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MEMS 2015 PROGRAM SCHEDULE

Monday, 19 January

07:55 **Opening and Welcome Address**
Jürgen Brugger, *EPFL Lausanne, SWITZERLAND*
Wouter van der Wijngaart, *KTH Royal Institute of Technology, SWEDEN*

Invited Plenary Speaker I

Session Chairs:
J. Brugger, *EPFL Lausanne, SWITZERLAND*
H. Toshiyoshi, *University of Tokyo, JAPAN*

08:15 **THE LONG PATH FROM MEMS RESONATORS TO TIMING PRODUCTS** 1
E. Ng[1], Y. Yang[1], V.A. Hong[1], C.H. Ahn[1], D.B. Heinz[1], I. Flader[1], Y. Chen[1], C.L.M. Everhart[1], B. Kim[2], R. Melamud[2], R.N. Candler[2], M.A. Hopcroft[2], J.C. Salvia[2], S. Yoneoka[2], A.B. Graham[2], M. Agarwal[2], M.W. Messana[2], K.L. Chen[2], H.K. Lee[2], S. Wang[2], G. Bahl[2], V. Qu[2], C.F. Chiang[2], **Thomas W. Kenny, Ph.D.[1]**, A. Partridge[3], M. Lutz[3], G. Yama[4] and G.J. O'Brien[4]
[1]Stanford University, USA, [2]PhD Alumni of Stanford University, USA, [3]SiTime Inc, USA, and [4]Robert Bosch RTC, USA

Session I - Micro and Nanofluidics

Session Chairs:
B. Stoeber, *University of British Columbia, CANADA*
F.G. Tseng, *National Tsing Hua University, TAIWAN*

09:30 **GRAPHENE OXIDE MEMBRANES FOR PHASE-SELECTIVE MICROFLUIDIC FLOW CONTROL** 2
J. Gaughran, D. Boyle, J. Murphy, and J. Ducrée
Dublin City University, IRELAND
*** Award Nominee**

We investigate the unique properties of Graphene Oxide (GO) as a barrier selective to the solvent and state of aggregation of the fluid. To this end, we developed novel processes for the assembly of GO as membranes into polymeric microfluidic systems. We show that GO completely blocks pressurized air and organic solutions while it is permeable to water. These GO membranes are then employed as a flow control element in a microfluidic system.

09:45 **STRUCTURE-BASED SUPERHYDROPHOBICITY FOR SERUM DROPLETS** 6
T. Liu and C.-J. Kim
University of California, Los Angeles, USA

We report that superhydrophobic (SHPo) surfaces based purely on surface structuring shows a robust super-repellency under a prolonged contact with serum droplet as an example of protein-rich biological fluids. In contrast, normal SHPo surfaces, which are based on surface chemistry and surface structuring, lose repellency and eventually get wetted by the same tests. This is the first report of a SHPo surface not degraded by a biological fluid.

10:00 **MICROFABRICATED LIQUID CHAMBER UTILIZING SOLVENT-DRYING FOR IN-SITU TEM IMAGING OF NANOPARTICLE SELF-ASSEMBLY** 8
W.C. Lee[1,2], J. Park[3,4,5], D.A. Weitz[5], S. Takeuchi[1,2], and A.P. Alivisatos[3,4]
[1]University of Tokyo, JAPAN, [2]Japan Science and Technology Agency (JST), JAPAN
[3]University of California, Berkeley, USA, [4]Lawrence Berkeley National Laboratory, USA, and [5]Harvard University, USA

We present a microfabricated liquid-sample chamber for real-time TEM (Transmission Electron Microscopy) of nanoscale processes driven by liquid evaporation. The present chamber (TEM liquid-cell) uses intended leakage/failure in its bonding process in order to generate solvent-drying during in-situ TEM imaging. The captured real-time nanometer-scale TEM movies visualize critical steps in the self-assembly process of 2 dimensional nanoparticle arrays.

10:15 **SYNTHETIC MICROFLUIDIC PAPER** 10
J. Hansson, H. Yasuga, T. Haraldsson, and W. van der Wijngaart
KTH Royal Institute of Technology, SWEDEN

We demonstrate a polymer synthetic microfluidic paper with the aim to combine the high surface area of paper or nitrocellulose with the repeatability, controlled structure, and transparency of polymer micropillars for lateral flow devices. It consists of a dense, high aspect ratio, stiff polymer micropillar array with thin slanted pillars that are interlocked, and is manufactured with multidirectional UV lithography in Off-Stochiometry-Thiol-Ene-Epoxy polymer.

10:30 **Break & Exhibit Inspection**

Session II - Actuators

Session Chairs:
M. Kohl, *Karlsruhe Institute of Technology, GERMANY*
F. Niklaus, *KTH - Royal Institute of Technology, SWEDEN*

11:00 **ASSEMBLED COMB-DRIVE XYZ-MICROSTAGE WITH LARGE DISPLACEMENTS FOR LOW TEMPERATURE MEASUREMENT SYSTEMS** **14**
G. Xue, M. Toda, and T. Ono
Tohoku University, JAPAN

In this research, we report the novel design, fabrication and testing of an assembled comb-drive XYZ-microstage that produces highly decoupled motions into X-, Y-, and Z-directions for the 3D scanning stage of magnetic resonance force microscopy. It is demonstrated that the assembled XYZ-microstage can achieve large displacements of 20.4 micrometre in X direction, 25.2 micrometre in Y direction and 58.5 micrometre in Z direction.

11:15 **PNEUMATIC BALLOON ACTUATOR WITH TUNABLE BENDING POINTS** **18**
L. Zheng[1], S. Yoshida[1], Y. Morimoto[1,2], H. Onoe[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

We propose a pneumatic balloon actuator capable of controlling its bending points. Local stiffness of the balloon actuator can be controlled by injected low-melting-point-alloy. The bending point can be changed depending on the position of the rigid low-melting-point-alloy. We believe that the proposed actuation mechanism will be useful in designing highly flexible actuators for soft robotics.

11:30 **SELF-LIFTING ARTIFICIAL INSECT WINGS VIA ELECTROSTATIC FLAPPING ACTUATORS** **22**
X. Yan[1,2], M. Qi[1], and L. Lin[3]
[1]Beihang University, CHINA, [2]Collaborative Innovation Center of Advanced Aero-Engine, CHINA, and [3]University of California, Berkeley, USA

We present a self-lifting artificial insect wings using electrostatic actuation for the first time. Excited by a DC power source, biomimetic flapping motions have been generated to lift the artificial wings under an operation frequency of 50-70Hz. Three achievements have been accomplished: (1) first successful demonstration of electrostatic flying wings; (2) low power consumption as compared to other actuation schemes; and (3) self-adjustable rotating wing design to provide the lifting force.

11:45 **SELF-ASSEMBLED HYDROGEL MICROSPRING FOR SOFT ACTUATOR** **26**
K. Yoshida and H. Onoe
Keio University, JAPAN

We found that the hydrogel microspring was formed by extruding sodium alginate pre-gel solution into calcium chloride using a bevel-tip microfluidic capillary. The formation of the microspring depends on the diameter of the capillary, flow rate and tip angle. As an example of soft actuator, the microspring including magnetic colloids was actuated by applying magnetic fields. We believe that the microspring will be used to various application including mechanical elements using soft materials.

12:00 **Lunch & Exhibit Inspection**

13:00 **Poster/Oral Session I**
Poster presentations are listed by topic category with their assigned number starting on page 14.

15:00 **Break & Exhibit Inspection**

Session III - Gyroscopes

Session Chairs:
F. Ayazi, *Georgia Institute of Technology, USA*
A. Seshia, *University of Cambridge, UK*

15:30 **PARAMETRIC DRIVE OF A TOROIDAL MEMS RATE INTEGRATING GYROSCOPE DEMONSTRATING < 20 PPM SCALE FACTOR STABILITY** **29**
D. Senkal[1], E.J. Ng[2], V. Hong[2], Y. Yang[2], C.H. Ahn[2], T.W. Kenny[2], and A.M. Shkel[1]
[1]University of California, Irvine, USA and [2]Stanford University, USA

In this paper, we report parametric drive of a MEMS rate integrating gyroscope for reduction of drifts induced by drive electronics, resulting in < 20 ppm scale factor stability. Due to the parametric pumping effect, energy added to each (x & y) mode is proportional to the existing amplitude of the respective mode. As a result, errors associated with finding the orientation of the standing wave and x-y drive gain drift can be bypassed, demonstrating > 20x improvement in scale factor stability.

15:45 **A 7PPM, 6°/HR FREQUENCY-OUTPUT MEMS GYROSCOPE** **33**
I.I. Izyumin[1], M.H. Kline[1], Y.C. Yeh[1], B. Eminoglu[1], C.H. Ahn[2],
V.A. Hong[2], Y. Yang[2], E.J. Ng[2], T.W. Kenny[2], and B.E. Boser[1]
[1]University of California, Berkeley, USA and [2]Stanford University, USA

We report the first frequency-output MEMS gyroscope to achieve <7 ppm scale factor accuracy and <6 deg/hr bias stability with a 3.24mm^2 transducer. By employing continuous-time mode reversal, the rate measurement is made insensitive to the resonant frequency of the transducer. The scale factor is almost entirely ratiometric; scale factor sensitivity to transducer and circuit parameters is significantly reduced compared to conventional open-loop and force-rebalance operating modes.

16:00 **LARGE FULL SCALE, LINEARITY AND CROSS-AXIS REJECTION IN LOW-POWER 3-AXIS GYROSCOPES BASED ON NANOSCALE PIEZORESISTORS** **37**
S. Dellea[1], F. Giacci[1], A. Longoni[1], P. Rey[2], A. Berthelot[2], and G. Langfelder[1]
[1]Politecnico di Milano, ITALY and [2]CEA-Leti, FRANCE

The work presents 3-axis rate gyroscopes based on nanoscale piezoresistive readout and eutectic bonding between a bottom wafer, where the sensor is formed, and a cap wafer, where routing and pads are fabricated. The design features a central levered sense frame, to maximize symmetry, compactness and vibration rejection. Operation on a ±3000 dps full-scale shows competitive performance, with linearity errors <0.2% and cross-axis rejections 50x better than state-of-the-art consumer gyroscopes.

16:15 **THE ELECTROMECHANICAL RESPONSE OF A SELF-EXCITED MEMS FRANKLIN OSCILLATOR** **41**
S. Shmulevich, I. Hotzen, and D. Elata
Technion - Israel Institute of Technology, ISRAEL

We present a self-excited MEMS Franklin oscillator, which responds in steady state vibrations when subjected to a dc voltage. The system is constructed from a floating rotor, which transfers charge between a source and drain electrodes. Current flows through the system only when the rotor is in transition. Surprisingly, at contact of the rotor with either the source or the drain electrodes, there is no current, and the charge transfer mechanism is essentially a recombination of opposite charges.

Session IV - Photonics

Session Chairs:
J. Conde, *Instituto Superior Tecnico, PORTUGAL*
C. Lee, *National University of Singapore, SINGAPORE*

16:30 **A NANOMACHINED TUNABLE OSCILLATOR CONTROLLED BY ELECTROSTATIC AND OPTICAL FORCE** **45**
J. G. Huang[1,2,3], B. Dong[2,3], H. Cai[2], Y. D. Gu[3], J. H. Wu[1], T. N. Chen[1],
Z. C. Yang[4], Y. F. Jin[4], Y. L. Hao[4], D. L. Kwong[3], and A. Q. Liu[3]
*[1]Xi'an Jiaotong University, CHINA, [2]Agency for Science, Technology and Research (A*STAR), SINGAPORE, [3]Nanyang Technological University, SINGAPORE, and [4]Peking University, CHINA*

We develop a miniaturized electrically tunable optomechanical oscillator, whose frequencies can be electrostatically tuned by as much as 10%. By taking advantage of the optical and the electrical spring, the oscillator achieves a high tuning sensitivity without resorting to mechanical tension. Particularly, the high-Q optical cavity greatly enhances the system sensitivity, making it extremely sensitive to the motional signal, which is often overwhelmed by spurious coupling or background.

16:45 **NANO-OPTOMECHANICAL STATIC RANDOM ACCESS MEMORY (SRAM)** **49**
B. Dong[1,2], H. Cai[2], Y. D. Gu[2], Z. C. Yang[3], Y. F. Jin[3], Y. L. Hao[3], D. L. Kwong[2], and A. Q. Liu[1]
*[1]Nanyang Technological University, SINGAPORE, [2]Agency for Science, Technology and Research (A*STAR), SINGAPORE, and [3]Peking University, CHINA*

We develop an on chip NEMS optomechanical SRAM, which is integrated with light modulation system on a single silicon chip. In particular, a doubly-clamped silicon beam shows bistability due to the non-linear optical gradient force generated from a ring resonator. The memory states are assigned with two stable deformation positions, which can be switched by modulating the control light's power with the integrated optical modulator.

17:00 **A LOW-POWER MEMS TUNABLE PHOTONIC RING RESONATOR FOR RECONFIGURABLE OPTICAL NETWORKS** **53**

C. Errando-Herranz, F. Niklaus, G. Stemme, and K.B. Gylfason
KTH Royal Institute of Technology, SWEDEN

*** Award Nominee**

We experimentally demonstrate a low-power MEMS tunable photonic ring resonator with 10 selectable channels for wavelength selection in reconfigurable optical networks. The tuning is achieved by changing the geometry of a silicon slot-waveguide ring resonator by vertical electrostatic parallel-plate actuation. Our device provides static power dissipation below 0.1 μW, a wavelength tuning range of 1 nm, and a bandwidth of 0.1 nm, i.e. 10-8 watts per selectable channel, the lowest number reported.

17:15 **NEMS OPTICAL CROSS CONNECT (OXC) DRIVEN BY OPTICL FORCE** **57**

H. Cai[1], J. X. Lin[2], J. H. Wu[2], B. Dong[1,3], Y. D. Gu[1], Z. C. Yang[4], Y. F. Jin[4], Y. L. Hao[4], D. L. Kwong[1], and A. Q. Liu[3]
*[1]Agency for Science, Technology and Research (A*STAR), SINGAPORE,*
[2]Xi'an Jiaotong University, CHINA, [3]Nanyang Technological University, SINGAPORE, and [4]Peking University, CHINA

We report a nano-silicon-photonic optical cross connect driven by optical gradient force, which demonstrates the all-optical OXC system on silicon. A switching time of 170 ns is experimentally demonstrated, which is much faster than that of conventional optical switches. In addition, the proposed switch system has the advantages of compact size (35 μm x 35 μm for switching element), high extinction ratio and low power consumption.

17:30 **Adjourn for the Day**

Tuesday 20, January

08:25 **Announcements**

Invited Plenary Speaker II

Session Chairs:
H. Toshiyoshi, *University of Tokyo, JAPAN*
J. Brugger, *EPFL Lausanne, SWITZERLAND*

08:30 **THE FUTURE OF MEMS SENSORS IN OUR CONNECTED WORLD** **61**
Gerhard Lammel, Ph.D.
Bosch Sensortec GmbH, GERMANY

Session V - Micro-Optics

Session Chairs:
I.-J. Cho, *Korea Institute of Science and Technology, SOUTH KOREA*
B. Legrand, *LAAS-CNRS, FRANCE*

09:15 **FABRICATION AND CHARACTERIZATION OF A NEW VARIFOCAL LIQUID LENS WITH EMBEDDED PZT ACTUATORS FOR HIGH OPTICAL PERFORMANCES** **65**
S. Nicolas[1], M. Allain[1], C. Bridoux[1], S. Fanget[1], S. Lesecq[1], M. Zarudniev[1], S. Bolis[2], A. Pouydebasque[2], and F. Jacquet[2]
[1]CEA, LETI, MINATEC Campus, FRANCE and [2]WAVELENS, FRANCE

This paper reports the fabrication and characterizations of a compact Varifocal microlens with an embedded MEMS actuator. Optical aperture is typically between 1.5 mm to 3 mm diameter with a total component thickness down to 400µm. High power efficiency (< 0.1 µW), high speed response time (down to 1 msec), high electro-optical performances (10 diopters optical power variation at 10V) and good optical quality (wavefront error lower than 50 nm) are reported through this paper.

