertial Sensors

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

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

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

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

09:45 **ULTRA-LOW POWER SELF-COMPUTING BINARY OUTPUT DIGITAL MEMS ACCELEROMETER** **251**
V. Kumar[1], X. Guo[1], R. Jafari[2], and S. Pourkamali[1]
[1]University of Texas, Dallas, USA and [2]Texas A&M, USA

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

10:00 **RELIABILITY OF GYROSCOPES BASED ON PIEZORESISTIVE NANO-GAUGES AGAINST SHOCK AND FREE-DROP TESTS** **255**
S. Dellea[1], F. Giacci[1], P. Rey[2], A. Capodici[3], and G. Langfelder[1]
[1]Politecnico di Milano, ITALY, [2]CEA-LETI, FRANCE, and [3]ST Microelectronics, ITALY

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

10:15 **Break & Exhibit Inspection**

Session XIV - Cell Cultures

10:45 **STRETCHABLE CULTURE DEVICE OF SKIN-EQUIVALENT WITH IMPROVED EPIDERMIS THICKNESS** **259**

N. Mori[1], Y. Morimoto[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

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

11:00 **ANISOTROPIC SPHERICAL COLLAGEN MICROPARTICLES FOR CONFINED 3D CELL CULTURE SYSTEM WITH SPATIALLY DESIGNED MICROENVIRONMENT** **263**

S. Yoshida[1], M. Takinoue[2], and H. Onoe[1]
[1]Keio University, JAPAN and [2]Tokyo Institute of Technology, JAPAN

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

11:15 **A MICROFABRICATED PLATFORM WITH ON-CHIP STRAIN SENSING AND HYDROGEL ARRAYS FOR 3D MECHANICAL STIMULATION OF CELLS** **267**

H. Liu, C.A. Simmons, and Y. Sun
University of Toronto, CANADA

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

11:30 **QUANTIFICATION OF CONTRACTILE PROPERTY FOR FUNCTIONAL DRUG TESTING WITH HUMAN IPS-DERIVED CARDIOMYOCYTES** **271**

Y. Morimoto[1,2], S. Mori[1,2], F. Sakai[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

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

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

12:00 **Conference Adjourns**

POSTER/ORAL PRESENTATIONS

M – Monday (13:05 - 15:05) **T** – Tuesday (13:15 - 15:15)
W – Wednesday (13:00 - 15:00)

Bio and Medical MEMS

Biochemical Sensors

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

Nanobiotechnology

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

Generic MEMS and Nanotechnologies

Generic MEMS and NEMS Manufacturing Techniques

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

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

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

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

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

Manufacturing for Bio- and Medical MEMS and Microfluidics

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

We report a method to improve the electrochemical properties of platinum electrodes fabricated using parylene-C based processes. It is found that the use of O_2-RIE to etch parylene-C, the state-of-the-art method for processing parylene-C, oxidizes a surface layer of platinum which results in high electrochemical impedance of the electrode. By introducing an Ar^+ etch step to remove the oxidized Pt, the electrochemical impedance of the electrode is reduced by an order of magnitude.

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

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

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

Materials for MEMS and NEMS

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

Packaging and Assembly

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

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

MEMS for Electromagnetics

DC and Low Frequency Magnetic and Electromechanical Components and Systems

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

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

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

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

Manufacturing for Electromagnetic Transducers

Other Electromagnetic MEMS

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

Photonic Components and Systems

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

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

RF MEMS Components and Systems

We describe, for the first time, a novel AlN resonator based on the excitation of a Lame mode in the cross-section of an AlN plate. As the resonator uses both the AlN e31 and e33 piezoelectric coefficients, a kt2 in excess of 4.6% at 1.02 GHz, was measured. To the best of our knowledge such a high kt2 value is the highest ever reported in AlN resonators using metallic IDTs to excite mechanical vibrations.

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

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

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

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

We present monolithic multi-frequency $LiNbO_3$ Lamb wave resonators fabricated on a 3in. X-cut thin-film LN-SiO2-LN wafer. Resonators with four different frequencies (667MHz, 793MHz, 846MHz, and 713MHz) are demonstrated. Resonators with the first three frequencies operate in S_0 mode, while resonators with the last frequency utilize the SH_0 wave. Exploiting a long transducer design, the resonators exhibits spur-suppressed response, <3Ω impedance at resonance, and k_{eff}^2 >17% without any de-embedding, and the highest k_{eff}^2 achieved is 24.1%.

THz MEMS Components and Systems

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

Micro- and Nanofluidics

Lab-on-Chip Medical Diagnostic Devices

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

Materials for Bio- and Medical MEMS and Microfluidics

Microfluidics and Nanofluidics

Physical Sensors

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

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

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

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

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

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

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

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

Gas and Chemical Sensors

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

Manufacturing Techniques for Physical Sensors

Materials for Physical Sensors

We report a novel ultraviolet photodetector based on TiO_2/Graphene hybrid. In the hybrid material, Graphene brings two major benefits: (1) large surface area, (2) the generated electrons are instantly collected which can overcome the low quantum efficiency of pristine TiO_2. Thus, the collaboration of TiO_2 and Graphene contributes to the high performance of the device. Moreover, this device is fabricated on a flexible substrate which broadens the future of photodetectors in wearable devices.

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

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

Nanoscale Physical Sensors

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

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

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

Other Physical Sensors

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

PowerMEMS and Actuators
Actuator Components and Systems

Manufacturing for Actuators and PowerMEMS

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

In this paper, we newely developed PDMS navity membrane and hsptic devive with this membrane.

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

Piezoelectric multimorph structure of $Pb(Zr,Ti)O_3$ (PZT) thin films by using sputtering deposition is realized for the applications of low-voltage and large generative force actuators. Test microcantilevers with four PZT layers are fabricated by a wafer level and batch-compatible dry etchings. All layers work well as piezoelectric material. In addition, limit of the lamination for PZT multimorph is also evaluated as an index of total stress.

Materials for Actuators and PowerMEMS

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

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

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

Nanoscale Actuators and PowerMEMS

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

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

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

Other Actuators and PowerMEMS

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

PowerMEMS Components and Systems