

LAS VEGAS • NEVADA • USA ≡ JANUARY 22-26, 2017

The 30th IEEE International Conference
on Micro Electro Mechanical Systems

MEMS 2017

FINAL PROGRAM

Conference Chairs:

Ellis Meng, *University of Southern California, USA*

Clark T.-C. Nguyen, *University of California, Berkeley, USA*

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SUNDAY, JANUARY 22

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

MONDAY, JANUARY 23

08:00 - 08:30 Welcome Address
Conference Chairs: Ellis Meng & Clark T.-C. Nguyen

08:30 - 09:15 **Plenary Speaker I**
Tsu-Jae King Liu, *University of California, Berkeley, USA*

09:15 - 10:00 **Session I - Single Session 1**

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

10:30 - 11:45 **Session II - Inertial Sensors**

11:45 - 13:00 **Lunch & Exhibit Inspection**

13:00 - 15:00 **Poster/Oral Session I**

15:00 - 16:00 **Session IIIa
Energy Harvesting**

**Session IIIb
Nano/Bio Technology**

16:00 - 16:30 **Break & Exhibit Inspection**

16:30 - 17:30 **Session IVa
Resonators I**

**Session IVb
Droplet Microsystems**

17:30 **Adjourn for the Day**

TUESDAY, JANUARY 24

08:00 - 08:45 **Plenary Speaker II**
Sunghoon Kwon, *Seoul National University, KOREA*

08:45 - 09:45 **Session V - Single Session 2**

09:45 - 10:00 **MEMS 2018 Announcement**

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

10:30 - 11:45 **Session VI - Medical Microsystems**

11:45 - 12:00

- IEEE Fellows Recognition in the Field of MEMS/NEMS
- IEEE Electron Devices Society Robert Bosch Micro and Nano Electro Mechanical Systems Award Recipient
Clark T.-C. Nguyen, *University of California, Berkeley, USA*

12:00 - 13:00 **Lunch & Exhibit Inspection**

13:00 - 15:00 **Poster/Oral Session II**

15:00 - 16:00 **Session VIIa
Bioparticle Handling
& Analysis**

**Session VIIb
Resonators II**

16:00 - 16:30 **Break & Exhibit Inspection**

16:30 - 17:30 **Session VIIIa
Actuators**

**Session VIIIb
Gas Sensors**

17:30 **Adjourn for the Day**

WEDNESDAY, JANUARY 25

08:00 - 08:45	Plenary Speaker III Andreas Hierlemann, <i>ETH Zurich, SWITZERLAND</i>	
08:45 - 10:00	Session IX - Single Session 3	
10:00 - 10:30	Break & Exhibit Inspection	
10:30 - 11:45	Session Xa Tactile & Flexible Sensors	Session Xb Manufacturing for BioMEMS
11:45 - 13:30	Lunch on Own & Exhibit Inspection	
13:30 - 15:00	Session XIa Materials & Manufacturing	Session XIb Optical MEMS
15:00 - 17:00	Poster/Oral Session III	
17:00	Adjourn for the Day	
19:00 - 22:00	Conference Banquet	

THURSDAY, JANUARY 26

08:00 - 08:45	Plenary Speaker IV Rich Ruby, <i>Broadcom, USA</i>	
08:45 - 10:00	Session XII - Single Session 4	
10:00 - 10:30	Break & Exhibit Inspection	
10:30 - 11:45	Session XIII - Single Session 5	
11:45 - 12:00	Outstanding Student Award & Final Remarks	
12:00	Conference Adjourns	



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- A** Plenary Sessions
- B** Concurrent Sessions a
- C** Concurrent Sessions b
- D** Poster Sessions
- E** Exhibits
- F** Breaks (mid-morning & afternoon)
- G** Lunch (Monday & Tuesday)
- H** Conference Banquet

See last page for the exhibit and poster floor plan.

Plenary Speakers

Monday, January 23

08:30 - 09:15 | Tsu-Jae King Liu, *University of California, Berkeley, USA*

Tuesday, January 24

08:00 - 08:45 | Sunghoon Kwon, *Seoul National University, KOREA*

Wednesday, January 25

08:00 - 08:45 | Andreas Hierlemann, *ETH Zurich, SWITZERLAND*

Thursday, January 26

08:00 - 08:45 | Rich Ruby, *Broadcom Ltd., USA*

Oral Sessions

Oral sessions will be held in the Rio Pavilion 8-11, with the parallel concurrent sessions in the Brasilia.

Poster/Oral Sessions

The poster/oral format will consist of three (3) scheduled 10 minute, oral presentations which will be presented during each poster session on their assigned day in front of each poster starting at the designated times below. The remainder of the time should be used for questions & answers. The chimes will ring five minutes before the start of each presentation.

All poster papers are listed in this program by topic category with their assigned number starting on page 34. See floor plan page 94.

Session I	Session II
Monday, January 23 13:00 – 15:00	Tuesday, January 24 13:00 – 15:00
Poster/Oral Presentation 1 – 13:30	Poster/Oral Presentation 1 – 13:30
Poster/Oral Presentation 2 – 14:00	Poster/Oral Presentation 2 – 14:00
Poster/Oral Presentation 3 – 14:30	Poster/Oral Presentation 3 – 14:30
Session III	
Wednesday, January 25 15:00 – 17:00	
Poster/Oral Presentation 1 – 15:30	
Poster/Oral Presentation 2 – 16:00	
Poster/Oral Presentation 3 – 16:30	

Guide to Understanding Poster Numbering

Each poster is assigned a unique number which clearly indicates when and where the poster is presented.

Poster number: **M-132**

The first character (i.e. **M**) indicates the day of the Conference:

M = Monday, **T** = Tuesday, **W** = Wednesday

The second character (i.e. **132**) is the poster board position on the floor plan.

SUNDAY, JANUARY 22**17:00 -
19:00**

Registration and Wine & Cheese Welcome Reception

MONDAY, JANUARY 23

Welcome Address

Rio Pavilion 8 - 11

08:00**MEMS 2017 Conference Chairs**Ellis Meng, *University of Southern California, USA*Clark T.-C. Nguyen, *University of California, Berkeley, USA***Plenary Speaker I**

Session Chair:

C.T.-C. Nguyen, *University of California, Berkeley, USA*

Rio Pavilion 8 - 11

08:30**THERE'S PLENTY OF ROOM AT THE TOP****Tsu-Jae King Liu¹**, U. Sikder¹, K. Kato², and V. Stojanovic¹¹*University of California, Berkeley, USA* and ²*University of Tokyo, JAPAN*

The virtuous cycle of integrated-circuit (IC) technology advancement has been sustained for over 50 years, resulting in the proliferation of information and communication technology with dramatic economic and social impact. Although there is still some "room at the bottom" today to manipulate and control matter at even smaller scale, physics and economics limit the benefits of further transistor scaling. This paper describes how the performance and functionality of microchips can be enhanced by forming MEMS on top of transistors, to sustain the IC revolution.

Session I - Single Session 1

Session Chairs:

J. Ducreé, *Dublin City University, IRELAND*H. Toshiyoshi, *University of Tokyo, JAPAN*

Rio Pavilion 8 - 11

09:15**CARBON NANOTUBES NETWORK CONTACT LUBRICATION FOR HIGHLY RELIABLE MEMS SWITCH**M.-H. Seo¹, E. Jo², S.-D. Ko^{1,3}, J. Choi⁴, Y.-H. Yoon¹, D.-S. Kwon², J. Kim², and J.-B. Yoon¹¹*Korea Advanced Institute of Science and Technology (KAIST), KOREA*,²*Yonsei University, KOREA*, ³*Georgia Institute of Technology, USA*, and⁴*Yeungnam University, KOREA*

We firstly reports a highly reliable MEMS switch employing CNTs-network lubricant in contact-area. We investigated that the reliability can be improved by the compressibility and durability of the CNTs-network. We also observed that the highly flexible CNTs-network does not deteriorate high-speed operation of the device (~1 μ s). The proposed switch exhibited 15 times longer lifetime under hot-switching conditions, compared to a comparison device without CNTs.

Session I - Single Session 1**Rio Pavilion 8 - 11****09:30 64-PIXEL SOLID STATE CMOS COMPATIBLE ULTRASONIC FINGERPRINT READER**

J.C. Kuo¹, J.T. Hoople¹, M. Abdelmejeed¹, M. Abdel-moneum², and A. Lal¹
¹Cornell University, USA and ²Intel Corporation, USA

In this work, we report on a 1D linear ultrasonic impedance imager for fingerprint sensing. This device is based on an all solid state aluminum nitride (AlN) transducer array that eliminates the need for released membranes. Our device uses GHz ultrasonic pulses, generated by driving AlN pixel transducers at resonance with a CMOS compatible voltage of 2V. From noise levels of signals and point measurements, we estimate that the ultimate single point resolution possible is 15-20 μm or ~ 1700 dpi.

09:45 CELLS SMELL ON A CMOS: A PORTABLE ODORANT DETECTION SYSTEM USING CELL-LADEN COLLAGEN PILLARS

Y. Hirata¹, Y. Morimoto¹, E. Nam^{1,2}, S. Yoshida¹, and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and
²Japan Science and Technology Agency (JST), JAPAN

We developed a portable odorant detection system composed of collagen micro-pillars containing cells expressing olfactory receptors and a CMOS image sensor. Due to the accumulation of fluorescence from the multiple cells in the pillars, the CMOS image sensor even with low sensitivity can catch the odorant-induced fluorescence. We believe that our approach would be an important step toward substitutions for working animals such as a drug-sniffing dog and a mine-sniffing rats.

10:00 Break & Exhibit Inspection**Session II - Inertial Sensors****Session Chairs:**

G. Langfelder, *Politecnico di Milano, ITALY*
C.-C. Lo, *Richtek Technology Corporation, TAIWAN*

Rio Pavilion 8 - 11**10:30 ENVIRONMENTALLY ROBUST DIFFERENTIAL RESONANT ACCELEROMETER IN A WAFER-SCALE ENCAPSULATION PROCESS**

D.D. Shin¹, C.H. Ahn², Y. Chen¹, D.L. Christensen³, I.B. Flader¹, and T.W. Kenny¹
¹Stanford University, USA, ²InvenSense Incorporated, USA, and
³Apple Incorporated, USA

This work demonstrates a temperature-compensated differential resonant accelerometer in wafer-scale encapsulation process. By utilizing a pair of ultra-stable, high-Q resonant beams as a strain gauge, we show differential operation with scale factor of 427Hz/g and bias instability of 0.16 μg . Furthermore, two beams' matched temperature coefficients of frequency provide first order cancellation of temperature drift, resulting in scale factor stability of 0.38% over -20°C to 80°C.