09:30 **IMPLEMENTATION OF NANOPOROUS ANODIC ALUMINUM OXIDE LAYER WITH DIFFERENT POROSITIES FOR INTERFEROMETRIC RGB COLOR PIXELS AS HANDHELD DISPLAY APPLICATION** **69**
P.-H. Lo[1], G.-L. Luo[2], and W. Fang[1]
[1]National Tsing Hua University, TAIWAN and [2]Asia Pacific Microsystems Inc., TAIWAN

This study employs the nanoporous anodic aluminum oxide (np-AAO) for interferometric modulation color pixels. Advantages of the proposed color-pixel are, (1) porosity of np-AAO layer can be adjusted to modulate therefractive index, (2) color-pixels of different porosities can be implemented on single np-AAO layer for different colors modulation, (3) the morphology of np-AAO with Al half-reflector could scatter reflect light to enhance view-angle, and (4) anti-stiction coating is not required.

09:45 **LOW-NOISE ALN-ON-SI RESONANT INFRARED DETECTORS USING A COMMERCIAL FOUNDRY MEMS FABRICATION PROCESS** **73**
V.J. Gokhale[1], C. Figueroa[1], J.M.L. Tsai[2], and M. Rais-Zadeh[1]
[1]University of Michigan, USA and [2]Invensense Inc,, USA

This work presents the first measured results for resonant AlN-based IR detectors fabricated in a proprietary AlN MEMS process. Resonators fabricated in the first fabrication run achieved high electromechanical performance (Q of ~1400 at 115 MHz), an infrared responsivity of 10.7%/W, and low noise, as evidenced by an NEDT of 51 mK and an NEP of 52.7 pW/Hz^0.5. The resonators are fabricated in a hybrid MEMS/CMOS wafer level packaged die, allowing for CMOS-based routing and readout.

10:00 **Break & Exhibit Inspection**

Session VI - Novel Fabrication

Session Chairs:
A. Dietzel, *Technische Universität Braunschweig, GERMANY*
H. Moon, *University of Texas, Arlington, USA*

10:30 **HARD MASK FREE DRIE OF CRYSTALLINE SI NANOBARREL WITH 6.7NM WALL THICKNESS AND 50:1 ASPECT RATIO** **77**
P. Liu, F. Yang, W. Wang, W. Wang, K. Luo, Y. Wang, and D. Zhang *** Award Nominee**
Peking University, CHINA

Crystal Si barrel with wall thickness of 6.7nm and aspect ratio of 50:1 were fabricated using IC/MEMS compatible process. PR mask was generated by e-beam lithography then etched into Si by fluorine based DRIE directly, without hard mask transfer. To achieve high anisotropic etching, a model of ions transportation around barrels in DRIE was established and studied. This tactic with high repeatability and manufacturability provides an arsenal for the next generation of 3D nano devices fabrication.

10:45 **SELF-HEALING METAL WIRE USING AN ELECTRIC FIELD TRAPPING OF GOLD NANOPARTICLES FOR FLEXIBLE DEVICES** **81**

T. Koshi and E. Iwase *** Award Nominee**

Waseda University, JAPAN

We developed a self-healing metal wire for flexible devices. A cracked metal wire on a stretchable substrate can get its conductivity again by the self-healing ability using an electric field trapping of gold nanoparticles. First, we analyzed the electric field trapping. Next, we fabricated cracked wires on a glass substrate and verified the self-healing by experiments. Finally, we demonstrated the self-healing on the stretchable substrate to show a usefulness for flexible devices.

11:00 **CONTROLLED FABRICATION OF NANOSCALE GAPS USING STICTION** **85**

F. Niroui, E.M. Sletten, P.B. Deotare, A.I. Wang, T.M. Swager, J.H. Lang, and V. Bulović

Massachusetts Institute of Technology, USA

Utilizing stiction, a common mode of failure in electromechanical systems, our work develops a method for the controlled fabrication of nanometer-thin gaps between electrodes. In this approach, through nanoscale force control, stiction promotes formation of nanogaps of controlled widths within the range as small as sub-15 nm. Our work demonstrates that through modifications of device design, the nanogaps can be optimized for applications in nanoelectromechanical and molecular devices.

11:15 **DIFFERENTIAL MICRO-PIRANI GAUGE FOR MONITORING MEMS WAFER-LEVEL PACKAGE** **89**

Y.-C. Chen, W.-C. Lin, H.-S. Wang, C.-C. Fan, K.C.-H. Lin, B.C.S. Chou, and M.C.-M. Liu

Taiwan Semiconductor Manufacturing Company, TAIWAN

We proposed a multiple-sensor-solution, where two Pirani gauges were constructed under different pressures; one in sealed micro-cavity for measuring pressures and the other one in opened micro-cavity as a reference. The differential scheme compensates errors, allowing accurate pressure determinations, and it was successfully used in examining reliabilities and monitoring processes of wafer-level packages.

11:30 **MICROFABRICATED ELECTROSTATIC PLANAR LENS ARRAY AND EXTRACTORS FOR MULTI-FOCUSED ION BEAM SYSTEM USING IONIC LIQUID ION SOURCE EMITTER ARRAY** **93**

R. Yoshida, M. Hara, H. Oguchi, and H. Kuwano

Tohoku University, JAPAN

To develop multi-focused ion beam system, we fabricated the electrostatic planar extractors and lenses, and integrated those with the field-emission ion source emitter array. Focusing ability of the integrated device was verified by confirming divergence angle reduction to ~70% of that without focusing effect. In addition, to find suitable ionic liquid for Si etching, we adopted various ionic liquid as an ion source and investigated etching characteristics by microscopy and mass spectrometry.

11:45 **NOVEL IONIC LIQUID - POLYMER COMPOSITE AND AN APPROACH FOR ITS PATTERNING BY CONVENTIONAL PHOTOLITHOGRAPHY** **97**

N.A. Bakhtina[1], A. Voigt [2], N. MacKinnon[1], G. Ahrens[2], G. Gruetzner[2], and J.G. Korvink[1] *** Award Nominee**

[1]University of Freiburg-IMTEK, GERMANY and [2]micro resist technology GmbH, GERMANY

We report a novel composite material based on an ionic liquid and a photoresist. In addition, an approach for the patterning of the composite material by conventional photolithography is introduced. The unique properties of the material are utilized for direct manufacturing of highly transparent, electrically conductive microcomponents.

12:00 **IEEE 2015 Andrew S. Grove Award Recipient**

Dr. Masayoshi Esashi, Ph.D.

Tohoku University, JAPAN

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 14.

15:15 **Break & Exhibit Inspection**

Session VII - Power & Energy I

Session Chairs:
H. Kim, *University of Utah, USA*
P. Woias, *Albert-Ludwig-University Freiburg, GERMANY*

15:30 **TRIBOELECTRIFICATION BASED ACTIVE SENSOR FOR POLYMER DISTINGUISHING** **102**
B. Meng, X.L. Cheng, M.D. Han, H.T. Chen, F.Y. Zhu, and H.X. Zhang *** Award Nominee**
Peking University, CHINA

We present a novel sensor to realize polymer distinguishing based on triboelectrification and electrostatic induction. Multiple cells of single friction layer and electrode are integrated on a flexible substrate. For different polymer groups, the friction layers can be selected according to the triboelectric serials. As an example, the distinguishing of PDMS, PE and PET has been well demonstrated by employing PI and PS friction layers, showing potential applications in robotics and industry use.

15:45 **SKIN BASED FLEXIBLE TRIBOELECTRIC NANOGENERATORS WITH MOTION SENSING CAPABILITY** **106**
L. Dhakar, F.E.H. Tay, and C. Lee *** Award Nominee**
National University of Singapore, SINGAPORE

This paper presents a novel triboelectric nanogenerator (TENG) using outermost layer of human skin i.e. epidermis as an active triboelectric layer for device operation. The human skin also has an advantage of high tendency to lose electrons relative to PDMS, which leads to improved performance of triboelectric mechanism. TENG is also demonstrated as a wearable self-powered sensor to track human motion/activity.

16:00 **FLEXIBLE TRIBOELECTRIC AND PIEZOELECTRIC COUPLING NANOGENERATOR BASED ON ELECTROSPINNING P(VDF-TRFE) NANOWIRES** **110**
X. Wang, B. Yang, J. Liu, Q. He, H. Guo, C.S. Yang, and X. Chen
Shanghai Jiaotong University, CHINA

We fabricate and characterize a triboelectric and piezoelectric coupling nanogenerator based on MEMS technology which is more flexible and thickness controllable than conventional process fabricated. The electrospinning PVDF-TrFE nanofibers and MWCNTs doped PDMS films are function and friction layers. To characterize the sandwich-shaped nanogenerator's performance, its open-circuit output voltage and energy power density under two kinds of energy generation mechanism are tested and discussed.

16:15 **HIGHLY RELIABLE MEMS RELAY WITH TWO-STEP SPRING SYSTEM AND HEAT SINK INSULATOR FOR POWER APPLICATIONS** **114**
Y.-H. Yoon, Y.-H. Song, S.-D. Ko, C.-H. Han, G.-S. Yun, M.-H. Seo, and J.-B. Yoon
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

This paper reports remarkably reliable MEMS relays having a unique two-step spring system and a heat sink insulator. The two-step spring system is designed to reduce Joule-heating by lowering contact resistance. The heat sink insulator is proposed for efficiently removing heat generated in the contact area. These two features are adopted in the MEMS relay for minimizing thermal damage in high current level, thus enhancing reliability significantly.

Session VIII - Power & Energy II

Session Chairs:
H. Kim, *University of Utah, USA*
P. Woias, *Albert-Ludwig-University Freiburg, GERMANY*

16:30 **SOLIDIFIED IONIC LIQUID FOR HIGH-POWER VIBRATIONAL ENERGY HARVESTERS** **118**
S. Yamada[1], H. Mitsuya[2], S. Ono[3], K. Miwa[3], and H. Fujita[1]
[1]University of Tokyo, JAPAN, [2]SAGINOMIYA SEISAKUSHO, Inc., JAPAN, and [3]Central Research Institute of Electric Power Industry, JAPAN

We propose a high power-output vibrational energy harvester based on ionic liquid. Ionic liquid enables very large capacitance (1.0-10 μF cm-2) on the electrode at bias voltage less than 1.9 V due to its extremely thin (~ 1 nm) electrical double layer. By mechanical squeezing and drawing the ionic liquid solidified with a polymer addictive between a pair of electrodes at 15 Hz, we stably obtained the current output of 22 μAp-p cm-2 at 1.5 V.

16:45 **FERROFLUID LIQUID SPRING FOR VIBRATION ENERGY HARVESTING** **122**
Y. Wang, Q. Zhang, L. Zhao, and E.S. Kim
University of Southern California, Los Angeles, USA

We developed a ferrofluid liquid spring to suspend a magnet array for harvesting vibration energy. For the first time, the concept of ferrofluidbased suspension is demonstrated for low resonant frequency and high reliability. A ferrofluid liquid spring has reduced the resonant frequency of a microfabricated electromagnetic energy harvester to around 340 Hz. 36 nW is delivered into a load of 2.3 Ω from 7 g acceleration.

17:00 **AN ELECTROSTATIC ENERGY HARVESTER EXPLOITING VARIABLE-AREA WATER ELECTRODE BY RESPIRATION** **126**

M.-H. Seo, D.-H. Choi, C.-H. Han, J.-Y. Yoo, and J.-B. Yoon
Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA

*** Award Nominee**

This paper reports an electrostatic energy-harvester exploiting water-layer formed by respiration as a variable-area electrode. We discover that electrically conductive water-layer (~45 Mohms/sq under 5 V) is instantly formed on a silicon-dioxide surface by exhaled-breath. We adopt this layer as variable capacitive electrodes for electrostatic energy-harvesting. The capacitance change was evaluated using a theoretical modeling and finite-element-method (FEM) simulation, and theoretical power-generation was estimated (~2 μW/cm^2 at 1 V). We then fabricated the prototype device and verified the capacitance change experimentally. Finally, the prototype showed charging and discharging characteristics by respiration successfully for being used as an energy-harvester driven by human-breath solely.

17:15 **SILICON ANODE SUPPORTED BY CARBON SCAFFOLD FOR HIGH PERFORMANCE LITHIUM ION MICRO-BATTERY** **130**

X. Li[1,2], X. Wang[1,2], and S. Li[1,2]
[1]Tsinghua National Laboratory for Information Science and Technology, CHINA and [2]Tsinghua University, CHINA

This paper reports a novel Si/void/C anode for lithium ion batteries, with high specific capacity and superior cyclability. SiNPs at anode make a significant contribution to specific capacity increase. Nano void spaces provide enough space for expansion and contraction of SiNPs to ensure a long cycle life. The porous carbon scaffold is obtained from a photoresist (SU-8) with SiNPs templates. As such, it's possible to implement direct prototyping of three dimensional (3D) micro-battery on chip.

17:30 **Adjourn for the Day**

Wednesday 21, January

08:25 **Announcements**

Invited Plenary Speaker III

Session Chairs:
W. van der Wijngaart, *KTH - Royal Institute of Technology, SWEDEN*
X. Wang, *Tsinghua University, CHINA*

08:30 **STATUS AND FUTURE TRENDS OF THE MINIATURIZATION OF MASS SPECTROMETRY** 134
Richard R.A. Syms, Ph.D.
Imperial College London, UK

Session IX - Acoustic Sensors

Session Chairs:
Y.-K. Kim, *Seoul National University, SOUTH KOREA*
T. Seki, *OMRON Corporation, JAPAN*

09:15 **SHORT-RANGE AND HIGH-RESOLUTION ULTRASOUND IMAGING USING AN 8 MHZ ALUMINUM NITRIDE PMUT ARRAY** 140
Y. Lu[1], H.-Y. Tang[2], S. Fung[1], B.E. Boser[2], and D.A. Horsley[1]
[1]*University of California, Davis, USA and* [2]*University of California, Berkeley, USA*
*** Award Nominee**

We demonstrate short-range (~mm) and high-resolution (<100µm) imaging based on piezoelectric micromachined ultrasonic transducers (PMUTs) and a 1.8V interface ASIC. The PMUTs use piezoelectric Aluminum Nitride (AlN), which has the advantages of low-temperature (<400°C) deposition and compatibility with CMOS fabrication but has a relatively low piezoelectric constant (e31=-0.5C/m2), making detection of ultrasound signals from tiny (50µm) PMUTs a challenging task.

09:30 **MEASUREMENT OF SURFACE ACOUSTIC WAVES PROPAGATION USING A PIEZORESISTIVE CANTILEVER ARRAY** 144
N. Minh-Dung, P. Quang-Khang, N. Thanh-Vinh, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We presents an approach for measuring the propagation of surface acoustic waves (SAW), using a piezo-resistive cantilever array. SAW was measured by cantilevers designed at the liquid-substrate interaction area by utilizing the structure of liquid-cantilever-air, which is highly sensitive and is able to measure acoustic wave at high frequency. Experiment results demonstrate that the measurable range was from 0.1 MHz up to 100 MHz.

09:45 **BROADBAND PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS BASED ON DUAL RESONANCE MODES** 146
Y. Lu[1], O. Rozen[1], H.-Y. Tang[2], G.L. Smith[3], S. Fung[1], B.E. Boser[2], R.G. Polcawich[3], and D.A. Horsley[1]
[1]*University of California, Davis, USA,* [2]*University of California, Berkeley, USA, and* [3]*US Army Research Lab, USA*

We demonstrate broadband PZT pMUTs that achieve a 97% fractional bandwidth by utilizing a thinner structure excited at two adjacent mechanical vibration modes. A front side XeF2 release process reduces fabrication cost and allows higher fill factor relative to pMUTs requiring through wafer DRIE. To reduce the frequency variations that result from non-uniform or inaccurately-controlled release etching, a 4µm thick metal layer defines the effective boundary of each pMUT.

10:00 **WHEN CAPACITIVE TRANSDUCTION MEETS THE THERMOMECHANICAL LIMIT: TOWARDS FEMTO-NEWTON FORCE SENSORS AT VERY HIGH FREQUENCY** 150
S. Houmadi[1,2], B. Legrand[3,4], J.P. Salvetat[2], B. Walter[5], E. Mairiaux[5], J.P. Aimé[1], D. Ducatteau[5], P. Merzeau[2], L. Buisson[2], J. Elezgaray[1], D. Théron[5], and M. Faucher[5]
[1]*CNRS, CBMN, FRANCE,* [2]*CNRS, CRPP, FRANCE,* [3]*CNRS, LAAS, FRANCE,* [4]*University de Toulouse, FRANCE, and* [5]*IEMN, CNRS, FRANCE*

We show that the capacitive transduction associated with a microwave detection scheme achieves the measurement of the thermomechanical noise spectrum of high-frequency (>10 MHz) high-stiffness (>105 N/m) microresonators, reaching the outstanding displacement resolution of 1fm/√Hz. This paves the way for vibrating sensors with exquisite force resolution in the fN/√Hz range, enabling large-bandwidth measurements of mechanical interactions at small scale and rheology of fluids at high frequency.

10:15 **Break & Exhibit Inspection**

Session X - Medical Microdevices

Session Chairs:
A. Hierlemann, *ETH Zurich, SWITZERLAND*
W. Li, *Michigan State University, USA*

10:45 **MEMS OXYGEN TRANSPORTER TO TREAT RETINAL ISCHEMIA** **154**
D. Kang[1], K. Murali[2], N. Scianmarello[1], J. Park[1], J.H.-C. Chang[1], Y. Liu[1], K.-T. Chang[1], Y.-C. Tai[1], and M.S. Humayun[2]
*** Award Nominee**
[1]California Institute of Technology, USA and [2]University of Southern California, Los Angeles, USA

A paradigm shift of treating diabetic retinopathy is proposed in the sense of using MEMS devices to bring more oxygen to retina. A passive MEMS oxygen transporter was designed, built, and tested both in mechanical models and pig eyes to confirm its feasibility. The results predict that the proposed approach can even treat a complete retinal ischemia, although our current on-going live animal experiments must finish before going for human trials.

11:00 **A NEW MONOLITHICALLY INTEGRATED MULTI-FUNCTIONAL MEMS NEURAL PROBE FOR OPTICAL STIMULATION AND DRUG DELIVERY** **158**
Y. Son[1], H.J. Lee[1], J. Kim[1], C.J. Lee[1], E.-S. Yoon[1], T.G. Kim[2], and I.-J. Cho[1]
[1]Korea Institute of Science and Technology (KIST), SOUTH KOREA and [2]Korea University, SOUTH KOREA

We present a monolithically integrated multifunctional MEMS neural probe by integrating both an embedded microfluidic channel for drug delivery and a SU-8 waveguide for optical stimulation using controlled glass reflow process. Using our multifunctional neural probe, we conducted successful in vivo experiments and recorded neural spike signals from individual neurons with a good SNR. In this work, we present distinctive changes in neural signals induced by both optical and chemical stimulation.

11:15 **MINIATURIZED 3×3 OPTICAL FIBER ARRAY FOR OPTOGENETICS WITH INTEGRATED 460 NM LIGHT SOURCES AND FLEXIBLE ELECTRICAL INTERCONNECTION** **162**
M. Schwaerzle, P. Elmlinger, O. Paul, and P. Ruther
University of Freiburg-IMTEK, GERMANY

We report on the design, fabrication, assembly, and optical and thermal characterization of a novel MEMS-based optical probe array for optogenetic research in neuroscience. Nine high-efficiency light emitting diodes (LED) are integrated as a 3×3 array in a micromachined silicon (Si) housing that ensures the mechanical stability and precise alignment of the nine 5-mm-long optical fibers. The overall housing volume of less than 2.2 mm^3 is compatible with chronic implantation.

11:30 **FLEXIBLE END-EFFECTOR INTEGRATED WITH SCANNING ACTUATOR AND OPTICAL WAVEGUIDE FOR ENDOSCOPIC FLUORESCENCE IMAGING DIAGNOSIS** **166**
Y. Muramatsu, T. Kobayashi, and S. Konishi
Ritsumeikan University, JAPAN

This paper presents a flexible end-effector integrated with a scanning actuator and optical waveguide for endoscopic fluorescence imaging diagnosis. Pneumatic balloon actuator (PBA) is used as the scanning actuator for the end-effector in consideration of its soft and safe features. SU-8 optical waveguides are integrated onto the PBA structure made of PDMS. Our developed device has successfully scanned, excited, and detected fluorescence beads distributed in a pseudo tissue.

11:45 **FULLY IMPLANTABLE AND RESORBABLE WIRELESS MEDICAL DEVICES FOR POSTSURGICAL INFECTION ABATEMENT** **168**
H. Tao[1], S.W. Hwang[2], B. Marelli[3], B. An[3], J.E. Moreau[3], M. Yang[3], M.A. Brenckle[3], S. Kim[2], D. Kaplan[3], J.A. Rogers[2], and F.G. Omenetto[3]
[1]Shanghai Institute of Microsystem and Information Technology, CAS, CHINA,
[2]University of Illinois, Urbana-Champaign, USA, and [3]Tufts University, USA

We present a therapeutic application of a microfabricated implantable and resorbable medical device by demonstrating in vivo elimination of bacterial infection by wireless activation of the device after implantation. The device disappears upon its completion, requiring no retrieval.

12:00 **MEMS 2016 Announcement**

12:15 **Lunch & Exhibit Inspection**

13:15 **Poster/Oral Session III**
Poster presentations are listed by topic category with their assigned number starting on page 14.

15:15 **Break & Exhibit Inspection**

Session XI.a - Resonant Sensors

Session Chairs:
C. Nguyen, *University of California, Berkeley, USA*
L. Sorenson, *HRL Laboratories, LLC, USA*

We demonstrate frequency tuning of the first instability window of a MEMS Meissner parametric resonator. We achieve parametric excitation by time-modulation of a negative electrostatic stiffness. In our device this negative electrostatic stiffness is not affected by motion. In contrast, all state of the art MEMS parametric resonators are either detrimentally affected by a nonlinear electrostatic stiffness, or are more sensitive to fabrication tolerances relative to our design.

This paper reports a method to measure viscosity based on the resonant vibration of droplets on a piezoresistive cantilever array. We demonstrate that viscosity of small droplets (3 µL) can be estimated from the attenuation rate of the cantilever output during free-decay of the droplet vibration. Moreover, we show that the optimized location of a cantilever should be on the periphery of the contact area where the force change is largest.

We report hollow MEMS plate oscillators for mass sensing in liquid with an expected mass resolution of 3 femtograms. The performances reached by our sensors – 10,000-range Q factor and ppb-range frequency stability – make them amenable to individual particles metrology from a few 10 nanometers up to the micrometre diameter range. Our devices are operated in air inside a customized "plug and play" test platform and do not need to work in vacuum sealed package.

We report wafer-level batch fabrication of microfluidic resonators based on Silicon-on-Nothing (SON) structures resulting from high temperature argon annealing of silicon wafers with periodic cylindrical pits. Besides the process optimization of SON structures, elemental fabrication techniques such as planarization, device release, metallization, and packaging are developed. These techniques reduce fabrication cost and time significantly and enable switching of the resonator materials.

Session XI.b - Cell Handling

Session Chairs:
N. Tas, *University of Twente, THE NETHERLANDS*
W. Wang, *Peking University, CHINA*

We report the micrfabrication, computer modeling and experimental testing of a novel, new means of mechanically lysing algae using a flow-driven grinding mill. The mill is demonstrated to have 96% efficiency in lysing the dinoflagellate genus Alexandrium, a neurotoxin producing algae, responsible for Red Tide and paralytic shellfish poisoning. Lysate DNA is demonstrated to be viable through successful PCR amplification using primers specific to Alexandrium.

We have developed a centrifugal microfluidic strategy for the isolation and sizing analysis of multicellular clusters from a blood sample. The strategy is based on passing the sample over a size exclusion rail that gates entry of clusters to underlying bins, allowing estimation of clustering extent in the sample.

We report on a novel tunable insulator-based dielectrophoresis (TiDEP) for three-dimensional, sheathless, single-stream cell and bacteria focusing. For the first time, objects as small as sub-micron sized infectious bacteria are continuously focused in the center of a channel without sheath flows. Compared to prior DEP works, this new TiDEP can provide an extremely long DEP interaction distance to migrate small objects with weak DEP forces to a focused single stream at high speed flows.

16:15 **CELL MANIPULATION METHOD BASED ON VIBRATIN-INDUCED LOCAL FLOW CONTROL IN OPEN CHIP ENVIRONMENT** **200**
T. Hayakawa, S. Sakuma, and F. Arai
Nagoya University, JAPAN

We present a novel cell manipulation method using vibration-induced local flow control in open-chip environment. By applying circular vibration to micropillars on a chip, whirling flow is induced around it. This phenomenon is theoretically analyzed considering an effect of convective flow. Based on it, we show two important applications; transport and 3D rotation of oocytes for 3D observation of oocyte. We succeeded in the transportation of oocytes with 25 μm/s and rotation with 184 degrees/s.

Session XII.a - Magnetic & Resonant Sensors

Session Chairs:
M. Rais-Zadeh, *University of Michigan, USA*
M. Sasaki, *Toyota Technological Institute, JAPAN*

16:30 **ULTRA SENSITIVE LORENTZ FORCE MEMS MAGNETOMETER WITH PICO-TESLA LIMIT OF DETECTION** **204**
V. Kumar, M. Mahdavi, X. Guo, E. Mehdizadeh, and S. Pourkamali *** Award Nominee**
University of Texas, Dallas, USA

This work presents ultra-high sensitivities for Lorentz Force resonant MEMS magnetometers enabled by internal thermal-piezoresistive vibration amplification. Up to 2400X sensitivity amplification has been demonstrated with the noise floor calculated to be as low as 18 pt/√Hz. This is by far the most sensitive MEMS Lorentz force magnetometer demonstrated to date.

16:45 **HIGH FREQUENCY MICROWAVE ON-CHIP INDUCTORS USING INCREASED FERROMAGNETIC RESONANCE FREQUENCY OF MAGNETIC FILMS** **208**
K. Koh[1], D.S. Gardner[2], C. Yang[1], K.P. O'Brien[2], N. Tayebi[2], and L. Lin[1]
[1]University of California, Berkeley, USA and [2]Intel Corporation, USA

The fabrication and characterization of high frequency on-chip inductors using sputtered magnetic films with an improved frequency range is presented. Reducing the sputtering power in the deposition process was found to result in smoother film surfaces and stronger uniaxial magnetic anisotropy and increased the FMR of CoZrTaB from 1.48 GHz to 2.13 GHz. A magnetic-core, on-chip inductor was fabricated using the CoZrTaB films. Results have shown 150% higher inductance and a larger Q-factor up to 1.2 GHz as compared to an air-core inductor.

17:00 **FUSION OF CANTILEVER AND DIAPHRAGM PRESSURE SENSORS ACCORDING TO FREQUENCY CHARACTERISTICS** **212**
R. Watanabe, N. Minh-Dung, H. Takahashi, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on an approach to measure sensitive barometric pressure by fusing a cantilever-based differential pressure sensor (DPS) and a commercial available diaphragm-based absolute pressure sensor (APS). At high frequency, the DPS can detect smaller absolute pressure change than the APS. At low frequency, the APS show absolute pressure of less drift than the DPS. By utilizing the DPS and APS at each advantageous frequency, we propose high sensitive measurement of barometric pressure.

17:15 **DYNAMICALLY-BALANCED FOLDED-BEAM SUSPENSIONS** **215**
S. Shmulevich, I. Hotzen, and D. Elata
Technion - Israel Institute of Technology, ISRAEL

We present a design methodology and experimental evidence of a dynamically balanced folded-beam suspension. This suspension responds as a linear spring at the fundamental resonance, which is in sharp contrast to the response of standard folded-beam suspensions. The dynamic response of standard suspensions becomes strongly nonlinear for motions larger than the width of the flexure beams. The resonance response of the new dynamically-balanced suspension is linear over a wider range of motions.

Session XII.b - BioSensing

Session Chairs:
E. Iwase, *Waseda University, JAPAN*
R. Yokokawa, *Kyoto University, JAPAN*

16:30 **MEMBRANE-BASED CHEMOMECHANICAL TRANSDUCER FOR THE DETECTION OF APTAMER-PROTEIN BINDING** **219**
J.-K Choi[1] and J. Lee[2]
[1]Small Machines Incorporation, SOUTH KOREA and [2]Seoul National University, SOUTH KOREA

We report a membrane-based chemomechanical transducer for the sensitive detection of surface molecular reaction through a highly reliable common mode rejection (CMR) technique. Chemomechanical transduction, originally based on the micro-cantilever, offers potential benefits: label-free assay, and real-time monitoring of molecular interaction via mechanical deformation. Here we show clear-cut detection of molecular binding using a membrane transducer fabricated with conventional MEMS technology.

16:45 **HIGHLY SENSITIVE SERS DIAGNOSIS FOR BACTERIA BY THREE DIMENSIONAL NANO-MUSHROOMS AND NANO-STARS-ARRAY SANDWICHED ON BACTERIAL AGGREGATION 223**

C.-W. Lee[1], J.-K. Wu[1], and F.-G. Tseng[1,2]
[1]National Tsing Hua University, TAIWAN and [2]Research Center for Applied Sciences, Academia Sinica, TAIWAN

This paper reports a highly sensitive SERS Diagnosis system by incorporating three dimensional Nano-Mushrooms and Nano-Stars-Array sandwiched on Bacterial Aggregation. Through the action of ACEOF and nano-mushroom/bacteria/nano-stars-array self-aggregation process, the signal can be much enhanced by 5 orders of magnitude in 5 minutes. Detection limit can approach 1 bacterium/ml from the analysis result.

17:00 **SIMULTANEOUS IMPEDANCE SPECTROSCOPY AND STIMULATION OF HUMAN IPS-DERIVED CARDIAC 3D SPHEROIDS IN HANGING-DROP NETWORKS 226**

S.C. Bürgel[1], Y. Schmid[1], I. Agarkova[2], D.A. Fluri[2], J.M. Kelm[2], A. Hierlemann[1], and O. Frey[1]
[1]ETH Zurich, SWITZERLAND and [2]InSphero AG, SWITZERLAND

We present a platform for in-situ electrical impedance spectroscopy (EIS) measurements and electrical stimulation of human iPS-derived cardiac 3D microtissue spheroids in hanging drop networks. Electrical stimulations and EIS measurements were performed in parallel through the same electrodes. Stimulation was performed with sine-wave signals. Our results reveal beating frequency modulation upon tuning the stimulation signal amplitude.