Session II - Inertial Sensors**Rio Pavilion 8 - 11****10:45 ULTRA-LOW-VOLTAGE GYROSCOPES BASED ON PIEZORESISTIVE NEMS FOR DRIVE-MOTION AND CORIOLIS-MOTION SENSING**

S. Dellea¹, G.S. Strazzeri¹, P. Rey², and G. Langfelder¹
¹Politecnico di Milano, ITALY and ²CEA-Leti, FRANCE

The work presents gyroscopes based on NEMS gauges used for sense and for drive-motion detection. No structural element is biased at voltages larger than 1V, so 1-2 orders of magnitude lower than voltage usually applied to the rotor of capacitive gyroscopes. Following the mechanical design, the electronics is adapted, relying on resistive sensing also in the drive loop. Within an area of $800 \times 1400 \mu\text{m}^2$, with drive Q factor of 35000 at 0.3 mbar, 1.4 dph/ $\sqrt{\text{Hz}}$ ARW is obtained.

11:00 A 0.5 MM² 7-MHZ CAPACITIVE BULK ACOUSTIC WAVE GYROSCOPE IN (100) SILICON WITH LARGE DYNAMIC RANGE

A. Rahafrooz¹, D.E. Serrano¹, D. Younkin¹, S. Nagpal¹, I. Jafri¹, and F. Ayazi^{1,2}
¹Qualtré Inc., USA and ²Georgia Institute of Technology, USA

This paper presents the smallest MEMS gyroscope reported to date. With a footprint of only 0.5 mm², the device consists of a high frequency symmetric bulk acoustic wave disk resonator which is fabricated using HARPSS process with robust performance to environmental disturbances and a large dynamic range beyond 6000 dps. The device exhibits a measured ARW of 1 $\%/\sqrt{\text{h}}$ and a bias instability of 15 $\%/\text{h}$, which are dominated by the thermal and flicker noise of the electronics, respectively.

11:15 AN INTERMITTENT FREE-VIBRATION MEMS GYROSCOPE ENABLED BY CATCH-AND-RELEASE MECHANISM FOR LOW-POWER AND FAST-STARTUP APPLICATIONS

R. Gando, H. Kubo, Y. Tomizawa, E. Ogawa, S. Maeda, K. Masunishi, Y. Hatakeyama, T. Itakura, and T. Ikehashi
Toshiba Corporation, JAPAN

We design and demonstrate a novel MEMS gyroscope operating in intermittent free-vibration enabled by a "Catch-and-Release (CR)" drive mechanism, which realizes substantial power reduction and fast startup ($<10 \mu\text{s}$) compared to existing stationary gyroscopes. In the CR architecture, the proof mass is captured at the maximum displacement position (catch-state), and then released to free vibration during which Coriolis detection is performed (release-state).

11:30 NANO-G ACCELEROMETER USING GEOMETRIC ANTI-SPRINGS

B.A. Boom¹, A. Bertolini¹, E. Hennes¹, R.A. Brookhuis², R.J. Wiegerink², J.F.J. van den Brand^{1,3}, M.G. Beker⁴, A. Oner¹, and D. van Wees¹
¹Nikhef, NETHERLANDS, ²University of Twente, NETHERLANDS,
³VU University, NETHERLANDS and ⁴Innoseis, NETHERLANDS

We report an ultra-sensitive seismic accelerometer with nano-g sensitivity, using geometric anti-spring technology. High sensitivity is achieved by an on-chip mechanical pre-tensioning system. Using this pre-tensioning mechanism, the stiffness in the sensing direction can be reduced by over a factor of 25, increasing the sensitivity to acceleration by the same factor. Equivalent noise levels below 2 ng/ $\sqrt{\text{Hz}}$ have been demonstrated in a 50 Hz bandwidth, using capacitive read-out.

11:45 Lunch & Exhibit Inspection**Poster/Oral Session I**

13:00 Poster presentations are listed by topic category with their assigned number starting on page 34.

Session IIIa - Energy Harvesting**Session Chairs:**L.F. Velásquez-García, *Massachusetts Institute of Technology, USA*X. Wang, *Tsinghua University, CHINA***Rio Pavilion 8 - 11****15:00 FLEXIBLE PIEZOELECTRIC STRAIN ENERGY HARVESTER RESPONSIVE TO MULTI-DIRECTIONAL INPUT FORCES AND ITS APPLICATION TO SELF-POWERED MOTION SENSOR**M.-O. Kim¹, Y. Oh¹, Y. Kang¹, K.-H. Cho², J. Choi³, and J. Kim¹¹*Yonsei University, KOREA*, ²*Agency for Defense Development, KOREA*, and³*Yeungnam University, KOREA*

A flexible piezoelectric energy harvester responsive to multi-directional forces from arbitrary human motions was developed. Unlike the most of conventional strain energy harvesters designed to be functional only for single directional motion, our design demonstrated the energy harvesting capability for all the input forces applied in various directions. Through the harvester mounted on a curved human body, the motion between body and arm was successfully converted to electricity.

15:15 ACOUSTIC ENERGY HARVESTER UTILIZING A MINIATURE ROTOR ACTUATED BY ACOUSTICALLY OSCILLATING BUBBLES-INDUCED SYNTHETIC JETS

D. Jang, J. Jeon, and S.K. Chung

Myongji University, KOREA

We present a new type of acoustic energy harvesting technology where a miniature rotor actuated by acoustically oscillating bubbles-induced synthetic jets makes piezocantilevers periodically vibrate to generate electric power. The proposed energy harvesting technology can extract mechanical power from acoustic energy using a miniature rotor driven by compressible bubbles in an aqueous medium and convert the mechanical power to electric power for wireless devices.

15:30 ELECTROSTATIC/TRIBOELECTRIC HYBRID POWER GENERATOR USING FOLDED ELECTRETSK. Tao^{1,2}, J. Wu¹, A.G.P. Kottapalli², L.H. Tang³, L.X. Hu¹, N. Wang¹, S.W. Lye¹, M.S. Triantafyllou^{2,4}, and J.M. Miao¹¹*Nanyang Technological University, SINGAPORE*, ²*Singapore-MIT Alliance for Research and Technology (SMART), SINGAPORE*,³*University of Auckland, NEW ZEALAND*, and⁴*Massachusetts Institute of Technology, USA*

Inspired by the ancient art of paper folding, a lightweight and robust electrostatic/triboelectric hybrid power generator using folded electrets is presented in this paper. High performance was achieved with the stacked multilayer architecture as well as dual corona charged electret plates. Real applications of as-fabricated generator in harvesting kinetic energy from various kinds of human motions were demonstrated.

15:45 PIEZOELECTRIC AND ELECTROMAGNETIC HYBRID ENERGY HARVESTER USING TWO CANTILEVERS FOR FREQUENCY UP-CONVERSION

D.-S. Kwon, H.-J. Ko, and J. Kim

Yonsei University, KOREA

In this paper, we developed frequency-up conversion hybrid energy harvester using two (internal and external) cantilevers. To increase harvesting power, the single harvester utilizes piezoelectric and electromagnetic conversions simultaneously. By adopting frequency up-conversion method which is enabled by the bending of multi-layered cantilevers and separation between them, it can harvest energy effectively from mechanical motion at extremely low frequency.

Session IIIb - Nano/Bio Technology**Session Chairs:**Y.-K. Lee, *Hong Kong University of Science and Technology, CHINA*W. van der Wijngaart, *KTH Royal Institute of Technology, SWEDEN***Brasilia****15:00 NANO-PATTERNING OF MOTOR PROTEINS TO CONTROL NUMBER OF KINESIN MOLECULES TRANSPORTING A SINGLE MICROTUBULE**T. Kaneko, H. Shintaku, H. Kotera, and R. Yokokawa
Kyoto University, JAPAN

We propose a nano-patterning method to control the number of kinesin molecules involved in a collective transport of a single microtubule filament. We fabricated Au nano-pillar array on Si/SiO₂ substrates and selectively formed silane-PEG SAM (silane-SAM) on SiO₂ surface, in which kinesin molecules were attached only on Au nano-pillars selectively. Our patterning method help us to study how the transport velocity is regulated by changing numbers of motors and space between motors in vivo.

15:15 DIRECT ASSEMBLY OF A HYDROGEL NANO-TIP ONTO SILICON MICROCANTILEVERS FOR WEAR STUDY AND FACILE REGENERATION OF SOFT ATOMIC FORCE MICROSCOPE PROBESS. Kim, Y. Yoon, and J. Lee
Sogang University, KOREA

We report the direct assembly of a hydrogel nano-tip onto silicon microcantilevers to investigate wear characteristics of hydrogel atomic force microscope (AFM) tips and their facile regeneration in the case of appreciable tip damage. With the proposed method, thorough wear studies of soft hydrogel AFM tips are enabled in comparison with silicon AFM tips at a well-matched resonance frequency or spring constant for the first time.

15:30 DESALTING HIGH SALINITY SHALE FLOWBACK WATER VIA HIGH-FLUX NANOFIUIDIC EVAPORATION-CONDENSATIONK.K. Rangharajan, V. Lochab, and S. Prakash
Ohio State University, USA

We demonstrate a novel, proof-of-concept prototype for desalting high salinity waters arising from shale oil/gas extraction. Our nanofluidic devices use forward osmosis to drive an isothermal evaporation-condensation system over tunable sections of functionalized hydrophobicity inside an 80 nm deep nanochannel. Desalting high salinity waters was demonstrated for various electrolytes but most prominently, we show greater than 90% desalting of Utica shale flowback water.

15:45 LINEAR ZERO MODE WAVEGUIDES FOR THE STUDY OF CHEMO-MECHANICAL COUPLING MECHANISM OF KINESINK. Fujimoto¹, Y. Morita¹, R. Iino², M. Tomishige³, H. Shintaku¹,
H. Kotera¹, and R. Yokokawa¹¹Kyoto University, JAPAN, ²Institute for Molecular Science, JAPAN, and³University of Tokyo, JAPAN

We propose simultaneous observation of motor protein kinesin and adenosine tri-phosphate (ATP) using linear zero mode wave guides (LZMWs) for further understand of kinesin motility. Design and fabrication of LZMWs device were established and higher concentration of fluorescent labeled ATP was observed by confining excitation lights in the trench of LZMWs. Realized concentration is around 10 times higher than the concentration in conventional methods like total internal reflection microscopy.

16:00 Break & Exhibit Inspection

Session IVa - Resonators I**Session Chairs:***A. Ionescu, Ecole Polytechnique Fédérale Lausanne (EPFL), SWITZERLAND**M. Rinaldi, Northeastern University, USA***Rio Pavilion 8 - 11****16:30 VERY-WIDE ELECTROTHERMAL TUNING OF GRAPHENE
NANOELECTROMECHANICAL RESONATORS***F. Ye, J. Lee, and P.X.-L. Feng**Case Western Reserve University, USA*

We report on the first demonstration of electrothermally tunable graphene nanoelectromechanical resonators via Joule heating. We fabricate single-, bi- & tri-layer graphene resonators. Graphene resonators exhibit fundamental frequency increase from 9.5MHz to 26.1MHz by electrothermal tuning, with tuning range up to 180%. The temperature is monitored by using Raman spectroscopy. The temperature increases up to 600K or to above 1000K in single-, and few-layer devices. This work proves that electrothermal effect could broadly tune graphene resonators with high efficiency.