17:15 **DROPLET FLOW FOCUSING FOR MOLECULAR BINDING DETECTION 230**

S. Kim and J. Lee
Seoul National University, SOUTH KOREA

We report the detection of interfacial molecular binding via droplet generation in a flow focusing device. We introduce the detection of DNA hybridization based on the mode of droplet production caused by interfacial tension shift at the oil-water boundary. Our report includes a molecular protocol to functionalize the interface with single-strand (ss) DNA as receptor, and flow condition tuning for an unambiguous distinction of complementary binding.

17:30 **Adjourn for the Day**

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

Thursday 22, January

08:40 **Announcements**

Invited Plenary Speaker IV

Session Chairs:
X. Wang, *Tsinghua University, CHINA*
W. van der Wijngaart, *KTH - Royal Institute of Technology, SWEDEN*

08:45 **SEMICONDUCTOR IC PACKAGING, THE NEXT WAVE** **234**
CP Hung, Ph.D.
Advanced Semiconductor Engineering Inc., TAIWAN

Session XIII - BioMEMS

Session Chairs:
T. Kawano, *Toyohashi University of Technology, JAPAN*
N. Roxhed, *KTH - Royal Institute of Technology, SWEDEN*

09:30 **ROTATIONAL CHAMBERS ON FLUIDIC CHANNELS FOR THE REPETITIVE FORMATION OF OPTICALLY OBSERVABLE LIPID-BILAYER MEMBRANES** **235**
F. Tomoike[1], T. Tonooka[1], T. Osaki[2], and S. Takeuchi[1]
[1]University of Tokyo, JAPAN and [2]Kanagawa Academy of Science and Technology, JAPAN

We develop a device adapted for repetitive formation of horizontal lipid bilayer membranes. This device enables simultaneous optical and electrophysiological measurements of the membranes. We integrated a rotational chamber on a fluidic channel via parylene micropores. The rotational motion enables us to form/reform the bilayer repeatedly. The formation of the bilayers was confirmed from the bilayer thickness and nanopore incorporation into the bilayer.

09:45 **MICROTUBULE SORTING WITHIN A GIVEN ELECTRIC FIELD BY DESIGNING FLEXURAL RIGIDITY** **238**
N. Isozaki[1], H. Shintaku[1], H. Kotera[1], E. Meyhöfer[2], and R. Yokokawa[1]
[1]Kyoto University, JAPAN and [2]University of Michigan, USA

We propose a method to control gliding directions of kinesin-propelled microtubules (MTs) corresponding to their flexural rigidity (EI). We prepared two kinds of MTs having different EI and their trajectories within an electric field were clearly separated. Therefore, this study demonstrated the EI-altered MTs can be workhorses to sort/concentrate various combinations of molecules with techniques of loading MTs with target molecules and capturing the sorted MTs.

10:00 **CARVING OF PROTEIN CRYSTAL BY HIGH-SPEED MICRO-BUBBLE JET USING MICRO-FLUIDIC PLATFORM** **242**
S. Takasawa[1], T. Syu[1], and Y. Yamanishi[1,2]
[1]Shibaura Institute of Technology, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

This paper reports a novel processing method for protein crystal with electric-induced-bubble. This minimally invasive micro-processing method overcomes the difficulties of processing fragile material such as protein crystal under water. The combination of electrically-induced bubble knife and glass capillary provide effective carving of protein crystal by ablation crystal and suction of chips respectively. Also, we successfully made a new micro-fluidic platform for processing protein crystal.

10:15 **Break & Exhibit Inspection**

Session XIV - Tactile and Force Sensors

Session Chairs:
N. Miki, *Keio University, JAPAN*
E. Sarajlic, *SmartTip B.V., THE NETHERLANDS*

10:45 **A NOVEL CONFIGURATION OF TACTILE SENSOR TO ACQUIRE THE CORRELATION BETWEEN SURFACE ROUGHNESS AND FRICTIONAL FORCE** **245**
R. Kozai, K. Terao, T. Suzuki, F. Shimokawa, and H. Takao
Kagawa University, JAPAN

We propose a novel configuration of MEMS tactile sensor that can interact with micro surface roughness at a high resolution are proposed and reported for quantification of the fingertip sense. Two-axis movements of the contactor-tip are independently detected by the two independent suspensions. In the evaluation experiments, correlation between the surface shape and the local frictional force were successfully obtained at the same time and at the same point for many samples for the first time.

11:00 **TUNNELING PIEZORESISTIVE TACTILE SENSING ARRAY FABRICATED BY A NOVEL FABRICATION PROCESS WITH MEMBRANE FILTERS** **249**
C.-W. Ma, T.-H. Ling, and Y.-J. Yang
National Taiwan University, TAIWAN

In this work, a highly-sensitive tactile sensor array using the tunneling piezoresistive effect is presented. The sensing element, which is made of multi-wall carbon nanotubes and polydimethylsiloxane conductive polymer, was patterned with microdome structures by a novel fabrication process on a membrane filter substrate. The tunneling piezoresistive effects of the interlocked microdome structures with different MWCNT concentrations are demonstrated.

11:15 **A TACTILE SENSOR WITH THE REFERENCE PLANE FOR DETECTION ABILITIES OF FRICTIONAL FORCE AND HUMAN BODY HARDNESS AIMED TO MEDICAL APPLICATIONS** **253**
Y. Maeda, K. Terao, T. Suzuki, F. Shimokawa, and H. Takao
Kagawa University, JAPAN

In this study, a highly sensitive tactile sensor with detection abilities of both human body hardness and frictional force is reported. Employing the new structure, hardness signal becomes less sensitive to the contact pressure, and hardness is stably measured even under an unstable contact force. Surface frictional force was successfully measured in real time. Also, shore A hardness was successfully measured in the range from 1HS to 54HS corresponding to the human organs.

11:30 **6-AXIS FORCE/TORQUE SENSOR FOR SPIKE PINS OF SPORTS SHOES** **257**
H. Ishido, H. Takahashi, A. Nakai, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on the method of force measurement of spike pins for sports shoes. It is important to measure force acting on spike pins, because they are related to the increase of GRF (ground reaction force) in running. We fabricated a $2 \times 2 \times 0.3$ mm^3 size 6-axis force/torque sensor chip that can be embedded in spike pins. The sensor chip consists of 6 straight piezo-resistive beams. We calibrated the spike-pin-shaped sensor, and confirmed that 6-axis force/torque was able to be detected.

11:45 **Award Ceremony**

12:00 **IEEE MEMS 2015 Conference Adjourns**

Poster/Oral Presentations

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

Generic MEMS and Nanotechnologies

Generic MEMS and NEMS Manufacturing Techniques

We present a novel method to form three-dimensional (3D) micro-scale electrical devices by using 3D printing and a liquid-metal-filling technique. Various RF passive components including inductors, capacitors and resistors are fabricated and characterized as proof-of-concepts. This technique establishes an innovative way to form arbitrary 3D structures with highly efficient, labor-saving metallization process.

We report a new method to fabricate multilayer interconnection without wet or dry etching or deposition of insulating layers. Electrical connections are completed by merely depositing metal layers and anodizing them after lithographically defining a photoresist. Without the need to etch metal layers or deposit and pattern insulation layers, the overall process is simple, cheap, safe, and of low temperature.

We develop a novel and simple process device based on the atmospheric pressure air microplasma jet for the selective etching of parylene-C film. The main feature of this process device is that it can be easily integrated with roll-to-roll systems for large-scale manufacturing of flexible electronic devices due to its operating at ambient conditions. In order to realize the selective etching, a quartz glass microtube (100 μm I.D) is employed to fabricate the microplasma jet source.

This study presents an electroplated stencil reinforced with arch structures and a surrounding buffer reservoir for printing conductive paste of fine and long lines. The developed reinforced stencil successfully solves the problems came with the conventional stencil structure including limited printable line width and ease of facture. This work presents a novel process for fabricating a thin yet robust MEMS-based stencil by using two AZ4620 layers and one SU-8 layer as the electroplating molds.

We report single crystalline 4H-SiC MEMS with homoepitaxial n-p-n structure. Single crystalline fully exploits the superior material properties of SiC for operations in harsh environments. The n-p-n structure makes electrostatic actuation applicable which is essentially important for applications of resonators and actuators to sensor devices, and extends the capability of monolithic integration between SiC MEMS and electronic devices/circuits with n-p-n configurations such as BJTs and MOSFETs.

We present a novel and highly efficient wafer-level batch transfer process for populating silicon (Si) wafers with distributed islands of 1 micrometer-thick single-crystalline germanium (Ge). This is achieved by transferring Ge from a Si donor wafer containing thick Ge dies to a Si target wafer by adhesive wafer bonding and subsequent low-temperature Ge exfoliation.

This paper demonstrates the fabrication of 3-D microstructures in 4H-silicon carbide (4H-SiC) substrates for the first time using a plasma etch and multilayer etch masks. This process was developed using a variety of thin film masks and demonstrated SiC etch rates as high as ~1 µm/min, a SiC:Ni etch selectivity as high as 60:1, and aspect ratio dependent etch characteristics. The microfabrication of complex SiC microstructures (mechanical gears, Lego®-like bricks, and poker chips) is presented.

We report an extension of a recently demonstrated technique to fabricate NEMS based on sidewall transfer lithography (STL). The process uses two STL steps to form intersecting nanoscale features such as suspension beams, breaking an important restriction of single-layer STL NEMS. The new process only requires optical lithography, making it suitable for low-cost mass parallel fabrication for complex NEMS on wafer scale. Current nanoscale features have a width of 100 nm and 50:1 aspect ratio.

This paper presents a new microfabrication method for surface ion traps and experimental results with trapped ions. Using SiO_2 timed-etch method or copper sacrificial layer method, the ion trap chips with electrode overhang structures are fabricated. The ion trap chips are implemented in a 1 x 10^{-11} Torr vacuum environment for ion trapping experiments. Successful results in trapping strings of $^{171}Yb^+$ and $^{174}Yb^+$ ions as well as manipulating $^{171}Yb^+$ ions for qubit operation are demonstrated.

We develop a novel post-release stress engineering process to provide an out-of-plane curvature to initially plane MEMS microstructures. The stressor layer(Chromium) is applied post-release and patterned appropriately with help of in-situ fabricated reconfigurable shadow masks. In addition to avoiding photolithography step, these shadow masks also provide variable coverage for underlying structures. A modified model is also shown which considers non-uniform Cr thickness on released structures.

We propose the use of the entropic effect (the depletion volume effect) for the self-assembly of microcomponents. When the solution contains macromolecule at relatively high concentration, microcomponents formed assembled structures. The bonding energy is not originated from the surface; it is generated by increasing the translational entropy of macromolecules in the solution. We expect that use of the depletion volume effect promotes the search of the global free-energy minima in the system by avoiding being trapped to the local minima in the self-assembly process.

We present a generic three-dimensional (3-D) integration method to fabricate suspended single-crystalline silicon (SCS) MEMS arrays on CMOS. This method is applicable to a large variety of SCS MEMS including accelerometers, gyroscopes, micromirrors, RF MEMS switches, and resonators. Key challenges including fabrication process, mechanical reliability, and residue stress induced deflection have been addressed.

We propose a trajectory control method for a MEMS falling object. The MEMS falling object is consisted of two units, an autorotation part and a non-rotation part. By using large falling objects, aerodynamics of the falling object was characterized. Then the MEMS falling object was designed considering with aerodynamics. The MEMS falling object was fabricated with a method of the SU-8 multi-layer structure. A MEMS autorotation part was fabricated and it rotated successfully in the wind-tunnel.

We report on the fabrication of carbon nanotube transistors designed as process control monitors for applications such as gas and pressure sensing. We demonstrate the concept for an integration process used for gas sensor fabrication on a 100 mm wafer. Our analysis on 4463 (including 2702 semiconducting) devices allows the extraction of distributions of threshold voltage, minimum device resistance, hysteresis width, process yield and wafer uniformity data on a 100 mm wafer.

Manufacturing for Bio- and Medical MEMS and Microfluidics

We introduce a batch fabrication technique for a mixed-scale monolithic carbon mold producing a mixed-scale PDMS channel. A SU-8 structure fabricated by UV lithography was converted to a carbon structure trough the pyrolysis. The carbon mold dimension could be easily controlled from micrometer-scale to nanometer-scale when the pyrolysis accompanies enormous volume reduction. The mixed-scale PDMS channel network has a functionality for the nanochannel electroporation (NEP) without roof collapse.

We report a novel, simple and time-saving lithography-free approach for fabricating patternable nanopillars. The key technique of the approach is to introduce a gap by covering it with a cap, which contains through holes and the material on its lower surface has a similar etching rate with the substrate. By adjusting sizes and profiles of the perforations, nanopillars with desirable patterns can be obtained. Thus a new way for fabricating microfluidic SERS devices is further developed.

We develop a shrink-induced grapheme sensor for label-free biomolecule detection. While Enzyme-linked immunosorbent assay (ELISA) is the most popular method to detect specific proteins in the current medicine, label-free biosensors have attracted great attention due to simplicity and ease of use. The sensor described in this work demonstrates the ability to detect alpha-fetoproteins (AFP), one of the most important tumor markers associated with liver cancer and ovarian cancer.

We develop a new technique for patterning functionalization layers on substrates with high topography. The method is based on a parylene-C template shaped by a structured, sacrificial photoresist layer and attached to the substrate where functionalization is not intended. We successfully demonstrate the technique with the guided growth of PC12 cells on honeycomb-shaped protein patterns on micropillars and microwells.

Wicking and particle separation are two required capabilities for many microfluidics and lab-on-a-chip devices, but they often require multiple materials and structures (e.g., paper, polymer filters) which are difficult to integrate with established microfabrication techniques and materials. In this work, we combine both properties into a single glass platform with a straightforward and economical fabrication process. By laser machining soda lime glass with a specific power and laser speed, we create channels defined by an array of micro cracks (3–4 μm) which provide particle separation properties and simultaneously enable rapid liquid transport (up to 24.2 mm/s) as a result of capillary forces from the crevices and laser-induced surface hydrophilization.

This paper describes a method to arrange liposomes into organized structures with biochemical binding of avidin biotin complex, inspired by the biological anchoring junction. This approach enhances the stability of the liposome structure, which would provide an improved model for a liposome-based tissue in synthetic biology.

We develop a novel Magnesium-embedded cell filter for Circulating Tumor Cell (CTC) capture, release and isolation. The new and novel feature is the use of thin-film Mg to release the captured CTCs based on the fact that any Cl- containing culture medium can readily etch Mg away. The releasing and the isolation of each individual CTC are demonstrated. The top PA-C filter pieces break apart from the bottom after Mg completely dissolves, enabling captured CTCs to detach from the filter.

A micro fluidic chamber with 178 nm-thick thin Si windows on a micro channel has been developed. Using this windows, the aquatic structure inside of the channel has been monitored by scanning electron microscopy. Secondary electrons from a sample in the channel are able to be detected in vacuum with an acceleration voltage of 15 kV. The micro fluidic chamber is possibly applied to cell imaging via the single crystal Si thin window in vacuum using magnetic resonance force microscopy.

This paper demonstrates a simple fabrication process of polydimethylsiloxane(PDMS) circular cross section microfluidic channels by using a PDMS master mold and thermal air molding. Based on this technique, circular cross section microchannel can be easily produced in a wide range of dimensions from 10μm to 500μm with simple bench top equipment. This technique can create perfect circular channels without any plasma activated bonding and alignment process. We can also apply this technique to fabricate micro concaves for spheroid culture, micro nozzles for droplet generation, and micro patch clamps for cell immobilization.

We constructed a skin-equivalent on a curved surface. The skin-equivalent consists of not only the epidermis/dermis but also perfusable channels. We embedded an anchoring structure in our device to prevent horizontal contraction of the tissue. Owing to perfusion, we can culture epidermis at the air-liquid interface for cornification. Our method enables the skin-equivalent construction on a curved surface that is necessary for the construction of 3D skin surface such as biohybrid robots' skin.

This paper reports for the first time the use of TFT (Thin Film Transistor) technology of display panels for biological cells electrical manipulation. This technology allows to have high density distributed transparent micro-electrodes, independently controllable, covering centimeter-size glass substrates. This technology is much superior to usual micro-technology used for Multielectrode Arrays (MEAs).The chosen application, to demonstrate the capability of such technology, is dielectrophoresis.

Materials for MEMS and NEMS

We reported a MEMS fabrication compatible, damage free method for in-process 3D morphology reconstruction of high aspect ratio microstructure. As a novel morphology tracer, Parylene C thin film was conformally deposited onto the structure and annealed at high temperature under N2. By scanning with a confocal microscopy, 3D morphology of the microstructure was reconstructed from the autofluorescence information of Parylene C.

We propose a new extraction method of gauge factor of nanowires for in-line monitoring of this parameter and piezoresistive material properties comparisons. Unlike conventional techniques which are destructive and suffer from reproducibility issues, this method allows a direct measurement of the GF locally at the nanoscale and at the wafer level. GFs have been reliably measured on a wide range of silicon-based NEMS resonators with different designs,crystalline structure and doping level.

Packaging and Assembly

This study presents a PDMS (Polydimethylsiloxane) fiber integrated with multi-devices scheme using stretchable electroplating copper spring. Each device was located on the node and embedded in PDMS-fiber. Thus, devices are mechanically connected by PDMS-fiber and electrically connected by inner stretchable spring. Advantages of this approach: (1) length magnification by stretchable spring; (2) thicker stretchable spring embedded in PDMS provides well mechanical/electrical characteristics; (3) node acts as a hub for devices implementation and integration; (4) partially stretched spring could reduce the resistance variation by external loads.

We develop an innovative, uncomplicated and inexpensive method based on a glass reflow process to fabricate void-free glass-embedded passives for 3D MEMS packaging. The embedded structures include cylindrical, annular cylindrical and coaxial cylindrical conductive through-holes, plate and coaxial torus trench capacitors, square spiral, circular spiral and folding type trench inductors, and filters. These void-free structures have vertical and smooth sidewall, large signal pathways.

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

During the deformability test of Red Blood Cell (RBC) by utilizing a micro fluidic channel, we found an interesting phenomenon where some RBCs behave just like elastic pinball. This phenomenon is called "Cell Pinball". Through visualization, we found that the RBC being in cell pinball mode rotates around the perpendicular axis to the flow line and its direction is one-to-one relationship with the moving direction. We also found that the rotating axis exists slightly behind the center of gravity

We develop a monolithic microfluidic device capable of on-chip sample preparation for complete blood count from raw blood. For the first time, on-chip sample processing (e.g. dilution, lysis, and filtration) and downstream measurements were fully integrated to enable sample preparation and single cell analysis from raw blood on a single device. RBC and WBC concentration, WBC differential, mean corpuscular volume and cell distribution width are determined by electrical impedance measurements.

We developed the microwell device for measurement of membrane transport for single adherent cells. When cells were cultured on the microwells with ~10 μm opening, they spread to form the closed picoliter space. Thus,molecules exported from cells accumulate in such a space and be detected by imaging. We show that, by employing horizontal microwell design,materials exported from the cell membrane can be visualized. Efflux of the cancer drug transported by the multidrug resistance protein was tested.

We develop a method for creating arrays of individually addressable cell seeded calcium alginate hydrogels for 3D cell culture using electrowetting on dielectric (EWOD) digital microfluidics (DMF). Combined with EWOD DMF's multiplexing abilities, we demonstrate how a single integrated DMF device is capable of forming cell seeded alginate hydrogels, generating different concentrations of chemicals and delivering these to different gels to observe the effect of chemical concentrations on 3D tissue

We develop an electrochemical microfluidic paper-based analytical device, featuring a working electrode decorated with semiconductor zinc oxide nanowires (ZnO NWs), for glucose detection in human serum. The integration of ZnO NWs into the paper device is realized via facile, low-cost hydrothermal synthesis of ZnO NWs on paper, and leads to superior analytical performance (high sensitivity and low limit of detection) and enhanced device stability (by removing light-sensitive electron mediators).

A capillary driven lab on a chip system using dissolvable films for on-chip reagent storage, volume metering and timing of a multi-step sequence is demonstrated. Activation of the chip with a single liquid causes rehydration of four different reagents stored in dissolvable polymer layers and sequential release of the reagents to a common reaction zone. This capillary driven, single-liquid triggered multi-reagent sequence can potentially be used for multi-step PoC immunoassays.

We report demonstration of on-chip tau detection based on difference of landing rate and binding density of microtubules on kinesin surface. Tau detection device comprises of a MT reservoir, channel and collector region with overhung structures. We assayed MTs decorated with three tau types in the kinesin coated device. Since the increase of fluorescent intensity at collector regions reflected the type of tau decorated on MTs, thus by measuring FI we distinguish wild 3R, 4R and P301L mutant tau.

We present a systematic study of the Capillary number effect on the capture efficiency of cancer cells on a composite microfluidic filtration chip. A phase diagram for the capture efficiency of microfiltration chips as a function of normalized cell diameter and Capillary number has been obtained, which will be useful for the designing the next generation of microfiltration devices for isolating circulating tumor cells.

Materials for Bio- and Medical MEMS and Microfluidics

This paper reports the culturing and expansion of mouse induced pluripotent stem cells (iPSCs) in hydrogel core-shell microfibers; the core consists of iPSCs with or without extracellular matrix (ECM) proteins, and the shell is composed of calcium alginate. We revealed mouse iPSCs cultured in the micro-scale space with ECM proteins sustain their pluriotency efficiently. This 3D culture system may be useful tool to expand iPSCs for clinical use.

In this work, collagen nanofibers are self-aligned in fully 2-dimensional substrates by applying cyclic stretch during the gelation process of collagen solution, and the fabricated collagen sheet induce the alignment of cells without any mechanical force within the cultivation period. We believe that our new aligned collagen sheet contributes to the regenerative medicine, which needs a scaffold that has biological structures and microenvironment.

This paper reported a simple and effective process of bonding-friendly Parylene C-caulked PDMS (pcPDMS) for low-permeability required microfluidics. Parylene C was deposited into PDMS matrix at an elevated temperature (higher than 135°C) to caulk the permeable sites. The so-prepared pcPDMS can be directly bonded with oxygen plasma treatment just as pristine PDMS. SEM EDAX and Laser scanning confocal microscopy (LSCM) were introduced to characterize the Parylene C caulked status in the PDMS.

We report the multiphoton fabrication of hybrid microstructures of photoresist and chemically responsive protein hydrogel for microactuation, such as a lever and a rotary stepper.

We present, for the first time, a method for the synthesis of core-shell microparticles in a single polymerization step using two-phase droplet microfluidics. We verify the successful generation of core-shell microparticles using the novel synthesis approach.

Microfluidics and Nanofluidics

Bio and Medical MEMS
Biochemical Sensors

We propose a method for constructing fiber-type 3D tissue of human iPS-derived cardiomyocytes and quantifying its contractile force in response to the addition of drug. By culturing the cardiomyocytes in micropatterned hydrogel with anchors, we successfully obtained the fibers with aligned cardiomyocytes and fixed the fiber edges to the anchors. The contraction of aligned fibers in a single direction provides us to measure the contractile force reproducibly.

We develop a microfluidic biosensor that combines aptamer-based specific enrichment and graphene conductance-based nanosensing on a single microchip, allowing label-free, specific, and quantitative detection of small biomolecules at low concentrations via aptamer-based competitive binding assay.

We demonstrate a microliter-sized (140 µL) microbial fuel cell (MFC)-based biosensor integrated with electrochemical sensing functionality and air-bubble trap, in which microorganisms act as the sensor for toxic substances in water. The small-scale MFC biosensor (i) reduces measurement time by increasing the probability of cell attachment and biofilm formation in the micro-sized chamber and (ii) enhances sensitivity by preventing air-bubbles on the sensing surface.

We demonstrate the use of paper-based sensing platform for rapid and high-throughput characterization of microbial electricity-generating capabilities. A 48-well microbial fuel cell (MFC) array was fabricated on paper substrates, providing 48 high-throughput measurements and highly comparable performance characteristics in a reliable and reproducible manner. Within just 15 minutes, we successfully determined the electricity generation capacity of ten bacterial species with two controls.

In this study, a new microfluidic device with a new methodology for measuring field-effect-transistor (FET)-based biosensors is presented. Not only can the proposed system work in a solution with physiological salt concentration but it also detects C-reactive protein with ultra-high sensitivity in an automatic fashion. This is the first time that a FET-based biosensor can effectively and automatically detect proteins in a physiological salt concentration without decreasing the sensitivity.

We introduce a fabrication and wireless chemical sensing scheme using a hydrogel/polymeric-magnet bilayer. Polymeric permanent magnets are batch fabricated/integrated on top of a hydrogel thin film. The swelling/shrinking of the hydrogel in response to chemical stimuli is remotely detected by a giant magneto resistance (GMR) sensor. The described device is the first integrated wireless hydrogel/polymeric-magnet transducer with potential applications in biomedical and environmental sensing areas

We report a method to measure contractile forces of cardiomyocytes at cellular level using microplates; pairs of microplates are connected by a flexible hinge at the center. Cardiomyocytes repeatedly contract and expand, and thereby fold the microplates at the flexible hinge. By measuring the change of the angle between folded microplates, we estimate contractile forces of cardiomyocytes. We believe that this method is a useful tool to study the dynamics of cardiomyocytes.

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

T-095 **AN IMPLANTABLE TIME OF FLIGHT FLOW SENSOR** **620**
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A micro time of flight (TOF) electrochemical impedance (EI) flow sensor was developed for characterization of in vivo flow dynamics. The transducer utilizes EI measurement between electrode pairs to monitor the passage of an electrolytically generated gas bubble within flowing solution. Biocompatible construction, low power consumption, and low profile thin film format make it ideally suited for chronic *in vivo* monitoring with immediate application in monitoring of hydrocephalus.

W-096 **APPLICATION OF PERIODIC LOADS ON CELLS FROM MAGNETIC MICROPILLAR ARRAYS IMPEDES CELLULAR MIGRATION** **624**
F. Khademolhosseini[1], C.-C. Liu[1,2], C.J. Lim[1,2], and M. Chiao[1]
[1]University of British Columbia, CANADA and [2]Child and Family Research Institute, CANADA

We conduct an experimental study on the application of active micropillar structures to control cell migration. In contrast to passive micropillar structures which cause no significant alterations in cell migration rates, active micropillar structures actuated at 1 Hz decrease cell migration rates by up to 80%. The magnetic micropillar structures presented can be actuated remotely, making them a viable candidate for the development of smart materials for tissue engineering applications in vivo.

M-097 **CELL MOTILITY REGULATION ON STEPPED MICRO PILLAR ARRAY DEVICE (SMPAD) WITH DISCRETE STIFFNESS GRADIENT** **628**
S. Lee, B. Saha, and J. Lee
Seoul National University, SOUTH KOREA

We report a micro pillar array device that provides discrete rigidity gradient to a cell with constant focal adhesion area. This goal is achieved through the use of "stepped" micro pillar array device (SMPAD) whose top area in contact with a cell is kept constant while the diameter of pillar bodies vary for variable mechanical stiffness. We show manipulating cell behavior using this simple, artificial platform that produces a pure physical stimulus.

T-098 **FIBERED REFLECTIVE MICRO OBJECTIVES FOR MINIATURIZED SCANNING CONFOCAL FLUORESCENCE MICROSCOPY** **632**
S. Xie[1], E. Shaffer[1], L. Jacot-Descombes[1], D. Joss[1], B. Rachet[1], D. Kosanic[2], and J. Brugger[1]
[1]École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND and
[2]SamanTree Technologies AG, SWITZERLAND

We report on a design, fabrication and characterization of a novel micro-optical system for imaging based on a miniaturized reflective objective, which is fabricated by combing two additive micro-fabrication techniques, inkjet printing to create the spherical mirror shape and stencil lithography for local metal deposition. This novel fabrication process produces reflective micro-objectives of different optical properties tailored for targeted bio-imaging application.

W-099 **FLEXIBLE SILICON-POLYMER NEURAL PROBE RIGIDIFIED BY DISSOLVABLE INSERTION VEHICLE FOR HIGH-RESOLUTION NEURAL RECORDING WITH IMPROVED DURATION** **636**
F. Barz[1], P. Ruther[1], S. Takeuchi[2], and O. Paul[1]
[1]University of Freiburg-IMTEK, GERMANY and [2]University of Tokyo, JAPAN

We present a novel concept for flexible, intracortical neural probes delivered into the neural tissue by bio-dissolvable insertion vehicles. A completely implantable, silicon-based electrode array constitutes the probe tip. It is interfaced by a flexible ribbon cable that reduces stiffness and volume of the probe system. This is expected to increase the longevity of high resolution neural recording. The probes are encased in the insertion vehicles by means of a centrifuge-based molding process.

M-100 **FLOW SPEED MEASUREMENT WITH DOPPLER EFFECT USING ULTRASONIC RECEIVER FOR SMALL-SIZED SMART CATHETER** **640**
R. Matsui, Y. Takei, N. Minh-Dung, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We propose a wide range frequency receiver which has "liquid / piezoresistive cantilever / air" multilayer structure. This structure can measure acoustic waves from Hz to MHz order frequency because the cantilever vibrates obeying the surface waves on liquid. Experimental results demonstrated that our device can measure flow speed in a cylindrical pipe ranging from 6 to 25 mm/s, which is equal to blood flow speed of an arteriole, with MHz order Doppler Effect within one percent error.

T-101 **HUMAN ADIPOSE-DERIVED STEM CELL FIBER FOR BREAST RECONSTRUCTION** **643**
A.Y. Hsiao[1], T. Okitsu[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and [2]Japan Science and Technology Agency (JST), JAPAN

We describe the construction and differentiation of human adipose-derived stem cell (ADSC) fibers into the adipocyte lineage for breast reconstruction. Human ADSCs cultured as fiber-shaped constructs were induced for adipogenic differentiation. Accumulation of lipid droplets of significant size was observed in the cells, and viability assay showed that most of the cells were alive. These findings suggest the use of ADSC fibers as a promising approach for breast reconstruction.

W-102 **MEASURING THE PROPAGATING TEETH VIBRATION OF HUMAN CHEWING** **646**
C. Suzuki, Y. Takei, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We measured the propagation waves of teeth's vibrations when chewing food. Human senses texture of chewing food by teeth's vibrations. Therefore, measuring the teeth's vibrations will allow us to quantify the food texture which human actually senses. We made the acoustic sensor that is small enough to be attached to teeth. For sensor evaluation, we conducted the rice cracker chewing test with our sensor attached to the real scale 3D jaw model, and propagation waves of around 500Hz are observed.