**16:45 RESONANT PIEZORESISTIVE AMPLIFIERS: TOWARDS SINGLE
ELEMENT NANO-MECHANICAL RF FRONT ENDS***A. Ramezany, S. Babu, V. Kumar, J.-B. Lee, and S. Pourkamali**University of Texas, Dallas, USA*

This work presents measurement and scaling results for micro/nano-mechanical resonant piezoresistive amplifiers showing the potential of such devices as single element receiver front-ends. Such active electromechanical devices can simultaneously amplify and filter incoming electrical signals while maintaining a low noise figure. Devices operating in the range of 5-162MHz have been fabricated to show the performance is improved as the dimensions shrink and the frequency increases.

**17:00 POWER-INSENSITIVE SILICON CRYSTAL-CUT FOR
AMPLITUDE-STABLE FREQUENCY SYNTHESIS***M. Ghatge, P. Karri, and R. Tabrizian**University of Florida, USA*

This paper reports on theoretical predication and experimental validation of a power-insensitive silicon crystal-cut for realization of amplitude-stable resonators. Waveguide-based resonators compensated for geometrical nonlinearities and aligned to this cut benefit from its fully-harmonic elasticity and demonstrate an extended linear operating range. An 80 MHz prototype, with a Q of 7000, is presented showing a 1dB compression point at 29 dBm, which is 50 × higher compared to <100> counterpart.

**17:15 A MULTI-TONE TESTING TECHNIQUE FOR PRODUCTION
CHARACTERIZATION OF MICRO-RESONATORS***E.T.-T. Yen, B. Kramer, T. Tarsi, D. Griffith, and B. Goodlin**Texas Instruments, USA*

This work applies a mixed-signal IC testing technique to perform high-frequency μ -resonator characterization. The implementation is based on observing the change in magnitude and phase of injected multi-tone signals. The ATE tester is capable of extracting resonance frequencies to single-digit ppm accuracy for in-situ process monitoring and pre-screening. Compared to conventional S-parameter measurements, this technique is expected to reduce production testing cost by at least 40%.

Session IVb - Droplet Microsystems**Session Chairs:**S.K. Cho, *University of Pittsburgh, USA*Y. Murakami, *Toyohashi University of Technology, JAPAN***Brasilia****16:30 AEROSOL PARTICLE SIZE SPECTROMETER USING A MICROMACHINED CASCADE IMPACTOR**H.-L. Kim, J.S. Han, S.-M. Lee, H.-B. Gown, J. Hwang, and Y.-J. Kim
Yonsei University, KOREA

This paper reports a MEMS-based particle size spectrometer using a micromachined cascade impactor. The proposed particle size spectrometer was developed for measuring airborne particle size distribution, while a MEMS-based particle counter in our previous research was developed for measuring the total number concentration of particles within certain size range. To the best of our knowledge, MEMS device for measuring aerodynamic particle size distribution is a first attempt.

16:45 A NOVEL SUB-PICOLITER MONODISPERSED DROPLET GENERATION DEVICE BASED ON LIQUID DIELECTROPHORESISK.N. Nampoothiri¹, V. Srinivasan¹, M.S. Bobji², and P. Sen¹¹*Indian Institute of Science, INDIA* and ²*University of Minnesota, USA*

We report a new phenomenon for jetting of droplets at lower voltages and demonstrate its use for generation and transfer of monodispersed droplets in sub-picoliter volumes. The reported technique is fast, achieving a dense transfer of micro-droplets in less than 10s. Compared to other microfluidic techniques, the new technique uses simpler fabrication and does not require bulky components. The technique is extremely easy and cheap to scale making it suitable for portable applications.

17:00 INTEGRATING MULTI-ELECTRODE ARRAYS IN MICROFLUIDIC HANGING-DROP NETWORKSP.M. Misun, A. Shadmani, A. Hierlemann, and O. Frey
ETH Zurich, SWITZERLAND

We present a highly versatile analytical platform concept for 3D microtissues. The device combines microfluidics with sensor technology for parallel and real-time monitoring of microtissue metabolism. Interconnected hanging drops are formed underneath a patterned glass chip, which hosts the integrated multi-electrode array. The electrodes can be individually functionalized and used as biosensors. The device is ideal for cultivation and continuous observation of 3D microtissues.

17:15 JUMPING FORCE OF COALESCING DROPLETS ON A SUPERHYDROPHOBIC SURFACET.-V. Nguyen¹, T. Mouterde², H. Takahashi¹, D. Quéré², and I. Shimoyama¹¹*University of Tokyo, JAPAN* and ²*École Polytechnique, FRANCE*

We report a direct measurement of the jumping force during the coalescence of two water droplets on a superhydrophobic surface using a MEMS-based force plate. Our measurement results show that the maximum jumping force could be more than 10 times larger than the total weights of the two droplets. The impulse calculated from the measured force was also consistent with jumping momentum of the merged droplet.

17:30 Adjourn for the Day



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Faculty

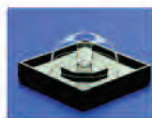
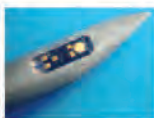
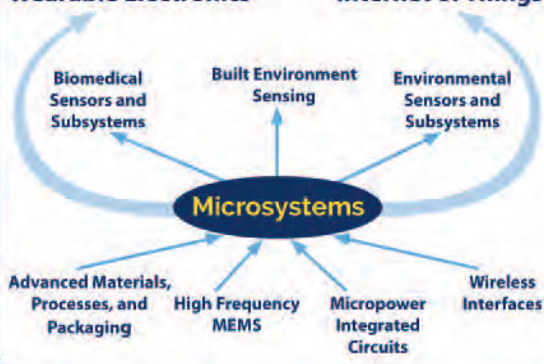
110+
Researchers

1600+
Publications

85+
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Wearable Electronics

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WIMS² Research Application Areas

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Environmental Monitoring

Explosive Detection

Factory Automation

Harsh Environment Sensing

Homeland Security

Immunoassays

Inertial Sensing

Infrastructure Monitoring

Neural Probes

Oil Exploration

Point of Care Diagnostics

Pollution Mapping

Radiation Detection

Smart Buildings

Smart Highways

Smart Homes

Space Probes

Surgical Tools

Trace Chemical Analysis

Water Quality Analysis

Wearable Electronics

Weather Forecasting

TUESDAY, JANUARY 24**Plenary Speaker II**

Session Chair:

S. Takeuchi, *University of Tokyo, JAPAN***Rio Pavilion 8 - 11****08:00 RAPID ANTIBIOTIC SUSCEPTIBILITY TEST: COMMERCIALIZATION OF LIFE SAVING MEMS DEVICES**H.Y. Jeong¹, E.-G. Kim², S. Han², G.Y. Lee¹, S. Han², B. Jin², T. Lim^{1,2}, H.C. Kim³, T. S. Kim³, D. Kim^{1,2,3}, and **Sunghoon Kwon**^{1,2,3}¹*Seoul National University, KOREA*, ²*Quantamatrix Inc., KOREA*, and³*Seoul National University Hospital, KOREA*

For the timely treatment of patients with infections in bloodstream and cerebrospinal fluid, a rapid antimicrobial susceptibility test (AST) is urgently needed. This paper describe a direct and rapid antimicrobial susceptibility testing (dRAST) system, which can determine the antimicrobial susceptibility of bacteria from a positive blood culture bottle (PBCB) in six hours that conventionally taking more than 30-50 hours. Design consideration, clinical verification, commercialization, and application of dRAST system to tuberculosis are reviewed.

Session V - Single Session 2

Session Chairs:

K. Cheung, *University of British Columbia, CANADA*M. Despont, *CSEM Microsystems, SWITZERLAND***Rio Pavilion 8 - 11****08:45 MUSCLE-ACTUATED BIOMIMETIC HYDROGEL-BASED 3D MICROSKELETON**M.R. Gullo¹, S. Takeuchi², and O. Paul¹¹*University of Freiburg, GERMANY* and ²*University of Tokyo, JAPAN*

This paper reports on a biomimetic microskeleton actuated by muscle fibers. The 3D microskeleton is based on concatenated rib elements fabricated by two-photon polymerization of a custom-made hydrogel. For the first time, micrometer-sized skeletons were fabricated, overgrown with functional muscle fibers, and contracted at significant amplitudes. Such 3D microskeletons can be shaped into arbitrary complex geometries, thereby opening pathways towards muscle-driven biohybrid microrobots.

09:00 TINY-SIZED ULTRA-SENSITIVE INFRARED-THERMOPILE FABRICATED WITH A SINGLE-SIDED BULK-SILICON MICROMACHINING TECHNIQUE

W. Li, Z. Ni, F. Chen, J. Wang, F. Feng, and X. Li

Chinese Academy of Sciences, CHINA

We report a tiny-sized (140 μm \times 140 μm) p-Si/Al infrared (IR) thermopile, which is low-cost bulk-micromachined only from the front-side of (111) wafer for IC-compatible manufacturing. Thanks to the novel structure and the higher Seebeck-coefficient of p-Si/Al thermocouple compared to traditional poly-Si/Al thermocouples, our tiny-sized thermopile achieves an ultra-high responsivity of 356V/W and ultra-short response-time of 0.59ms.

Session V - Single Session 2**Rio Pavilion 8 - 11****09:15 PIEZOELECTRIC/MAGNETOSTRICTIVE MEMS RESONANT SENSOR ARRAY FOR IN-PLANE MULTI-AXIS MAGNETIC FIELD DETECTION**

H.J. Kim^{1,2}, S. Wang^{1,3}, C. Xu¹, D. Laughlin¹, J. Zhu^{3,4}, and G. Piazza¹
¹Carnegie Mellon University, USA, ²Daegu Gyeongbuk Institute of Science and Technology (DGIST), KOREA, ³Sun Yat-sen University, CHINA, and ⁴Sun Yat-Sen University-Carnegie Mellon University Shunde International Joint Research Institute, CHINA

We present an array of piezoelectric/magnetostrictive MEMS resonant sensors for multi-axis magnetic field detection. AlN resonators with different excitation directions but coated with a magnetostrictive layer with the same easy axis exhibit unique mechanical and electrical responses as a function of the applied magnetic field and its direction. Resonators exhibit high Q (~1500) and kt² (~2%). In an oscillator, the resonator ensures a measurement resolution of 53 nT while consuming only 1.3 mW.

09:30 DROPLET MANIPULATIONS BY DIELECTROWETTING: CREATING, TRANSPORTING, SPLITTING, AND MERGING

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

We present fundamental droplet manipulations for digital microfluidics using dielectrowetting principle including creating, splitting, merging and transporting.