There have been increasing demands for stretchable and high-sensitivity sensors for use in structure health monitoring, human motion capture, sport performance monitoring and rehabilitation. Here, we present a novel, highly stretchable, self-powered and ultra-sensitive strain sensor based on piezoelectric PVDF electrospun nanofiber. Complete studies on mechanical and piezoelectric characteristics of the single PVDF nanofiber are presented.

Here we report on our recent development of high-density neural probes for high resolution, multiscale electrophysiology. Our 64-channel hybrid silicon-parylene probes provide at least three-fold better spatiotemporal resolution compared to the state of the art and minimize the tethering force on the brain tissue by two orders of magnitude. We demonstrate, for the first time, the design of ultracompact polymer optical waveguides that can be monolithically integrated with our neural probes.

We report a heterogeneous integration of vertically aligned extracellular microscale silicon (Si)-probe arrays/(111) with MOSFET amplifiers/(100), by IC processes and subsequent vapor–liquid–solid (VLS) growth of Si-probes. To improve the extracellular recording capability of the microprobe with a high impedance of > 1 Mohm at 1 kHz, here we integrated (100)-Si source follower buffer amplifiers by ~700 degree VLS growth compatible (100)-Si MOSFET technology.

All published adult zebrafish ECG recorded to this date have been done acutely with anesthetized fish. This work presents, for the first time a wearable flexible parylene (PA) micro-electrode that monitors the Adult Zebrafish ECG in longer term. We show here the design, fabrication and testing of the flexible electrode along with a micro-molded ultrasoft density adjusted silicone jacket, allowing ECG recording to be carried under water, in the fish's natural habitat with no need for anesthesia.

Nanobiotechnology

We report a method to control the velocity of gliding microtubules by light irradiance and a gold pattern. The irradiance controlled a temperature in the assay condition by heat transfer from the gold pattern. The result showed that the velocity of microtubule increased approximately 1.8 folds from initial velocity at the irradiance of 13.5 W/cm2 in the gold pattern. This is first demonstration to perform the control and the switching velocity on the patterned gold surface.

This work describes the first exploration of directly culturing and measuring breast cancer cells, at single-cell level, by using silicon carbide (SiC) microdisk resonators. Enabled by the superior biocompatibility of SiC, individual breast cancer cells are observed to attach and spread on device surface within 3hrs of culturing. Multimode responses of SiC microdisk resonators (20-30μm in diameters) to single MDA-MB-231 cell loading are characterized by taking advantage of their robust high-frequency multimodality in water and biological solutions.

This paper reports a microfluidic platform for studying physical mechanisms of plant root at early growth stage. To measure driving force of root growth precisely and quantitatively, we developed a silicon microchannel device integrated with force displacement sensor which mimics a barrier in soil. By using developed microsystem, we successfully measured the driving forces of root growth in three kinds of plants including Arabidopsis thaliana known as model organism.

Physical Sensors

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

This paper reports a cantilever with comb structure, mimicking a bristled wing of thrips which acts as a continuous membrane wing because of the effects of low Reynolds numbers. The comb structures are formed at the edges of the cantilever and its surrounding. When differential pressure is applied to the cantilever, both comb structures act as airflow suppression through the gap. The leakage of the fabricated comb cantilever was smaller than the normal cantilever.

We report an airflow wall shear stress sensor consisting of a plate and surrounding membrane with narrow gap. The plate is supported by side-wall doped beams, which can detect the horizontal deformation of the plate due to airflow wall shear stress. The sensor structure does not disturb target airflow circumstance because of flat surface, and measures shear stress directly. Wind tunnel test shows our sensor was able to measure laminar airflow shear stress with the resolution under 1.0 Pa.

We develop novel designed and fabricated micro airflow sensors based on the hot-wire sensing principle, i.e. gas cooling of electrically heated resistance. With three micro Ti/Pt hot-wire components fabricated on a glass tube in five degrees of freedom (5DOF) UV lithography system with multi-layer alignment, the sensors on a cylindrical base have demonstrated high sensitivity, fast response time and ability to detect wind speed and direction.

We realized piezoelectrically self-actuated self-sensing cantilever sensors for liquid monitoring purposes excited in higher roof tile-shaped modes. This advanced class of vibration modes supports very high Q-factors in liquid media and very high volume strain values which result in combination with an optimized electrode design in very high strain related conductance peaks. Therefore, precise fluid property measurements even for highly viscous liquids like D500 (~ 430 cP) are feasible.

A novel pressure sensing technique is proposed here for measuring local pressure inside a microfluidic device. By the proposed method, the local pressure can be directly "seen" without any wire foils but simply microbeads patterns. The experimental results show that microbeads pattern is stable and repeatable where the variation for the same given pressure is less than 1%. The correlation between the pressure obtained from the proposed method and a commercial pressure connected outside is 0.995.

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

This paper reports the first 3-axis (normal and shear force) all-elastomer capacitive MEMS tactile sensor. Sensor area is 1.5 x 1.5 mm and uses vertical capacitive structures with 20 µm electrode gaps to achieve high shear force sensitivities of 8.8 fF/N, shear force resolutions of 50 mN, and shear range up to 700 mN; this aligns with the developed finite element prediction. Fabrication utilizes a simple elastomer molding process with reusable DRIE silicon molds for inexpensive manufacturing.

We propose the 6-axis force-torque sensor chip composed of 16 piezoresistive beams whose area, 2 mm square in size, is one-third of that of the state of the art, which will enhance the mounting density of sensor array and also reduce the cost in case of volume production. This paper will show the design, a part of the fabrication process in MNOIC, 8-inch MEMS foundry in Japan, especially ion doping method by oblique ion implantation, the calibration method and experimental results.

We report the highest resolution achieved with a single-chip atomic force microscope (sc-AFM). Images of a 20nm AFM calibration standard were obtained to show, for the first time, that a single-chip instrument may obtain a vertical resolution comparable to state-of-the-art instruments at a minuscule fraction of the size (1/1,000,000) and cost (1/1000). The reported performance represents a four-fold improvement in resolution when compared to previously reported sc-AFMs.

We developed a tool for orthodontic research and education, namely an instrumented tooth (IT) that allows measuring all six applied force and moment components. The core component is an 11.6-mm-high and 3.5-mm-diameter sensor module based on a CMOS stress sensor chip sandwiched between two metal pins. In the IT, the sensor module constitutes the root. The stiff and robust sensor module is capable of measuring orthodontically relevant forces up to 60 N and moments up to 10 Ncm in all directions.

This paper reports an up to 95.9% angle detection accuracy enhancement for capacitive tactile sensors, which entails asymmetric and intentionally shifted electrodes. The asymmetric electrodes containing one fan- and one square-shape in capacitors reduced unexpected and rotational-shift induced errors, by keeping the same overlap area of the electrodes. The minimal angle detection resolution was improved from 5.8 to 0.3-degree, making the tactile sensor practical and reliable in artificial skins.

We developed ultra-stretchable, flexible and very soft conductors based on the carbon nanotubes (CNTs)-siliconrubber (Ecoflex®) nanocomposite thin films. Highly stretchable conductors were utilized as skin-mountable and wearable strain sensors. The resistance of the CNTs-Ecoflex nanocomposite thin film was fully recovered undercyclic loading/unloading for strains as large as 510%. Finally, motion detection of finger and wrist joints was conducted using CNTs-Ecoflex nanocomposite thin film.

We have developed a miniaturized laser Doppler velocimeter (LDV), designed for use as a slip sensor in the control of a robot hand. This sensor is only 1/10,000th of the volume of commercial LDVs, which enables the sensor to be attached to a robot hand. Our LDV was able to detect scattering objects moving at velocities ranging from 10 μm/s to 20,000 μm/s. The output of this sensor is independent of the type of material measured, which included aluminum, cardboard, or rough-surface black plastic.

We report a new design concept of a micromechanical cantilever system incorporating the internal resonance during dynamic mode AFM. The passive amplification of nth harmonic triggered through the mechanism of 1:n internal resonance enables AFM to utilize multiple harmonics. Detailed theoretical and experimental studies of the proposed design demonstrate that the multi-harmonic AFM is capable of simultaneous topography and compositional mapping with 10-fold enhanced sensitivity.

Conventional flexible tactile sensors detect the bending of a substrate in addition to a tactile pressure, and that is the one of bottlenecks to realize stable operation of flexible device such as an artificial electronic skin. To achieve high sensitivity, a cantilever type strain sensor and a temperature sensor in a flexible substrate are developed by using a fully printed method.

We have designed and implemented a sensory skin that monitors in real time finger flexure (3 sensors per finger) of a user's hand. Compared to current technologies, the electronic skin is made entirely of stretchable materials integrating silicone rubber, low resistivity liquid metal interconnects and highly strain sensitive, microstructured thin metal films. We incorporated the skin on a textile glove and demonstrated its function as an interface for finger motion detection.

Gas and Chemical Sensors

We develop a suspended ZnO nanowire forest as a highly sensitive gas sensor. The nanowires were grown selectively on a suspended single glassy carbon nanowire using hydrothermal method so that the detrimental effects from the substrate inclusive of contamination, stagnant layer and limited mass transfer could be alleviated. The novel geometry of the radially grown ZnO nanowires resembling burs of a chestnut is expected to enhance the gas sensing capability because of enhanced mass transfer.

This paper reports a high-sensitivity and high-speed capacitive humidity sensor with resorcinol-formaldehyde (RF) aerogel fill-in. A novel capacitive vertical parallel-plate (VPP) array topology was designed and implemented based on standard TSMC 0.18µm CMOS process and subsequent in-house post-processes.

This paper reports the first implementation of a highly sensitive micro helium discharge photoionization detector in a silicon-glass architecture and its monolithic integration with a separation column. The new detector requires a two-mask fabrication process, is universal, non-destructive, low power (<5mW), and insensitive to flow and temperature variations. It has yielded a minimum detection limit of ~10pg which is on par with the widely used destructive flame ionization detector.

An implantable fiber ATR sensor enhanced by silver nanoparticles on circumferential surface was presented for continuous glucose monitoring. U-shaped structure was addressed to increase optical length for sensitivity enhancement. A novel method to fabricate silver nanoparticles on circumferential surface of fiber sensor based on chemical reduction of its silver halide material directly without any preliminary nanoparticles synthesis and the following covalent bond or self-assembly was proposed.

The paper reports a novel H2S sensing-effect for intrinsic ZnO nanowires (NWs) chemiresistive sensor. Herein50nm-diameter ZnO-NWs are found and verified to be sulfurized by H2S to form ZnS that can be latterlydesulfurized back to ZnO by ambient oxygen, which is different from conventional ZnO sensing-mechanism where resistance of semiconductor ZnO is changed via electron depletion-layer variation by surface adsorbed ambientoxygen.The ZnO-NWs have realized detection to 50ppb H2S.

We fabricated flexible humidity sensor which responds 10 times faster than commercial CMOS humidity sensor. Our sensor is based on Ionic-Gel-coated Fabric (IG-Fabric). IG-Fabric has wide surface area and high gas permeability so that gases can be easily absorbed and detached. As a demonstration, we fabricate flu-mask-type IG-fabric humidity sensor and measured the relative humidity change caused by human breath.

Imitating on-site liquid-droplet analysis/assay with test-papers, a novel tri-beam structure dog-bone resonator is proposed for low-cost quick detection of trace-amount biochemical liquid sample. Effective depression to signal feed-through effect is realized by independent piezoresistive readout with the specifically designed central beam, thereby, the new tri-beam resonator exhibits high-Q resonance of extension-mode in liquid and liquid-droplet detection of ppb-level mercury ion in water.

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

This paper presents, for the first time, the design and implementation of a dynamically mode-matched high-frequency piezoelectric silicon disk gyroscope utilizing a unique pair of in-plane flexural gyroscopic modes. A linear bidirectional frequency tuning scheme compatible with piezo-only transduction is introduced to achieve dynamic mode-matching via electromechanical feedback. A fabricated AlN-on-Silicon solid disk gyroscope was frequency tuned by 500 ppm to yield a sensitivity of 410 pA/°/s.

In this work, an oxide-refill process is used to realize passive TCF compensation for silicon MEMS resonators as well as integrated thermal isolation structures. The technology enables fabrication of a low-power ovenized micro-platform on which multiple MEMS devices can be integrated. Intrinsic frequency drifts of two MEMS resonators are utilized for temperature sensing, and closed-loop oven control is realized by phase-locking two MEMS oscillators at a specific temperature.

We report an approach to suppress anchor loss in thin-film piezoelectric-on-silicon MEMS resonators by patterning 2D phononic crystals (PnCs) externally on the anchors. According to our measurements, adding the PnCs helps to double the unloaded quality factor (Q), while reducing the motional resistance by half. The results suggest significant reduction of acoustic leakage to the substrate by the PnCs.

We report, for the first time, a 1.5mm batch-fabricated polycrystalline diamond Cylindrical Resonator (CR) for gyroscope applications. A quality factor (Q) of 313,100 is measured at the 23kHz 2theta elliptical wineglass modes, producing a ring-down time of 4.32seconds. Annealing CRs at 700°C in a nitrogen atmosphere improved Q from 75,000 to over 300,000 with an excellent frequency mismatch of 3Hz (130ppm) between the 2theta degenerate wineglass modes without applying any tuning voltage.

The paper reports on design, fabrication, and characterization of micromachined spherical resonators with integrated high-aspect ratio silicon electrodes. The electrical connection of the spherical, non-conductive micromechanical resonator is possible thanks to Atomic Layer Deposition (ALD) of Tungsten inside the shell. Operating frequencies in the range of MHz have been measured providing one of the highest frequencies in spherical resonator shells up to date.

We demonstrates an inside-encapsulation ovenization method for the temperature compensation of Lamé-mode epi-sealed silicon resonators. With this method, the square Lamé-mode resonator itself acts both as a thermometer and a heater, which allows for simultaneous in situ sensing and control of the operating temperature. In this device, only the resonating element is heated, minimizing the time constant and the heating power.

This paper presents stress effects on a vacuum packaged MEMS gyroscope zero rate output (ZRO), scale factor (SF), and resonance frequencies by using on-chip environmental sensors measuring the temperature and stress separately, for the first time. Environmental sensors comprise released SOI-silicon resistors. Experimental results show that a system model can be established to compensate the gyroscope ZRO using the environmental sensor outputs.

Manufacturing Techniques for Physical Sensors

We present a facile, low-cost approach to fabricate highly porous conductive carbon patterns on elastomeric substrates using laser carbonization of polyimide and subsequent transfer of locally pyrolyzed features onto a PDMS sheet. Using this technique, we fabricated stretchable interconnects and an array of piezoresistive tactile sensors. Characterizations of the stretchable patterns showed linear sensitivities of 8.912kΩ/ε% and 518Ω/N to strain and normal force, respectively.

We report a new fabrication technology for making complete wineglass resonators through forming thin fused silica (FS) shell resonators integrated with arbitrarily sized FS solid stems through a simultaneous process of micro blow-torching and micro welding. The fabricated wineglass resonator operates at 22.6 kHz with long ring down time (35.9 s) and high quality factor (2.55 million). The ring down time and Q are the best reported values for micro FS devices.