09:45 MEMS 2018 Announcement**10:00 Break & Exhibit Inspection****Session VI - Medical Microsystems****Session Chairs:**

W. Li, *Michigan State University, USA*
S. Takeuchi, *University of Tokyo, JAPAN*

Rio Pavilion 8 - 11**10:30 HOOK AND LOOP MICROFASTENER: FLEXIBLE MICROELECTRODES TIED TO A NERVE**

Y. Seki, S. Yamagiwa, Y. Morikawa, H. Sawahata, R. Numano, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

We propose a highly flexible and biocompatible parylene-based microelectrode array with a hook and loop fastener design, realizing the electrode tied to a nerve (~ 1 mm in diameter). Here we fabricated a pair of the hook and loop fasteners using 10- μ m-thick parylene film, which consists of a Pt-microelectrode array. The attachment and recording capabilities of the film electrode were demonstrated using rodent's peripheral nerves with tunable tie position and reattachable features.



Neon Icons: July 2007 © AP Photo/LVNB-Bob Brye

Session VI - Medical Microsystems**Rio Pavilion 8 - 11****10:45 A SALIVA-POWERED PAPER BIOBATTERY FOR DISPOSABLE BIODEVICES**M. Mohammadifar¹, K. Zhang², and S. Choi¹¹*State University of New York, Binghamton, USA and*²*Jericho High School, USA*

We develop a paper-based microbial fuel cell (MFC) which generates power from human saliva. Upon adding one drop of saliva, the dried exoelectrogens, pre-inoculated in a conductive paper reservoir of the MFC, activate their respiration by oxidizing organic sources in the saliva and transferring electrons to the anode. This novel saliva-powered MFC will be a simple, low-cost, easy-to-use, and disposable power supply for potentially one-time use diagnostic devices in resource-limited settings.

11:00 FLEXIBLE AND TRANSPARENT pH MONITORING SYSTEM WITH NFC COMMUNICATION FOR WOUND MONITORING APPLICATIONS

R. Rahimi, U. Brener, M. Ochoa, and B. Ziaie

Purdue University, USA

This paper reports on a non-invasive, flexible, and wireless pH sensing system for monitoring wound healing progress. The device consists of a disposable flexible pH sensor interfaced with a custom-designed, flexible, batteryless and reusable wireless data transmitting platform. The transparent sensing electrodes are fabricated by low-cost direct laser scribing of ITO films. The sensor accurately measures a physiologically relevant range of pH 4-10 with an average sensitivity of -55mV/pH.

11:15 DEVELOPMENT OF AN ANATOMICALLY CONFORMAL PARYLENE NEURAL PROBE ARRAY FOR MULTI-REGION HIPPOCAMPAL RECORDINGSA.W. Hirschberg, H. Xu, K. Scholten, T.W. Berger, D. Song, and E. Meng
University of Southern California, USA

We report the first Parylene C neural probe array that anatomically matches hippocampal layers and successfully records from targeted regions. No prior polymer probe array has achieved recordings at the depth of the hippocampus (5.5 mm probe length) and at such a high electrode density (64 electrodes). Bare probes were implanted without insertion shuttles which enables acquisition of dense recordings from deep brain targets while minimizing tissue disruption to the bare probe cross-section.

11:30 A PRESSURE-SENSING SMART STENT COMPATIBLE WITH ANGIOPLASTY PROCEDURE AND ITS IN VIVO TESTINGX. Chen, B. Assadsangabi, D. Brox, Y. Hsiang, and K. Takahata
University of British Columbia, CANADA

This study reports a micro-pressure sensor integrated "smart" stent for wirelessly diagnosing long-term complication after implantation. The helical stent functioning as both an electrical inductor and a mechanical scaffold, is coupled with a MEMS capacitive pressure sensor to form a passive inductor-capacitor tank. The prototype shows compatibility with standard angioplasty procedure, and demonstrates wireless and real-time tracking of local intravascular pressure change in animal testing.

11:45

- IEEE Fellows Recognition in the Field of MEMS/NEMS
 - IEEE Electron Devices Society Robert Bosch Micro and Nano Electro Mechanical Systems Award Recipient
- Clark T.-C. Nguyen, University of California, Berkeley, USA*

12:00 Lunch & Exhibit Inspection

MEMS 2017

ROBERT BOSCH AWARD RECIPIENT



MICRO and NANO ELECTRO MECHANICAL SYSTEMS AWARD

The Robert Bosch Micro and Nano Electro Mechanical Systems Award was established by the IEEE Electron Devices Society in 2014 to recognize and honor advances in the invention, design, and/or fabrication of micro- or nano- electromechanical systems and/or devices. The 2017 Bosch Award will be presented on Tuesday, January 24 at 11:45.

Clark T.-C. Nguyen

For pioneering research on high-frequency MEMS vibrating systems and for extraordinary efforts in support of MEMS in industry, government, and teaching.

Clark T.-C. Nguyen received a Ph.D. from the University of California at Berkeley in 1994 in Electrical Engineering and Computer Sciences (EECS). In 1995, he joined the faculty of the University of Michigan, Ann Arbor, where he spent ten years, then returned to UC Berkeley in 2006, where he is presently a Professor in the EECS Department and a Co-Director of the Berkeley Sensor & Actuator Center. His research interests focus on MEMS and include integrated micromechanical signal processors and sensors, merged circuit/micromechanical technology, and RF communication architectures. In 2001, Prof. Nguyen founded Discera, Inc., the first company to commercialize micromechanical resonator-based timing oscillators for consumer electronics. In mid-2002, he joined the Defense Advanced Research Projects Agency (DARPA) on an IPA, where he served for four years as the Program Manager of ten MEMS-centric programs that provided several hundred million dollars in funding for MEMS research. Prof. Nguyen is the 2006 IEEE UFFC Cady Award winner, served as a Distinguished Lecturer for the IEEE Solid-State Circuits Society from 2007 to 2009, and is an IEEE Fellow. He was the Technical Program Chair of the 2010 IEEE Frequency Control Symposium, a Co-General Chair of the 2011 Joint IEEE Frequency Control Symposium and European Frequency and Time Forum, and is presently Co-Chairing the 2017 IEEE MEMS Conference. From 2008 to 2013, he served as Vice President of Frequency Control in the IEEE Ultrasonics, Ferroelectrics, and Frequency Control (UFFC) Society, and is currently President of the society.



IEEE Electron Devices Society with financial support from Robert Bosch LLC.

Poster/Oral Session II

13:00

Poster presentations are listed by topic category with their assigned number starting on page 34.

Session VIIa - Bioparticle Handling & Analysis

Session Chairs:

S.J. Kim, *Seoul National University, KOREA*N. Roxhed, *KTH Royal Institute of Technology, SWEDEN*

Rio Pavilion 8 - 11

15:00 CONTINUOUS-FLOW ELECTROPHORETIC SEPARATION OF BIOMOLECULES IN A TWO-DIMENSIONAL CAPILLARY-WELL MOTIF

L. Duan, X. Xing, and L. Yobas

Hong Kong University of Science and Technology, CHINA

A two-dimensional (2D) capillary-well (CW) motif featuring thousands of integrated cylindrical glass capillaries 100 and 600 nm in diameter is a novel structure realized through low-resolution photolithography ($\sim 2 \mu\text{m}$) and standard silicon processing techniques. This structure offers a rapid high-performance sieving of biomolecules as demonstrated here for the continuous-flow electrophoretic separation of DNA and proteins.

15:15 RED BLOOD CELL DEFORMABILITY UPON CONTINUOUS OR REPETITIVE LOADINGS
H. Ito¹, R. Murakami¹, C.-H.D. Tsai¹, M. Horade¹,
M. Tanaka², and M. Kaneko¹¹*Osaka University, JAPAN* and ²*University of Heidelberg, GERMANY*

We focus on the comparison of red blood cell (RBC) deformability under continuous and repetitive loadings. We utilized a feedback position-control system and a narrow microfluidic channel for applying different stress patterns on RBCs. RBCs upon these loadings surprisingly shows the same mechanical responses as long as the total loading duration is the same. The finding indicates that the internal mechanical stress accumulates even if the apparent cell shape recovers.

15:30 DEVELOPMENT OF PIEZOELECTRIC NANOSTRUCTURES FOR CELL STIMULATION
G. Murillo¹, A. Blanquer², C. Vargas¹, L. Barrios², E. Ibáñez²,
C. Nogués², and J. Esteve¹¹*IMB-CNM, CSIC, SPAIN* and ²*Universitat Autònoma de Barcelona, SPAIN*

In this work, we propose the use of piezoelectric NGs for the electrical stimulation of living cells. We analyzed changes in motility and intracellular calcium concentration ($[\text{Ca}^{2+}]$) induced by the NGs. Cells are able to proliferate and differentiate when cultured for up to 14 days on the NGs. We observed that electromechanical NG-cell interaction stimulates the macrophage motility and triggers the opening of the calcium channels in osteoblast-like cells, leading to an increase of the $[\text{Ca}^{2+}]$.

15:45 DIELECTROPHORETIC CELL SORTING VIA SLIDING CELLS ON 3D SILICON MICROELECTRODES
X. Xing¹, M.L. Chau¹, K.A. Roshan², and L. Yobas¹¹*Hong Kong University of Science and Technology, CHINA* and
²*Sharif University of Technology, IRAN*

We present an innovative design for flow-through cell sorting through sliding target cells on silicon bulk microelectrodes featuring sidewall undercuts using DEP forces and hydrodynamic drag. This unique design takes full advantage of such unique microelectrodes that can induce a highly efficient DEP force field and segregate cells along channel depth, and further achieves continuous-flow cell sorting at an order of magnitude higher throughput than with designs featuring thin-film electrodes.

Session VIIIb - Resonators II**Session Chairs:**

J. Arcamone, *CEA-Leti, FRANCE*
R. Kubena, *HRL Laboratories, USA*

Brasilia**15:00 COUPLED PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS WITH IMPROVED PULSE-ECHO PERFORMANCE**

Q. Wang, Y. Kusano, and D.A. Horsley
University of California, Davis, USA

This paper presents a novel piezoelectric micromachined ultrasonic transducer based on mechanical coupling between a circular resonator and an outer annular membrane. The design allows the PMUT diameter to be matched with acoustic wavelength for high fill-factor and high sensitivity. The measured displacement is 2x greater than a conventional PMUT. Pulse echo measurements show a 1.9x and 6.5x increase in TX/RX sensitivity at 6MHz and 8MHz compared to a conventional array with the same area.

15:15 AN SHO LITHIUM NIOBATE DISPERSIVE DELAY LINE FOR CHIRP COMPRESSION-ENABLED LOW POWER RADIOS

T. Manzanique, R. Lu, Y. Yang, and S. Gong
University of Illinois, Urbana Champaign, USA

We present the first demonstration of a shear-horizontal mode Lithium Niobate dispersive delay line, featuring a measured TB product of 100, a high electromechanical coupling, an average insertion loss of 13 dB, and instantaneous voltage gain of 3 for a designed linear chirp. The device shown herein has greatly outperformed the state of the art, namely SAW-based delay lines which typical have an insertion loss greater than 25 dB for a comparable TB product.