We report for the first time a highly sensitive paper-based tactile sensor using laminated graphite drawn on paper.Due to a high gauge factor of 26.2, as well as its excellent humidity-resistance, plastic-laminated graphite-on-paper has a high potential for mechanical sensors. Additionally, the plastic lamination combined with the laser cutting technique proposed in this study will bring a step forward to the mass production of cleanroom-free fabrication and low-cost MEMS devices.

This paper presents a surface structuring method for a closed micro channel. Because fine photolithography can only be made on a flat surface, it has been difficult to make complicated patterns on the inside walls of non-planar microfluidic channels. Here, we demonstrated that micro-scale hierarchical patterns can be formed on the inside walls of the micro channel simply by depositing a plastic thin film in the channel and stretching the micro channel.

We present a wafer level fabrication process of the QCR load sensor that has three-layer structures; two Si-hold layers and a quartz layer. Using microfabrication and atomic diffusion bonding, the assembly process was simplified. The proposed sensor is easily integrated in outer package and design the measurement range. We succeeded in multi-biosignals (heartbeat, body motion) detection using fabricated QCR sensor and outer case.

A process to make self-curved diaphragms by engineering residual stress in thin films has been developed to construct highly responsive piezoelectric micromachined ultrasonic transducers (pMUT). This process enables high device fill-factor to achieve better than 95% wafer utilization with controlled formation of curved membranes.

Thermocouples on the trench sidewall fronting on the flowing material are fabricated by applying 3D photolithography. The first novelty is the fabrication technique to realize the device. And, the fabricated thermocouple is confirmed to work having the advantage sensing the flow temperature directly. The metals on the sidewall do not make the shadow allowing the observation inside the microchannel using the optical microscope.

To realize MEMS sensors in the flexible fashion, we proposed to apply a Cu On Polyimide (COP) substrate as a starting material, and introduced a sacrificial etching for producing a cavity and an electrical feed through into the COP substrate. We also newly introduced a vacuum cavity realizing high thermal isolation in flexible thermal sensor, for the first time.

Materials for Physical Sensors

We present a structure and a method for the characterization of impact and adhesion between MEMS moving and fixed parts: the focus is to monitor an inertial mass colliding with a stopper. From the measurements we evaluate the energy balance during impacts. The work analyzes the adhesion evolution after a number of collisions comparable to a 5-year operation. Results show growing and stabilizing adhesion forces of 170 nN. We also show the possibility to change and track the impact kinetic energy.

This work presents an in-depth study on the Q-factor of the passively temperature compensated CMOS-MEMS resonators through the collected material/experimental database and finite-element simulation. By adapting an anchor-loss-free double-ended tuning fork (DETF) resonator design, the intrinsic material loss is expected to be the major loss mechanism in CMOS-MEMS resonators that limits the maximum Q-factor below 3,400 at the frequency of interest (300 kHz–3 MHz).

Nanofiber forests with high hydrophilicity are reported in this work. They are fabricated from polyimide(PI) by a plasma-stripping technique. In a relative humidity range of 50%-80%, nanofiber forest-based devices have a capacity ~50% larger than those of PI-based sensors. Besides, the absorption and desorption of moisture take less time. It is expected that the performance of such devices can be improved owing to the simple and fast processes for both nanofiber forests and the humidity sensors.

We have developed robust and mechanically flexible piezoelectric paper and we have demonstrated its suitability for physical sensing at the example of a tactile sensor. This piezoelectric paper is mechanically strong and has the largest piezoelectric coefficient reported for paper to date (d_{33}=45.7□4.2 pC/N); this coefficient is comparable to that of commercially available piezoelectric polymers (polyvinylidene fluoride; PVDF d_{33}=30 pC/N).

Nanoscale Physical Sensors

This work presents an SU-8 clamped graphene nano-electro-mechanical-systems (GNEMS) accelerometer, with a SU-8 proof mass located at the center of the membrane. This GNEMS accelerometer is approximately three orders of magnitude smaller than state-of-the-art MEMS accelerometers with the graphene diameter of 3-5 μm and its proof mass diameter of 1-3 μm. The fabrication and experimental periodic calibration results show a repeatable response to a periodic input acceleration levels of ~40 gs.

We develop and model a graphene field effect transistor (GFET) nanosensor that, with a back gate provided by a high-κ solid dielectric allows analyte detection in liquid media at low gate voltages (~1.5 V). On the basis of the experimental observations and quantitative analysis, we are able to propose that the charging of the electrical double layer capacitor, instead of the surface transfer doping, is the major mechanism responsible for the pH sensing.

We report a novel graphene-based micromechanical resonant platform with resistive and mass-dependent frequency-sensing for thermal-response measurements of thin-film analytes. Resistance-temperature variation of atomically thin graphene, which also serves as the resistive heater, due to surface-interactions with spun-on analytes, and mass-sensing with silicon-nitride as structural layer provides unique dual-signal electrical and mechanical signatures of analytes.

We demonstrate the first high-frequency ultrathin MoS2 nanomechanical resonators, freely-suspended on microtrenches (~13µm wide and 14µm deep) fabricated on flexible substrates, with bendability and stretchability. Through investigations of the device resonances via optical excitation and detection, we observe multimode resonances up to ~50MHz with the PDMS substrate under different bending and stretching conditions. This platform will enable studies of strain coupling effects in 2D crystals.

Other Physical Sensors

A novel MEMS resonant sensing device consisting of three weakly coupled resonators that is ultra-sensitive to stiffness change was designed, fabricated and electrically tested. By measuring amplitude ratio change of two resonators caused by mode localization, due to a change of spring stiffness of one resonator, a 49 times improvement in sensitivity compared to a previously reported 2DoF resonator sensor, and 4 orders magnitude enhancement compared to a 1DoF resonator sensor has been achieved.

This work presents chip-scale integration of a MEMS resonant mass balance along with an aerosol impactor on a single SOI. A three mask microfabrication process has been developed to produce the main components; mass balance, impactor nozzle, and impaction micro-chamber. In addition to extreme miniaturization of a conventionally bulky setup and allowing real-time particulate mass concentration data collection, this approach addresses misalignment issues between MEMS resonators and nozzle.

Harbor seals (Phoca vitulina) are able to track their prey underwater by detecting minute water movements using their whiskers. Through comparative experimental study conducted using two MEMS sensors -one possessing a circular cylindrical haircell and the other processing a haircell with whisker-like undulations, we validate the VIV reduction of in case of whisker geometry to be 50 times lower.

This paper reports the first 3D Hall sensor with isotropic sensitivity for the three spatial components of the magnetic field. The silicon device has the shape of a hexagonal prism with symmetric sets of three contacts on its top and bottom surfaces. Sending currents obliquely across the device allows one to operate it as three mutually crossing, identical, and effectively orthogonal Hall sensors. We demonstrate a design achieving sensitivities of Sx=33.0 mV/VT, Sy=33.9 mV/VT and Sz=33.3 mV/VT.

We present a mechanism that converts in-plane to out-of-plane motion, which is fully compatible with mass-fabrication technology. The motion conversion ratio of the mechanism is constant over a wide range of motion, and this ratio can be easily tuned by adding or subtracting modular elements into the design of an otherwise unchanged planform. The mechanism enables harnessing well behaved in-plane comb-drive actuators to achieve a well behaved out-of-plane motion.

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

We have successfully demonstrated "bimorph" piezoelectric micromachined ultrasonic transducers (pMUT) with unique advantages, dramatically improving the device capabilities in the process. The bimorph pMUT utilizes two active AlN layers in a CMOS-compatible process. This innovative design is the first bimorph pMUT with two active piezoelectric layers separated by a common electrode.

MEMS for Electromagnetics

DC and Low Frequency Magnetic and Electromechanical Components and Systems

A complete 1-D magnetic field sensing system including a z-axis Lorentz force MEMS sensor and an integrated circuit (ASIC) is presented. Measurement results show an achievable sensor resolution of 220 nT·mA/√Hz with an achievable bandwidth 100 Hz. The ASIC low-noise performance does not impair the minimum detectable magnetic field, mainly limited by the MEMS thermo-mechanical noise. Dissipating only 400 μW, the circuit satisfies the consumer electronics low-power requirements.

We report the first chip-scale electrodynamic synthetic jet actuator that integrates both a coil and permanent magnet via micro-fabrication. This is achieved by integrating bonded NdFeB powder magnets into standard silicon micro-machining processes. The device has a volume of 7.5 mm x 7.5 mm x 1.1 mm and generates a fluidic jet with a peak velocity of 2.1 m/s while operating at 180 Hz with 20 mW input power. The actuator has applications in flow control and active cooling of electronic devices.

A fully-polymeric NEM relay based on a conductive polymer, Poly(3,4-Ethylenedioxythiophene):Polystyrene-Sulfonate (PEDOT:PSS), and dielectric polymers is proposed for the first time to enable flexible, transparent, ultralow-power electronics and sensors, and the first functional prototype fabricated using a five-mask low-thermal-budget process is demonstrated. Exploiting the water-absorption behavior of PEDOT:PSS, the potential use of the relay as a biochemical sensor is also demonstrated.

We report for the first time piezoelectric Quartz MEMS magnetometers based on acoustic coupling between resonance modes. The magnetic sensors employ a novel transduction scheme to upconvert the desired near-DC magnetic field signal (using the fundamental flexural mode) onto frequency modulated (FM) sidebands of the primary quartz thickness shear (TS) oscillation. First-generation devices exhibit flexural and TS resonances at 2.77kHz and 583.31MHz, respectively, and a magnetic sensitivity of 63.6V/T.

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

This paper presents a 2-axis electrothermal single-crystal-silicon (SCS) micromirror that is tilted 45° out of plane on a silicon optical bench (SiOB). The tilt of the mirror is achieved with the bending of a set of stressed bimorph beams and the stop provided by the silicon sidewall. To the best of our knowledge, this is the first demonstration of an integrated SiOB with a 2-axis SCS mirror tilted at a fixed angle without assembly.

We present a new approach to make a very compact near-eye display (NED) using only two layers of microlens arrays (MLA) working in conjunction as a magnifying lens (MLA magnifier). The purpose of the MLA magnifier is to generate a virtual image of a display, positioned within several centimeters from the eye, at optical infinity to minimize the optical disparity between the surrounding scenery and the image on the display.

We report an open-structure electrowetting-based reflective display with capacitive sensing feedback that enables an effective self-dosing of ink, high contrast, and the precise control of color level. We introduce an display that can achieve such improvements via an open structure design and a capacitive feedback system including the effective ink dosing process, off color area being ~ 8% of viewable area, and precision control of color area even under a large variation of interfacial tension.

This paper reports a liquid based tunable metamaterial which is using droplets as unit cell structures. It can function as a tunable lens array, whose focus spot can be continuously tuned, for the first time, from defocusing to sub-wavelength focusing in THz region. This work also develops a new tuning method to reconfigure the shapes of the liquid micro-droplets, which is using air pressure to expand the height of the micro channel so that the height of the droplets will be enlarged.

Manufacturing for Electromagnetic Transducers

Modeling and experimental characterization of a fabrication method for forming magnetic microstructures with complex shapes using self-assembled iron oxide (Fe3O4) magnetic nanoparticles. This method can potentially be used in roll-to-roll production of magnetic structures either patterned onto substrates or lifted off to create free-floating micromagnetic actuators.

Other Electromagnetic MEMS

The authors have proposed the novel concept of a sliding system called "AGO" (antiwear probe with a groove and oil lubrication) for probe-based archive memories. The system has been proven to have the ability to endure a meter-scale probe slide, not only in terms of electric contact stability but also in regards to the readout resolution degradation of the recorded pattern. This demonstrates the possibility of bringing probe-based memories into actual products used in data archiving, which requires limited time data access.

We develop a NEMS optomechanical VOA driven by optical gradient force. The VOA is realized via waveguide based optical directional coupler. The gap between the directional coupler is controlled via optical force driven actuator. The doubly clamped silicon beam actuator is controlled by tuning the wavelength of control light. The NEMS VOAs have merits such as small dimension, low power consumption and good capability for all optical integration as compared with conventional MEMS based fiber VOA.

Photonic Components and Systems

We present a super-regenerative optical receiver that detects on-off key modulated light input via the radiation-pressure gain of a self-sustained electro-opto-mechanical oscillator (EOMO). With oscillation amplitude a function of the intensity of light coupled into the oscillator, this device now allows data to be directly demodulated using only silicon-compatible materials, i.e., without the expensive III-V compound semiconductor materials often used in conventional optical receivers.

This paper presents a new type of acousto-optic modulator based on the conjunction of a piezoelectric contour mode resonator with a photonic whispering gallery mode resonator. The monolithic aluminum nitride device exhibits coupling of piezoelectrically-generated lateral vibrations into a traveling-wave photonic ring resonator in a fully-integrated platform with electrodes directly patterned on the resonator body. We demonstrate the optical sensing of an actuated mechanical mode at 654 MHz.

We report on the first demonstration of a spectrally selective uncooled MEMS resonant IR detector based on an ultra-thin piezoelectric resonant metamaterial. High quality factor of 1407 and electromechanical coupling coefficient of 1.9%, and spectrally selective absorption (~40%) of long wavelength infrared radiation (8.8 μm with FWHM of 1.88 μm) in an ultra-low volume device were achieved, resulting in a fast (~650 μs) and high resolution (NEP ~7 nW/rt-Hz at 200 Hz bandwidth) MEMS IR detector.

RF MEMS Components and Systems

This work reports a CMOS-MEMS Resonant-Gate Field Effect Transistor (RGFET) oscillator comprising only one single transistor.A band-to-band tunneling (BTBT) charging technique is implemented for the first time. Furthermore, this charging phenomenon on the floating gate can be well preserved for more than one day. Finally, a CMOS-MEMS RGFET self-sustained oscillator with only one active transistor is demonstrated with a decent far-from-carrier phase noise of -122 dBc/Hz.

We design, demonstrate and optimize active reflectors for enhancing the electromechanical coupling (k_t^2) and suppressing spurious modes in Laterally Vibrating Resonators (LVRs) based on X-cut ion-sliced Lithium Niobate (LN) thin film on silicon dioxide (SiO_2). Optimized active reflectors that resort to 100% metal coverage of the λ/4 extensions at the two ends of the resonant plate enable: (i) a considerable improvement of k_t^2 (up to 13%) (ii) spurious mode suppression, robustness to processing (iii) misalignment and (iv) over/under-etching.

By 3D integration of an array of 12 nominally identical AlN MEMS sub-filters with a CMOS switching matrix and application of statistical element selection to the same system, we have built a self-healing filter offering 495 unique filter responses and a tuning range of 500 kHz for both center frequency and bandwidth. This system enables correction of intrinsic, fabrication-induced variation in filter performance that would otherwise severely limit the manufacturing yield of standalone filters.

This work experimentally proves the physics of damping in this class of MEMS resonators. We first confute a previously developed theory of interfacial dissipation that assumed a stress (or Young modulus) jump between different materials and then find that damping is instead related to either interfacial dissipation due to a velocity jump or thermoelastic dissipation (TED) in the electrodes.

This paper demonstrates the feasibility of a novel fabrication approach of MEMS resonators above standard CMOS circuitry and with zero-level vacuum package. As a proof of concept a monolithical CMOS-MEMS-closed loop oscillator showing dual-clock capabilities (11.9 MHz and 24.5 MHz) is presented. These two frequencies correspond to two different resonator modes, specifically the torsional and vertical out of plane, of a paddle shaped MEMS resonator.

We present the effect of nonlinear elasticity on the coupling between different bulk modes of silicon MEMS resonators. From experimental data, the coupling has a strong dependence on the order and the shape of the coupled resonant modes, as well as the doping type/concentration, and crystal orientation, leading to a variety of complex and potential useful phenomena.