15:30 MICRORESONATOR WITH GOLD NANOROD ARRAY FOR LASER WAVELENGTH MEASUREMENT BY PHOTO-THERMAL CONVERSION

K. Sugano¹, Y. Tanaka¹, E. Maeda², R. Kometani², and Y. Isono¹
¹*Kobe University, JAPAN* and ²*University of Tokyo, JAPAN*

We developed the resonator-based sensor device for measurement of laser wavelength changes in a wavelength division multiplexing system. Laser light is absorbed into the gold nanorod array on the resonator beam, which has wavelength dependent absorption, resulting in temperature change of the beam. The wavelength change can be measured from resonant frequency shift. The maximum shift and resolution were 68.8 Hz/nm and 0.29 pm, respectively.

15:45 LOCAL-GATE ELECTRICAL ACTUATION, DETECTION, AND TUNING OF ATOMIC-LAYER MoS₂ NANO-ELECTROMECHANICAL RESONATORS

R. Yang¹, C. Chen², J. Lee¹, D.A. Czaplowski², and P.X.-L. Feng¹
¹*Case Western Reserve University, USA* and
²*Argonne National Laboratory, USA*

We report on the first single- and few-layer MoS₂ NEMS resonators with local-gate all-electrical actuation, detection and tuning at VHF. The local-gate structure facilitates frequency modulation detection by reducing the parasitic capacitance. We scale down the devices to length of 800nm and air gap of 170nm, attaining fundamental mode resonance up to 130MHz. These devices lay the foundation for individually addressable MoS₂ resonators, which could enable arraying and large-scale integration.

16:00 Break & Exhibit Inspection

Session VIIIa - Actuators**Session Chairs:**T. Seki, *OMRON Corporation, JAPAN*H. Shea, *Ecole Polytechnique Fédérale Lausanne (EPFL), SWITZERLAND***Rio Pavilion 8 - 11****16:30 A BIDIRECTIONAL KNUDSEN PUMP WITH SUPERIOR THERMAL MANAGEMENT FOR MICRO-GAS CHROMATOGRAPHY APPLICATIONS**Q. Cheng, Y. Qin, and Y.B. Gianchandani
University of Michigan, USA

We report a bidirectional high-flow Knudsen pump (KP) with 2X–3X better performance than previous results as a consequence of superior thermal management. Having no moving parts, the KP is reliable, silent and scalable. However, bidirectional KPs require controlled thermal dissipation that matches the pumping need in each direction. This work integrates a micromachined KP with customized planar heat sinks that enhance the heat dissipation.

16:45 TRIBOELECTRIFICATION DRIVEN FIN-FACT (FLIP-FLOP ACTUATED CHANNEL TRANSISTOR) FOR SECURITY APPLICATIOND. Kim¹, D.-C. Ahn², M.G. Allen¹, and Y.-K. Choi²¹*University of Pennsylvania, USA* and ²*Korea Advanced Institute of Science and Technology (KAIST), KOREA*

A silicon-nanowire switch with triboelectricity is proposed for future electronics with enhanced security application. The dimensions of the nanowire switch are width 50 nm and thickness 100 nm, fabricated with aid of CMOS fabrication technology. By hand-touch on gate pad, the fabricated switch can turn-on as well as turn-off by destruction of fin-channel which comes from electrostatic force by triboelectricity. This technology is expected as a security-enhanced future electronics.

17:00 ELECTROSTATIC BENDING ACTUATORS WITH LIQUID FILLED NANOMETER SCALE GAPM. Gaudet^{1,2}, S. Uhlig^{1,2}, M. Stolz¹, S. Arscott³, H. Conrad¹, S. Langa^{1,2}, B. Kaiser¹, and H. Schenk^{1,2}¹*Fraunhofer Institute for Photonic Microsystems, GERMANY,*²*Brandenburg University of Technology (BTU), GERMANY, and*³*CNRS, FRANCE*

We report a considerable improvement in the electrostatic actuation of silicon-based nano electrostatic drive (NED) structures via the insertion of a liquid into the nanosystem. The dielectric liquid provides an insulating, high dielectric constant deformable medium in the actuation gaps that enhances the generated force per unit-applied volt performance. The NEDs are micro/nanoelectromechanical systems (MEMS/NEMS); such NEDs show a vast improvement in terms of quasi-static actuation and chip area consumption compared to traditional actuation approaches, e.g. electrostatic comb-drive actuators.

17:15 A 25 MG MAGNETICALLY ACTUATED MICROROBOT WALKING AT > 5 BODY LENGTHS/SECD. Vogtmann, R. St. Pierre, and S. Bergbreiter
University of Maryland, College Park, USA

This paper presents the first demonstration of an untethered legged microrobot walking at speeds greater than 5 body lengths/second. To accomplish this feat, this work integrates contributions in multi-material robot leg design and microfabrication as well as high power actuation using an external magnetic field. The resulting 25mg, 4mm x 4mm x 5mm hexapedal robot has been measured walking at speeds in excess of 20 mm/sec.

Session VIIIb - Gas Sensors**Session Chairs:**P. Feng, *Case Western Reserve University, USA*X. Li, *Chinese Academy of Sciences, CHINA***Brasilia****16:30 HIGHLY SENSITIVE DETECTION OF VOC USING IMPACT IONIZATION INDUCED BY PHOTOELECTRON**Y. Kang, H.-I. Jung, D.-H. Baek, K. Lee, S. Pyo, and J. Kim
Yonsei University, KOREA

This paper reports the first detection of volatile organic compounds (VOCs) at various concentration using impact ionization induced by photoelectron. Photo ionization detectors (PIDs) cannot acquire reliable data of the gas species with ionization energy above 10 eV, unlike ours, and this is a highly advantageous aspect of our approach compared to PIDs. We observed decrease in current of the tested sensor very sensitively at the exposure to VOCs, and this novel detection mechanism is proposed.

16:45 MOF NANO-CRYSTALS OF ZIF-8 IDENTIFIED AS AMBIENT NO₂ GAS ABSORBENT BY USING RESONANT MICRO-CANTILEVER EXPERIMENTP. Xu, H. Yu, T. Xu, and X. Li
Chinese Academy of Sciences, CHINA

Based on resonant cantilever measurements, the MOF (metal-organic-framework) material of ZIF-8 is identified as an excellent adsorbent to capture NO₂ in ambient air. Herein, the adsorbing properties of ZIF-8 to NO₂ have been examined not only for qualitative judgment, but also for thermodynamic evaluation. Moreover, the molecular structure of hydrate NO₂ in air can be quantitatively obtained. Our results can help to reveal the formation mechanism of NO₂ associated PM2.5 and acid-rain.

17:00 HIGHLY ALIGNED SUSPENDED NANOWIRE ARRAY FOR SELF-HEATING TYPE GAS SENSORSK.-W. Choi, M.-H. Seo, J.-S. Lee, K. Kang, I. Park, and J.-B. Yoon
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We demonstrate a unique structure of highly aligned and suspended palladium nanowire array as a sensing element for self-heating type hydrogen gas sensors. The highly aligned nature of nanowires and top-down fabrication/integration technique of the nanowires enable controllable and uniform device fabrication. Moreover, a suspended structure removes heat loss through substrates, thus leading to efficient self-heating and fast gas sensing response with ultra-low power consumption.

17:15 LOW-VOLTAGE AND LOW-POWER FIELD-IONIZATION GAS SENSOR BASED ON MICRO-GAP BETWEEN SUSPENDED SILVER NANOWIRES ELECTRODES FOR TOLUENE DETECTIONH.-I. Jung, S. Pyo, and J. Kim
Yonsei University, KOREA

We demonstrate field-ionization gas sensor using suspended silver nanowires as electrodes. The tight gap between two facing sets of suspended in-plane nanowires on top of silicon microelectrodes. This produces field emission of electrons that result in ionization of gas molecules at a very low voltage applied. Resultantly, extremely low power consumption of 75 nW for toluene sensing is also achieved.

17:30 Adjourn for the Day

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WEDNESDAY, JANUARY 25**Plenary Speaker III**

Session Chair:

E. Meng, *University of Southern California, USA*

Rio Pavilion 8 - 11

08:00 DIRECT INTERFACING OF NEURONS TO HIGHLY INTEGRATED MICROSYSTEMS**Andreas Hierlemann***ETH Zurich, SWITZERLAND*

High-density transducer arrays and integrated microsystems enables fundamentally new neuroscientific insights. They enable high-throughput monitoring of action potentials of large neuronal networks over extended time to see effects of disturbances or developmental effects, and they facilitate detailed investigations of neuronal signaling characteristics at subcellular level. An example is the study of axonal signal propagation that has been largely inaccessible to other methods. Applications include research in neural diseases and pharmacology.

Session IX - Single Session 3

Session Chairs:

E. Meng, *University of Southern California, USA*J.-B. Yoon, *Korea Institute of Science & Technology (KAIST), KOREA*

Rio Pavilion 8 - 11

08:45 3D PRINTED THREE-FLOW MICROFLUIDIC CONCENTRATION GRADIENT GENERATOR FOR CLINICAL E. COLI-ANTIBIOTIC DRUG SCREENING

E.C. Sweet, J.C.-L. Chen, I. Karakurt, A.T. Long, and L. Lin

University of California, Berkeley, USA

Here, we demonstrate a three-dimensional, multi-input microfluidic concentration gradient generator, fabricated via ultra-high resolution Multijet 3D printing. The device is applied as an enhanced antibiotic screening tool to easily and rapidly determine individual antibiotic minimum inhibitory concentration values as well as to study the interactions of three antibiotics simultaneously in a gradient of "drug cocktails" on ampicillin-resistant K-12 E.Coli Bacteria.

09:00 WIDE BANDGAP β -Ga₂O₃ NANOMECHANICAL RESONATORS FOR DETECTION OF MIDDLE-ULTRAVIOLET (MUV) PHOTON RADIATION

X.-Q. Zheng, J. Lee, S. Rafique, L. Han, C.A. Zorman, H. Zhao, and P.X.-L. Feng

Case Western Reserve University, USA

We report the first experiments on suspended β -Ga₂O₃ nanostructures, and the demonstration of the first nanomechanical resonators made from single-crystal β -Ga₂O₃ nanosheets grown via LPCVD on 3C-SiC on Si. The devices exhibit multimode resonances from 10 to 80MHz, up to the 6th mode. A Young's modulus of $E_y=254$ GPa is extracted from the resonance measurement. Upon exposure to middle ultraviolet (MUV) radiation, these resonators exhibit frequency shifts with a responsivity of -3.8Hz/pW.

Session IX - Single Session 3**Rio Pavilion 8 - 11****09:15 NANORIM: SUB-MICRON STRUCTURING WITH REACTION INJECTION MOLDING**

R. Zandi Shafagh, W. van der Wijngaart, and T. Haraldsson
KTH Royal Institute of Technology, SWEDEN

We report "nanoRIM", the first reaction injection molding (RIM) replication method for thermosets with demonstrated feature sizes down to 250 nm. NanoRIM constitutes the first scalable manufacturing method for thermoset polymers that allows combining large (> cm) and small (< μm) lateral feature sizes and varying replica thickness in the same device. We demonstrate nanoRIM for manufacturing replicas in OSTE thermoset.

09:30 POWERING PORTABLE ELECTRONICS USING VOCAL FOLD VIBRATIONS

H. Cho¹, K. Noh², T. Ishikawa³, D. Yang¹, E. Sánchez-Sinencio², and H. Choo¹
¹California Institute of Technology, USA, ²Texas A&M University, USA, and
³Tohoku University, JAPAN

Using a multi-stacked array of vibration-driven energy harvesters and a custom-designed energy-harvesting (EH) circuit, we have achieved stable 3.12-mW power generation at 5.5 VDC from the acousto-mechanical vibrations of the human vocal folds at 75 dB. Using this approach, we have successfully charged 100-mAh Lithium-Polymer (LiPo) battery and operated a portable 2×16 LCD display (requiring 2.8 V, 10 mA). This approach proved to be a practical on-demand power source for wearable electronics.

09:45 FABRICATION OF BIOCOMPATIBLE FLUORESCENT HYDROGEL FOR IMPLANTABLE CONTINUOUS GLUCOSE MONITORING DEVICE

J. Sawayama, E. Nam, and S. Takeuchi
University of Tokyo, JAPAN

We developed the glucose-responsive fluorescent tetra-PEG gel based on diboric acid for implantable continuous glucose monitoring device. The fluorescent dye having diamine unit was immobilized into tetra-PEG gel. When the glucose concentration increased, the fluorescence intensity increased depending on the glucose concentration. By combining the tetra-PEG gel with implantable device, CGM system using fluorescent hydrogel can be a powerful approach for practical in vivo.

10:00 Break & Exhibit Inspection**Session Xa - Tactile & Flexible Sensors****Session Chairs:**

A. Bosseboeuf, *Centre for Nanoscience and Nanotechnology, FRANCE*
H. Takao, *Kagawa University, JAPAN*

Rio Pavilion 8 - 11**10:30 A "MICRO-MACRO" INTEGRATED PLANAR MEMS TACTILE SENSOR FOR PRECISE MODELING AND MEASUREMENT OF FINGERTIP SENSATION**

K. Watatani¹, R. Kozai¹, K. Terao^{1,2}, F. Shimokawa^{1,2}, and H. Takao^{1,2}
¹Kagawa University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

In this paper, a "micro-macro" integrated planar MEMS tactile sensor with two different scale tactile sensors are presented. The "micro-scale" tactile sensor detects "micro surface shape" and "micro-area frictional force" that are generated and detected at a fingerprint in the human's fingertip skin. On the other hand, the integrated "macro-scale" tactile sensor detects "overall contact pressure" and "macro-area sliding friction" that are detected by wide-area of skin.

Session Xa - Tactile & Flexible Sensors**Rio Pavilion 8 - 11****10:45 A KIRIGAMI-BASED PARYLENE C STRETCH SENSOR**

A. Baldwin and E. Meng
University of Southern California, USA

We report a Parylene C 'kirigami' device that transduces stretch. The array of slits etched into the Parylene C film permits elongation to 9 mm (180%) without plastic deformation or compromise of electrical integrity. Stretch was monitored via DC resistance, high-frequency impedance, and inter-trace capacitance. Parylene's high flexibility allowed comparable DC sensitivity to previous devices over a wider stretch range, and impedance and capacitance show promise for future applications.

11:00 STRESS-FREE STRETCHABLE ELECTRONIC DEVICE USING FOLDING DEFORMATION

Y. Iwata and E. Iwase
Waseda University, JAPAN

We developed a two-dimensionally (2-D) stretchable electronic device with stress-free region by applying origami folding. The key idea is to achieve "a stretching deformation of whole device" by "a local bending deformation". Because our device has stress-free region, we can use a rigid chip such a MEMS sensor and a metal wire without mechanical fracture or metal fatigue. In this paper, we demonstrated a 2-D deformability of the device with inorganic LED chips without wire problems.

11:15 A WIRELESS, SMARTPHONE-AIDED MAGNETIC STRAIN SENSOR FOR BIOMEDICAL APPLICATIONS

T. Zhang, M. Ochoa, R. Rahimi, and B. Ziaie
Purdue University, USA

We report an implantable wireless strain sensor comprising laser-machined polymeric magnetic stripes encapsulated in stiffer PDMS packages which are then embedded in a softer Ecoflex[®] band. This unique structure prevents the dislocation of magnetic stripes due to poor bonding while keeping the band stretchable. Strains within cardiac relevant range (60-100 bpm, 40-60 %strain) can be picked up wirelessly by a smartphone at a distance practical for cardiovascular applications.

11:30 ALL-PRINTED, PLANAR-TYPE MULTI-FUNCTIONAL WEARABLE FLEXIBLE PATCH INTEGRATED WITH ACCELERATION, TEMPERATURE, AND ECG SENSORS

D. Yamamoto, S. Nakata, K. Kanao, T. Arie, S. Akita, and K. Takei
Osaka Prefecture University, JAPAN

This study proposes a planar-type multi-functional flexible patch integrated with acceleration sensor, skin temperature sensor, and electrocardiogram sensor formed by all printing methods. By studying a strain engineering and proposing a new fabrication process and structure using Kirigami concept, all sensors are successfully integrated and demonstrated in an in-plane polyethylene terephthalate film.



Las Vegas Strip as viewed from the Voodoo Rooftop at the Rio Hotel

Session Xb - Manufacturing for BioMEMS**Session Chairs:**K. Kurabayashi, *University of Michigan, USA*P. Ruther, *University of Freiburg, GERMANY***Brasilia****10:30 PLASMONIC MICROPILLARS FOR MASSIVELY PARALLEL PRECISION CELL FORCE MEASUREMENT**

F. Xiao, X. Wen, and P.-Y. Chiou

University of California, Los Angeles, USA

We develop a gold nanoparticle embedded micropillar (GNEM) platform for large area, massively parallel, and high-precision cell force measurement. Gold nanoparticles implanted into PDMS micropillars by laser pulses serve as strong, point-source-like scattering centers under dark-field imaging. Precision tracking of micropillars can be realized under a low numerical aperture (NA) objective lens for simultaneous and parallel measurement of cell traction forces across a large area.

10:45 FIBER-SHAPED ARTIFICIAL TISSUE WITH MICROVASCULAR NETWORKS FOR BOTTOM-UP TISSUE RECONSTRUCTION

R. Sato and H. Onoe

Keio University, JAPAN

We describe a fiber-shaped microscale tissue with blood vessel networks. We co-cultured Hep-G2 and HUVEC in a collagen/alginate core-shell hydrogel microfiber. We observed difference in construction of blood vessel networks in the hepatic tissue by varying in the ratio of co-cultured cells and the diameter of the core. By arranging the fiber-shaped tissues to construct macroscale tissue assembly, we confirmed the connection of blood vessel networks between the assembled fiber-shaped tissues.

11:00 3D-EBP: A PROGRAMMABLE 3D BIONANORECEPTOR ASSEMBLY

S. Chu, B. Hurwitz, T.E. Winkler, A.D. Brown, J.N. Culver, and R. Ghodssi

University of Maryland, College Park, USA

This paper presents a novel fabrication method, electro-bioprinting, for 3-D hierarchical bionanoreceptor arrays enabled by highly localized and controlled electrowetting of Tobacco Mosaic Viruses on micropillar arrays. The process evaluation results through SEM and fluorescent labeling confirms successful application of electrowetting principles for advanced biofabrication processes toward multiplexed 3-D biosensors.

11:15 2D AND 3D FUNCTIONAL NANOSTRUCTURES OF GENETICALLY ENGINEERED SPIDER SILK USING FOCUSED ION BEAMJ. Jiang¹, S. Zhang², N. Qin¹, Z. Zhou¹, X. Xia³, H. Tao¹, and K. Liu¹¹Chinese Academy of Sciences, CHINA, ²University of Texas, Austin, USA, and ³Shanghai Jiao Tong University, CHINA

We report a new technique for both 2d and 3d protein nanostructuring by using focus ion beam (FIB) as the fabrication tool and genetically engineered recombinant spider silk as the biocompatible and biofunctional photoresist. Recombinant spider silk is mechanically strong, biocompatible, biodegradable and biofunctionalizable. Precise control of 2d and 3d nanostructures using genetically engineered spider silk and FIB offers new route to design protein-based functional nanoarchitectures.

Session Xb - Manufacturing for BioMEMS**Brasilia****11:30 STRAIN ENGINEERED 3D MAGNETIC MICRO ACTUATORS WITH PROGRAMMED MAGNETIC ANISOTROPY**

C. Peters, S. Staufert, and C. Hierold
ETH Zurich, SWITZERLAND

This work combines programmed magnetic anisotropy and strain engineering in superparamagnetic polymer composites to enable tailored deformation of planar strips into three-dimensional actuators with shape-independent magnetic properties. The developed process allows for pattern feature sizes below 5 μm using composite with a particle content of 10 %vol. The feasibility of this approach is demonstrated by fabricating helically swimming microrobots with diameters as small as 100 μm .

11:45 Lunch on Own & Exhibit Inspection**Session XIa - Materials & Manufacturing****Session Chairs:**

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

M. Ziaei, *iSono Health, USA*

Rio Pavilion 8 - 11**13:30 STRETCHABLE ELECTRONIC DEVICE WITH REPEAT SELF-HEALING ABILITY OF METAL WIRE**

T. Koshi and E. Iwase
Waseda University, JAPAN

We developed a stretchable electronic device with self-healing ability of a wire crack. The crack caused by stretching is healed when a voltage is applied to the cracked wire covered with metal nanoparticles solution. By designing a circuit, we controlled the applied voltage and current for the healing to be avoid excessive Joule heating in the healed crack. This consideration enables us to heal a crack of tens of micrometers in width and to practically achieve a stretchable electronic device.

13:45 HORIZONTALLY ALIGNED CARBON NANOTUBE SCAFFOLDS FOR FREESTANDING STRUCTURES WITH ENHANCED CONDUCTIVITY

C. Silvestri¹, F. Marciano¹, B. Morana^{1,2}, V. Prodranovic¹,
S. Vollebregt¹, G.Q. Zhang¹, and P.M. Sarro¹

¹*Delft University of Technology, NETHERLANDS and*

²*Institute of Materials for Electronics and Magnetism, ITALY*

By combining the capability to grow long vertically aligned CNTs with a liquid-assisted flattening technique, dense arrays of HACNTs exhibiting a high degree of alignment are realized and integrated at wafer-scale. We obtained an unprecedented enhancement in electrical conductivity of horizontally aligned carbon nanotube structures, using a 10 nm conformal coating of alumina or amorphous silicon carbide.

14:00 ARTIFICIAL INSECT WINGS WITH BIOMIMETIC MORPHOLOGY AND STIFFNESS

Z. Liu¹, X. Yan^{1,3,4}, M. Qi^{1,2}, Y. Zhu¹, X. Zhang¹, and L. Lin²

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

³*Collaborative Innovation Center of Advanced Aero-Engine, Beijing, CHINA, and ⁴National Key Laboratory of Science and Technology on Aero-Engine Aero-Thermodynamics, CHINA*

We present both fabrication and characterization methodologies for artificial insect wings with biomimetic morphology and stiffness using laser cutting and bonding of multilayer materials. Two distinctive achievements have been accomplished: (1) simple and versatile fabrication for the wing shape and venation pattern; and (2) good matches of mass, fundamental natural frequency and equivalent stiffness to the real biological insect wings.