We demonstrate a radio frequency (RF) probe based on microelectromechanical systems (MEMS) design and processing technologies. The probe responds to the current needs of microelectronics requiring microwave characterization of nanoscale devices and systems having sub-micron pad sizes. The use of MEMS technologies enables the probe contact pad area dimensions to be reduced by a three orders of magnitude compared to existing commercial RF probes.

This paper reports on the design of ring-type electrostatically transduced bulk acoustic wave resonators designed for increased shock and vibration resistance. This was achieved through a 2D Phononic Crystal (PnC) support, simultaneously a mechanically strong and acoustically well-confined support. We manufactured SiGe-resonators at 137.8MHz with a Q-factor around 15k. Another feature to this design is the process tolerance of the Q-factor towards mask misalignment for the center support.

This paper reports on a novel hybrid integration concept that enables the realization of high-quality (Q) factor, low-frequency cavity resonators with well-defined capacitive-loading and variable center frequency. It is based on a silicon-micromachined spacer that is mounted on top of a conventional CNC-machined metallic cavity to functionalize the resonator's capacitance. For the first time, it is demonstrated that low-frequency resonators with micrometer-scale gaps (10s of microns), relatively large Q-factor (459-505) and tunable response (18.5%) can be constructed without the need for post-fabrication tuning. To demonstrate these benefits, a resonator assembly was designed, built and experimentally tested at UHF band and for a frequency tuning range between 1424-1711 MHz.

An array of capacitive-gap MEMS resonators with different frequencies combined with an ASIC amplifier, provides a first MEMS-based multi-frequency oscillator generating simultaneous oscillation outputs around 62MHz while employing only a single amplifier. Enabled via a softening non-linearity, amplitude is limited here for each MEMS resonator individually. Furthermore, electrical stiffness frequency tuning enables FSK modulation of the output waveform, offering a simple multichannel transmitter.

This paper presents a new Phononic Crystal (PnC) resonator design in which a tapered PnC is used to confine a 970 MHz SAW resonance in a GaN-on-Si platform. The use of a tapered PnC reflector in this work reduces the footprint of SAW resonators by >100X relative to the case of conventional metal grating reflectors while maintaining high Q. A 3.5X improvement in Q is experimentally demonstrated relative to uniform PnC reflectors of comparable dimensions.

THz MEMS Components and Systems

We demonstrate a method to improve the controllabilty of the MEMS tunable metamaterials by individually actuating the alternate lines in the metamaterial array. This is the first step towards the realization of Programmable metamaterial, where each of the unit cell can be addressed independently.

PowerMEMS and Actuators
Actuator Components and Systems

A bi-directional extended range parallel-plate electrostatic actuator using feedback linearization control is presented in this paper. The actuator can have stable displacements up to 90% of the full-gap (limited by mechanical stoppers) on both directions, i.e, the device can move ±2um within a ±2.25um gap. The system has successfully tracked references until 1 kHz (limited by the dynamics of the device) and it presents a capacitor tuning rage of 17, using an actuation voltage from 0 to 10V.

We present a thermoresponsive circuit breaker micromachined in a form of titanium-packaged chip for biomedical applications with a focus on electronic implants. This micro breaker has a temperature-sensitive cantilever actuator to serve as an absolute temperature limiter for the device of interest being protected from overheating, a critical safety feature for smart implants including those that are electrothermally active. Temperature regulation of a wireless heater powered by external RF field

This paper reports controllable somersault magnetic soft robotics consisting of polymeric magnet embedded in a high friction silicone polymer. The soft structures are actuated by the rotation of a permanent magnet at fixed position and exhibit controllable linear movement in a flip-and-forward manner for extended distance on both horizontal and vertical non-magnetic surfaces. The control of direction of motion is also achieved.

We have developed a cyborg beetle, which is the hybrid of a miniature wireless communication system and a living beetle platform. We can remotely stimulate neuromuscular sites of the living beetle platform via the miniature system. In this study, we stimulated the subalar flight muscle, a major muscle directly inserted to the wing base of beetle, and demonstrated the thrust control of the cyborg beetle with graded response.

This paper reports the design, optimization, and test results of a new magnetic structure for kinetic energy harvesters allowing seven-fold increase in power density compared to single-magnet configuration. For the first time, electromagnetic energy harvesters with "single cylindrical Halbach array" and "double-concentric Halbach array" magnetic structures are fabricated and tested.

This paper proposes the on-chip Fluid Separated Volumetric Flow Converter (FSVFC) capable of high speed cell position control with high resolution, while the actuation fluid is physically separated from working fluid for biological considerations. By utilizing the newly developed on-chip comb shaped FSVFC, an online high speed vision sensor and a high speed PZT, we succeeded in controlling the position of a cell in microfluidic channel with the time constant of 12 ms and the resolution of 240 nm

This paper reports a novel on-chip enucleation method using an untethered microrobot incorporated with an acoustically excited microbubble, which will allow minimally invasive cell surgery for cloning techniques and biomedical applications. The proposed microrobot mainly consists of a compressible bubble for the manipulation of cells and twin permanent magnets for the manipulation of the microrobot in an aqueous medium.

We propose a novel concept of out-of-plane micro-force function generator for micro-deformation modifying. The proposed generator is based on batch micro-fabricated polymer thermal actuators array and could actively modify micro-substrate warpage. This strategy constructively utilizes the inherent self-feedback for in-situ deformation control and has the potential for solving stress-induced problems of micro-fabricated devices.

Manufacturing for Actuators and PowerMEMS

This study reports a paper-like micro-supercapacitor with in-plane interdigital buckypaper electrodes on a filter membrane substrate. A vacuum filtration method assisted by lithography techniques is proposed for patterning buckypaper. The proposed micro-SC features advantages including a flexible structure, simple fabrication, easy chip integration, and high specific capacitance. The specific capacitance measured by cyclic voltammetry was 107.27 mF/cm2 at a scan rate of 20 mV/sec.

We report an electrostatic energy harvester based on the potassium ion (K+) electret that could be stacked up into a 3D structure to multiply the output power. Vertical comb electrodes are implemented in a silicon-on-insulator (SOI) wafer with a relatively heavy mass in the handle layer to lower the resonance. A single substrate formation exhibited a 0.34 μW output at 310 Hz for a load resistance of 1 MOhm.

This paper reports a 3D micro electromagnetic energy harvester. Compared to state of the art, multiple layers of conductive coils are dispensed on the micro-machined cantilever diaphragm by an injecting machine, which will increase the potential power density of the harvester.

We present a wafer-level fabrication method for triboelectric energy harvester (TEH), which, for the first time, fabricates the TEH completely in MEMS process, without any manually assembly. Compared to state of the art, the proposed TEH is batch fabricated in CMOS-compatible process and the reduced size allows it to be integrated with other electronic devices (e.g., keyboards). This device can produce 235 mV peak voltage at the frequency of 30 Hz, under the 100 MΩ external resistance.

Materials for Actuators and PowerMEMS

A fabrication method for a hybrid structure of the poly-N-Isopropylacrylamide (pNIPAAm) gel as a soft material and the SU-8 as a solid material is proposed. This pNIPAAm-SU8 hybrid structure is utilized various applications such as gel actuators. Our hybrid structure was not broken through repeating swelling-shrinking states for 10 times. The SU-8 solid structure magnified a minute displacement of the gel which is occurred by the phase transition.

For the first time, electret that can be used in the liquid environment has been realized toward higher energy density of electret generators and actuators. By using super-lyophobic overhanging pillar surface with SiO2 layer, stable Cassie-Baxter state for low-surface-tension liquid is sustained even with high surface potential. The pillar surface is successfully charged with soft X-ray photoionization. Surface potential after liquid contact has been significantly improved with the pillars.

We report a micro-scale arrayable single-trigger valve of graphene transferred on silicon-nitride for vaporizable electronics. Graphene serves as a nanoscale barrier to oxygen diffusion and as a resistive heater for pulsed-power thermomechanical cleaving to expose sealed alkali metals for heat generation to vaporize polymer electronics. Our valve demonstrates long-storage lifetime, durability under pressure and low-power triggering.

We report the new doped-AlN thin film, (Mg,Zr)AlN, based micro energy harvester. By co-doping Mg and Zr into AlN crystal, (Mg,Zr)AlN shows giant piezoelectricity and preserves low permittivity. (Mg,Zr)AlN has higher figure of merit (FOM=$e_{31}^2(\varepsilon_0\varepsilon)$) than conventional PZT. The 13 at%-(Mg,Zr)AlN had the experimental FOM of up to 16.7 GPa. The micromachining harvester provided the high normalized power density of 3.72 mW.g^{-2}.cm^{-3}. This achievement was 1.5-fold increase compared to state of the art.

We present simple but fast poling technique to enhance the piezoelectric property of PZT thin films. Application of pulse voltage to the PZT thin films on MEMS microcantilevers has resulted in large piezoelectric constant (d31) as high as 105 pm/V. It took only 1 second for poling the PZT thin films.

Nanoscale Actuators and PowerMEMS

This paper reports a novel betavoltaic microcell based on semiconducting single-walled carbon nanotubes (s-SWCNTs). The aligned arrays of p-type s-SWCNTs were prepared onto n-type silicon forming the p-n heterojunction as the energy conversion. This heterojunction displays good rectification characteristics with I_0=1.5pA and n=1.83. Under 7.8mCi/cm^2 ^{63}Ni irradiation, the microcell achieves higher performance of V_{OC}=62mV, J_{SC}=3.8μA/cm^2, FF=33.4% and η=9.8% compared with our previous devices.

Other Actuators and PowerMEMS

This paper reports a novel electrostatic actuated microgripper with a ratchet self-locking mechanism which enables the longtime gripping without continuously applying the external driving signal such as electrical, thermal or magnetic fields. This greatly reduces the influence and damage on the gripped micro objects induced by the external driving signals.

PowerMEMS Components and Systems

In this work, a high-efficient piezoelectric energy harvester based on non-contact coupling technique is proposed and characterized, which allows it, for the first time, to take advantage of multi-cantilevers and frequency-up conversion technique to enhance the power generation efficiency for ambient excitation. The unique energy harvester can effectively scavenge environmental vibration energy with a wide bandwidth. Aiming for high space efficiency, folded cantilevers are designed.

This paper reports a bidirectional thermoelectric energy generator (TEG) with double type lenses for concentrating solar power. When solar power was applied to the TEG, solar energy is concentrated by PMMA lens firstly. The concentrated energy is absorbed as heat energy through phase-change of PCM. And then, the liquid PCM lens focuses energy on the TEG. After removing energy source, the latent heat in PCM is released. Therefore, the proposed TEG generates energy steadily.

We present hierarchical Ni/NiO supercapacitor electrodes utilizing Tobacco mosaic virus (TMV) as bio-nanotemplates. The hierarchical electrodes were fabricated by integrating high aspect ratio silicon micropillars with thermally oxidized nickel-coated TMVs. An ultra-high areal capacitance of 585.9mF/cm2 was achieved with hierarchical Ni/NiO electrodes, exceeding the capacitance of nanostructured only and planar Ni/NiO by a factor of 3.4 and 29.7, respectively.

M-224 **DOUBLY RE-ENTRANT CAVITIES TO SUSTAIN BOILING NUCLEATION IN FC-72** **1122**
T. Liu and C.-J. Kim
University of California, Los Angeles, USA

We report a micro/nano-machined surface cavity on which boiling nucleation resumes after ceasing in refrigerant FC-72 for a short time. Having the lowest surface tension of all liquids, FC-72 completely wets any existing material including Teflon so that all existing cavities get flooded once nucleation stops and could not restart boiling without excessive heat. We experimentally confirm the half-century old idea of doubly re-entrant cavities as a boiling site, encouraging further development.

T-225 **EXPERIMENTALLY VERIFIED MODEL OF ELECTROSTATIC ENERGY HARVESTER WITH INTERNAL IMPACTS** **1125**
B.D. Truong, C.P. Le, and E. Halvorsen
Buskerud and Vestfold University College, NORWAY

We present experimentally verified progress on modeling of MEMS electrostatic energy harvesters with internal impacts on transducing end-stops. The model includes nonlinearities of the electromechanical transduction, the squeezed-film damping and the impact force. The comparison between simulation and measurement shows that these effects are crucial and gives good agreement for phenomenological parameters. This is a significant step towards accurate modeling of this complex system.

W-226 **MONOLITHIC 2-AXIS IN-PLANE PZT LATERAL BIMORPH ENERGY HARVESTER WITH DIFFERENTIAL OUTPUT** **1129**
S. Nadig, S. Ardanuç, and A. Lal
Cornell University, USA

We report a novel 2-axis (X-Y) piezoelectric energy harvester, whose sensitive axis in-plane is rotationally invariant, a result achieved by spiral cascading of lateral bimorphs. This is different than conventional piezoelectric energy harvesters that are sensitive only along one axis or can realize multi-axis sensitivity through integration or assembly of multiple devices at different orientations.

M-227 **SOLID-STATE FLEXIBLE MICRO SUPERCAPACITORS BY DIRECT-WRITE POROUS NANOFIBERS** **1133**
C. Shen[1], G. Luo[1], A. Kozinda[1], M. Sanghadasa[2], and L. Lin[1]
[1]University of California, Berkeley, USA and [2]US Army, USA

We report solid-state flexible micro supercapacitors based on direct-write porous polymer nanofibers. Compared with state-of-art supercapacitors, key innovations include: 1) porous 3D nanostructure of conductive nanofibers via the near-field electrospinning process; 2) flexible solid-state micro electrodes with high energy density using the pseudocapacitive effect; (3) simple and versatile process compatible with different substrates and surfaces.

T-228 **STRETCHABLE WIRELESS POWER TRANSFER WITH A LIQUID ALLOY COIL** **1137**
S.H. Jeong[1] and Z.G. Wu[1,2]
[1]Uppsala University, SWEDEN and [2]Huazong University of Science and Technology, CHINA

A stretchable wireless power transfer (WPT) device was fabricated with a liquid alloy coil, which was integrated with rigid electronic chips in elastomer packaging. Tape transfer masking with spray deposition was applied for patterning a long coil of the liquid alloy. The WPT efficiency reached 10% at 140 kHz and worked with 25% strain. Different sizes of liquid alloy coils and soft magnetic composite cores were tested for a higher efficiency system.

W-229 **THREE-AXIS PIEZOELECTRIC VIBRATION ENERGY HARVESTER** **1141**
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This paper reports for the first time a piezoelectric harvester for scavenging vibrational energy in all three-dimensions. The device is formed of optimized PZT/Si unimorph crab-legs such that the first three resonance modes are linear in-plane and out-of-plane vibrational modes with closely spaced frequencies. Partitioned electrodes collect vibrational energy in the transverse piezoelectric mode, and have different phases in their outputs according to the axis of the applied vibration.

M-230 **VERTICAL CAPACITIVE ENERGY HARVESTER POSITIVELY USING CONTACT BETWEEN PROOF MASS AND ELECTRET PLATE - STIFFNESS MATCHING BY SPRING SUPPORT OF PLATE AND STICTION PREVENTION BY STOPPER MECHANISM** **1145**
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In a vertical capacitive energy harvester, two methods to effectively use the contact between proof mass and electret plate are proposed; one is to match the stiffness between plate and mass, which is effective to increase their contact duration. For this purpose, instead of a gel shock-absorber, a soft spring for supporting plate is employed. Another is to surely detach mass from plate after their contact, opposing electrostatic attraction. The output power was improved by 5 times up to 50 μW.