Session XIa - Materials & Manufacturing**Rio Pavilion 8 - 11****14:15 A FACILE DRY-PMMA TRANSFER PROCESS FOR ELECTRON-BEAM LITHOGRAPHY ON NON-FLAT SUBSTRATES**J.-H. Kim¹, Q. Zhou², and J. Chang¹¹University of Utah, USA and ²University of Nebraska, USA

A technique that facilitates high resolution patterning on irregular substrates by transferring a dry-PMMA film. The film can be pre-e beam or post-e beam patterned, depending on the applications. It can then be transferred to challenging substrates that include the edge of the silicon wafer, the suspended bridge, the conical surface, and sharp tip of a sewing needle. It is possible to make the patterns on irregular surface. Also it allows to fix various shaped chips or narrow circuits.

14:30 ELECTROSTAMPING THROUGH SAM LAYER FOR 1:1 TRANSFER OF 40-NM-WIDE PATTERNS OVER MM² AREAY. Li¹, H. Toshiyoshi², and H. Fujita²¹Toshiba Corporation, JAPAN and ²University of Tokyo, JAPAN

SAM layer is used for the first time on the contact surfaces of electrostamping/nanoimprinting molds to control meniscus size and thereby to achieve high-resolution 1:1 transcription of 40-nm-wide patterns over several mm² area.

14:45 PRECISE CONTROL OF NATURAL AND SYNTHETIC SILK NANOSTRUCTURES USING ELECTRON BEAM LITHOGRAPHYN. Qin¹, S. Zhang², J. Jiang¹, Z. Zhou¹, X. Xia³,
H. Tao^{1,2}, and K. Liu¹¹Chinese Academy of Sciences, CHINA, ²University of Texas, Austin, USA, and ³Shanghai Jiao Tong University, CHINA

We demonstrate the ability to finely control the nanostructure of silk proteins (both naturally derived and genetically engineered) in two and three dimensions. This control is obtained by careful water-based reverse engineering and synthesis of silk materials through self-assembly coupled with directed electron beam interaction with the protein's matrix. Engineered recombinant spider silk proteins show higher resolution thanks to added control over the molecular weight of the protein.

Session XIb - Optical MEMS**Session Chairs:**S. Lucyszyn, *Imperial College London, UK*O. Solgaard, *Stanford University, USA***Brasilia****13:30 STEREO METAMATERIAL CONSISTING OF THREE DIMENSIONAL META-ATOMS FABRICATED BY PROGRAMMABLE STRESS INDUCED DEFORMATION FOR OPTICAL MODULATION**

Y. Mao, Z. Chen, J. Zhu, Y. Pan, W. Wu, and J. Xu

Peking University, CHINA

We present a general three-dimensional (3D) nanofabrication technique, focused ion beam stress induced deformation (FIB-SID), to construct stereo metamaterials which could realize considerable optical response. Such technique is simple-step process, allowing programmable and accurate origami on various metal and dielectric thin films. Theoretical and experimental results manifest that the metamaterial composed of the 3D SRRs has reflection minimum and abrupt phase change at 5.3 μm .

Session XIb - Optical MEMS**Brasilia****13:45 SUB-WAVELENGTH OPTICAL LITHOGRAPHY VIA NANOSCALE POLYMER LENS ARRAY**J. Wu¹, K. Tao¹, D. Chen², and J. Miao¹¹*Nanyang Technological University, SINGAPORE and*²*Shanghai Jiao Tong University, CHINA*

For the first time, under exposure is employed to fabricate the patterned photoresist templates with hemispherical cross-sectional profile. The long-range highly regular polymer lens array is replicated from the photoresist templates. The polymer lens array is utilized as the soft phase shift element to produce nearly perfectly periodic nanostructures with sub-100 nm feature size across centimeter-scale areas.

14:00 MEMS TUNABLE SILICON PHOTONIC GRATING COUPLER FOR POST-ASSEMBLY OPTIMIZATION OF FIBER-TO-CHIP COUPLINGC. Errando-Herranz, M. Colangelo, S. Ahmed, J. Björk, and K.B. Gylfason
KTH Royal Institute of Technology, SWEDEN

We experimentally demonstrate the first MEMS tunable photonic fiber-to-waveguide grating coupler, and apply it to electrically optimize the light coupling between an optical fiber and an on-chip silicon photonic waveguide. Efficient and stable fiber-to-chip coupling is vital for combining the optical quality of fibers with the integration density of silicon photonics. Our device has the potential to lower assembly cost and extend device lifetime, by enabling electrical post-assembly adjustments.

14:15 A BI-DIRECTIONAL FREE-SPACE OPTICAL COMMUNICATION SYSTEM WITH MEMS SPATIAL LIGHT MODULATOR FOR AGILE DATA LINKS. Jeon and H. Toshiyoshi
University of Tokyo, JAPAN

We report an FSO (free space optical) communication system for bi-directional PON (passive optical network) based on a MEMS SLM (spatial light modulator). A piezoelectric PZT scanner is used to display a marker image to invite a POT (passive optical terminal) and to keep the optical link even when the POT moves. Unlike wireless network that broadcast radio signals, the FSO system in this work provides high security data transmission.

14:30 ULTRAHIGH-Q SILICA-ALN HYBRID DISK OPTOMECHANICAL MODULATORD.B. Sohn, J. Kim, and G. Bahl
University of Illinois, Urbana Champaign, USA

We design and fabricate a silica-AlN hybrid optomechanical modulator for high-efficiency operation. The device is composed of an ultrahigh optical Q silica disk wedge resonator with integrated AlN electromechanical transduction layer. This system combines extremely high optical Q (silica) material with the best known electro-mechanical transduction strategy.

14:45 A RESONANT EYE-TRACKING MICROSYSTEM FOR VELOCITY ESTIMATION OF SACCADES AND FOVEATED RENDERINGN. Sarkar^{1,2}, B. O'Hanlon^{1,2}, A. Rohani^{1,2}, D. Strathearn^{1,2},
G. Lee^{1,2}, M. Olfat^{1,2}, and R.R. Mansour^{1,2}¹*University of Waterloo, CANADA and* ²*AdHawk Microsystems, CANADA*

We demonstrate the first MEMS-based eye tracking system that operates in resonance to obtain >3300 eye position measurements per second, a 25-fold improvement over previously reported MEMS. The system achieves a 10x improvement in bandwidth, volume (0.5 cm³) and power consumption (20mW) when compared to existing systems, all without compromising resolution. The system produces accurate real-time velocity measurements within saccades, enabling on-the-fly prediction of gaze and foveated rendering.

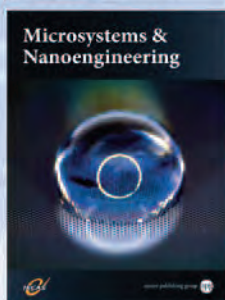
15:00	Poster/Oral Session III Poster presentations are listed by topic category with their assigned number starting on page 34.
17:00	Adjourn for the Day
19:00 - 22:00	Conference Banquet

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THURSDAY, JANUARY 26**Plenary Speaker IV**

Session Chair:

C.T.-C. Nguyen, *University of California, Berkeley, USA***Rio Pavilion 8 - 11****08:00 THE "HOW AND WHY" A DECEPTIVELY SIMPLE ACOUSTIC RESONATOR BECAME THE BASIS OF A MULTI-BILLION DOLLAR INDUSTRY****Rich Ruby***Broadcom Ltd., USA*

The paper focuses on piezoelectric resonators called FBAR. In order to understand the device, the paper gives a tutorial on the derivation of certain key Figure of Merit values including coupling coefficient and Q. The paper allows the talk to give a more historic view of how and why this deceptively simple device became the basis of a multi-billion dollar industry. The project was cancelled approximately 7 times and there were roughly equal number of 'miracles' that kept the program alive. The paper provides the basis for a better appreciation of the FoM and the dollars placed on high performance filters.

Session XII - Single Session 4

Session Chairs:

J. Ducr e, *Dublin City University, IRELAND*J. Lotters, *Bronkhorst High-Tech BV, NETHERLANDS***Rio Pavilion 8 - 11****08:45 ADVANCED SURFACE MICROMACHINING PROCESS – A FIRST STEP TOWARDS 3D MEMS**J. Classen¹, J. Reinmuth¹, A. K alberer¹, A. Scheurle¹, S. G unther¹,
S. Kiesel¹, B. Schellin¹, J. Br auer¹, and L. Eicher²¹*Robert Bosch GmbH, GERMANY* and ²*Bosch Sensortec GmbH, GERMANY*

An advanced micromachining process has been developed to further push the performance limits of mass-produced inertial MEMS. The main achievement of the new platform technology is the usage of two independent silicon layers instead of one to form 3D-like masses, springs, and electrodes. The first accelerometer generations using this technology are being manufactured for automotive and CE applications and provide an unparalleled offset stability even in stress-affected mold packages.

09:00 NANO-ELECTROKINETIC PURIFICATION DEVICE FOR A CONTINUOUS PERITONEAL DIALYSATE RECYCLERW. Kim¹, K. Kim¹, H. Lee², Y.S. Kim², J.C. Lee¹,
G.Y. Sung³, and S.J. Kim¹¹*Seoul National University, KOREA*, ²*Seoul National University Hospital, KOREA*, and ³*Hallym University, KOREA*

Nano-electrokinetic purifier, for the first time, was applied for a novel continuous peritoneal dialysate recycler. Most of hazardous substances were sufficiently removed by ion concentration polarization (ICP) mechanisms. Slightly charged toxin (creatinine) was mostly eliminated through nanoporous membrane, and uncharged toxin (urea) was perfectly decomposed by electrochemical reactions. A macro ICP purifier was finally demonstrated for practical applicability.

Session XII - Single Session 4**Rio Pavilion 8 - 11****09:15 VIRTUALLY ROTATED MEMS GYROSCOPE WITH ANGLE OUTPUT**

I.P. Prikhodko, J.A. Gregory, and M.W. Judy
Analog Devices, Inc., USA

We experimentally demonstrate a virtually rotated MEMS rate integrating gyroscope capable of measuring rates below 0.1 deg/s, which is two orders of magnitude below the rate threshold set by frequency and damping mismatches arising from fabrication imperfections. Measurements below the threshold are possible because angle-dependent bias drifts are averaged out by applying virtual rotation using gyroscope electrodes. Our method may enable commercialization of angle measuring MEMS gyroscopes.

09:30 MONOLITHIC TRI-AXIS HIGH-SHOCK ACCELEROMETERS WITH MHz- LEVEL ULTRA-HIGH RESONANT FREQUENCY

H. Zou^{1,2}, F. Chen¹, J. Wang¹, H. Bao¹, and X. Li^{1,2}

¹*Chinese Academy of Sciences, CHINA and*

²*University of the Chinese Academy of Sciences, CHINA*

This paper reports a novel structure for monolithically integrated tri-axis high-shock accelerometer. All the tri-axial sensors feature ultra-high resonant-frequencies. Axially compressed/stretched tiny-beams serve as piezoresistors and are connected into Wheatstone-bridge. The sensors are bulk-micromachined in non-SOI (111) wafers. Tested under 10000g high-shock acceleration, every of the three accelerometers exhibit 1-2 μ V/g sensitivity and about 1.5MHz resonant frequency.

09:45 A BI-DIRECTIONAL LARGE-STROKE ELECTROTHERMAL MEMS MIRROR WITH MINIMAL THERMAL AND TEMPORAL DRIFT

W. Wang^{1,2,3}, Q. Chen¹, D. Wang¹, L. Zhou³, and H. Xie³

¹*WIO Technologies Ltd. Co., CHINA, ²Shanghai Jiao Tong University, CHINA, and ³University of Florida, USA*

This paper reports a novel bi-directional electrothermal MEMS mirror with its mirror plate's position insensitive to ambient temperature and stable over time. In contrast, the electrothermal MEMS mirrors demonstrated previously are unidirectional and the position of the mirror plate changes with ambient temperature and drifts over time.

10:00 Break & Exhibit Inspection**Session XIII - Single Session 5****Session Chairs:**

M. Despont, *CSEM Microsystems, SWITZERLAND*

D. Horsley, *University of California, Davis, USA*

Rio Pavilion 8 - 11**10:30 FABRICATION OF SUSPENDED NANOWIRES USING SUSPENDED CARBON NANOTUBES AS TEMPLATE FOR GAS SENSING**

D.-H. Baek¹, J. Choi², and J. Kim¹

¹*Yonsei University, KOREA and ²Yeungnam University, KOREA*

This paper reports a method to fabricate nanowires suspended between electrodes using suspended carbon nanotubes as template for highly sensitive gas sensing. Since all the fabrication steps are scalable and dry process, the sensors with nanowires could be mass-produced suppressing possible contamination or damage. The wide variety of material choice with similar morphology of suspended nanowires may be harnessed for the fabrication of highly sensitive gas sensors with diverse sensing targets.

Session XIII - Single Session 5**Rio Pavilion 8 - 11****10:45 CAPILLARY PUMPING WITH A CONSTANT FLOW RATE INDEPENDENT OF THE LIQUID SAMPLE VISCOSITY AND SURFACE ENERGY**

W. Guo, J. Hansson, and W. van der Wijngaart
KTH Royal Institute of Technology, SWEDEN

We introduce and verify a capillary pump design that, for the first time, enables autonomous pumping of sample liquid with a flow rate constant in time and independent of sample viscosity and surface energy. These results are of interest for applications that rely on a predictable flow rate and where fluid viscosity or surface energy are not precisely known, e.g. in capillary driven lateral biosensors for urine or blood sample, where large variations exist in viscosity and surface energy.

11:00 GEOMETRY INFLUENCE OF THE MICRO ALKALI VAPOR CELL ON THE SENSITIVITY OF THE CHIP-SCALE ATOMIC MAGNETOMETERS

Y. Ji, Q. Gan, L. Wu, and J. Shang
Southeast University, CHINA

This paper focuses on the micro alkali vapor cell's geometry influence on the sensitivity of the chip-scale atomic magnetometers. For the first time, by using micro spherical alkali vapor cells instead of traditional planar alkali vapor cells, we demonstrate a chip-scale atomic magnetometer with a ten-fold improvement in sensitivity experimentally.

11:15 FIRST THRUST FROM A MICROFABRICATED ATMOSPHERIC ION ENGINE

D. Drew, D.S. Contreras, and K.S.J. Pister
University of California, Berkeley, USA

We present the first thrust from a new kind of MEMS actuator, the atmospheric electrohydrodynamic (EHD) ion engine. Outlet air velocity is directly measured to deduce thrust produced by the engine, which is consistent with theory, simulation, and current/voltage measurements. A thrust to weight ratio of over 15 has been demonstrated, significantly higher than wing-based MEMS flyers. We propose to use this actuator to build autonomous flying microrobots with no moving parts.

11:30 3D SULFONATED GRAPHENE HYDROGEL FOR ENHANCED CHEMICAL SENSING

J. Wu¹, K. Tao¹, D. Chen³, J. Miao¹, and L.K. Norford²
¹*Nanyang Technological University, SINGAPORE,*
²*Massachusetts Institute of Technology, USA, and*
³*Shanghai Jiao Tong University, CHINA*

One-step, hydrothermal synthesized 3D sulfonated reduced graphene oxide hydrogel (S-RGOH) is exploited to detect several gases with high sensitivity, fast response and reversibility. Compared with unmodified RGOH counterpart, the 3D NaHSO₃ functionalized S-RGOH sensor exhibits more than two orders of magnitude higher responses to NO₂ and a 58.9 times higher response to NH₃. Importantly, an integrated microheater is deployed to improve the selectivity of detecting various gaseous chemicals.

11:45 Outstanding Student Award & Final Remarks**12:00 Conference Adjourns**

MONDAY
13:00 - 15:00**TUESDAY**
13:00 - 15:00**WEDNESDAY**
15:00 - 17:00**TRACK/CLASSIFICATION****Bio and Medical MEMS****Materials, Fabrication and Packaging****MEMS Actuators and PowerMEMS****MEMS for Electromagnetics****MEMS Physical Sensors****Micro- and Nanofluidics****Technical Topics on MEMS Products**

See poster floor plan on the last page of this program.

Bio and Medical MEMS**Biosensors and Bioreactors****M-001 A BIOLOGICALLY-INSPIRED ELECTRO-CHEMICAL
REFERENCE ELECTRODE**H. Ren, C.I. Torres, Z. Zhang, and J. Chae
Arizona State University, USA

Inspired by the possibility of controlling the respiration of micro-organisms, we present a unique biologically-inspired reference electrode, demonstrating a stable electro-chemical potential for extended period of time. The bio-inspired reference electrode sits in a microfluidic chamber, having specific micro-organisms, *Geobacter sulfurreducens*, on a platinum thin film, which is an exoelectrogen capable of transferring electrons outside its outer membrane to complete its respiration process.

**T-002 A MONOLITHIC DIELECTROPHORETIC CHIP FOR REAL-TIME
LOW-ABUNDANCE BACTERIA DETECTION**K. Kikkeri and M. Agah
Virginia Tech, USA

We report the development of a low-cost, disposable, monolithic chip integrating bacteria enrichment using passivated-electrode insulator-based dielectrophoresis (π DEP) and capacitively-coupled bioimpedance sensing enabling real-time detection of small populations of bacteria (~100 cells) in water. Accuracy of the chip was determined by testing *Staphylococcus epidermidis* at various concentrations and enrichment times. The chip features electric field tuning, enabling selective enrichment.

**W-003 CODE-DIVISION MULTIPLEXED RESISTIVE PULSE SENSOR
NETWORKS FOR SPATIO-TEMPORAL DETECTION OF
PARTICLES IN MICROFLUIDIC DEVICES**N. Wang, R. Liu, R. Khodambashi, N. Asmare, and A.F. Sarioglu
Georgia Institute of Technology, USA

We introduce a technique based on code-based multiplexing of micro-machined resistive pulse sensors to detect spatiotemporally distributed particles on a microfluidic device. To demonstrate our technology, we designed and fabricated a network comprised of 10 sensors integrated in a microfluidic device and characterized our device using human cancer cell line. To decode sensor signals, we introduce an algorithm that combines machine-learning techniques with minimum mean-squared error estimation.

Biosensors and Bioreactors**M-004 A SELF-POWERED SENSOR PATCH FOR GLUCOSE MONITORING IN SWEAT**

E. Cho, M. Mohammadifar, and S. Choi
State University of New York, Binghamton, USA

We develop a self-powered sensor patch for detection of glucose levels in sweat. This wearable, non-invasive biosensor integrates a vertically stacked paper-based glucose/oxygen enzymatic fuel cell into a standard Band-Aid patch. The device, attached directly to human skin, wicks sweat from human skin and monitors an electrochemical energy conversion as a transducing element for glucose monitoring in sweat, thus obviating the requirement of external power sources and readout instrumentation.

T-005 DETECTION OF PLANT HORMONE ABSCISIC ACID (ABA) USING AN OPTICAL APTAMER-BASED SENSOR WITH A MICROFLUIDICS CAPILLARY INTERFACE

C. Song, C. Chen, X. Che, W. Wang, and L. Que
Iowa State University, USA

This paper reports an optical aptamer-based plant hormone sensor with a microfluidics capillary interface. The ssDNA aptamer-based sensor has better sensitivity with excellent specificity for detecting abscisic acid than the ELISA detection kit from Sigma, indicating its potential for screening different plant hormones in a complicated matrix. Additionally, its microfluidics capillary interface allows the samples to be delivered to the sensor automatically without external pumps.

W-006 DEVELOPMENT OF PATTERNABLE NANOPOROUS CARBON ELECTRODES FOR USE AS BIOSENSORS BASED ON REDOX CYCLING EFFECT

Y. Lim, D. Sharma, and H. Shin
Ulsan National Institute of Science & Technology (UNIST), KOREA

This paper reports a highly sensitive electrochemical-enzymatic redox cycling based biosensor platform using patternable nanoporous carbon electrodes. 3D carbon electrodes with macro-/micro-sized pores were fabricated in a batch way using microwave O₂ plasma etching and carbon-MEMS. Enzymes were selectively immobilized on the nanoporous carbon electrode via diazonium reduction. The enzyme-functionalized nanoporous carbon based sensors showed enhanced response for the detection of glucose.

M-007 EMBROIDERED BIOSENSORS ON GAUZE FOR RAPID ELECTROCHEMICAL MEASUREMENTS

X. Liu and P.B. Lillehoj
Michigan State University, USA

We demonstrate for the first time embroidered electrochemical sensors on gauze for rapid measurements of wound biomarkers. Robust, flexible electrodes were successfully fabricated onto medical gauze and wound dressings via embroidery. Proof-of-concept was carried out by performing quantitative measurements of uric acid, a biomarker for wound healing, in simulated wound fluid.

T-008 MEMS BASED IMPEDANCE BIOSENSOR FOR RAPID DETECTION OF LOW CONCENTRATIONS OF FOODBORNE PATHOGENS

A. Abdullah¹, I. Jasim¹, M. Alalem², M. Dweik², and M. Almasri¹
¹University of Missouri, USA and ²Lincoln University, USA

We design, fabricate and test a single impedance based biosensor for rapid detection of food-borne pathogens with low concentration. The performance of the devices was excellent as evidenced by the focusing capability that increased the strength of the measured signal by a factor of 18 for cell concentration of 25 CFU/ml, high sensitivity for low concentration of (13 CFU/ml) and rapid turnaround time of 2 hours.

Biosensors and Bioreactors

W-009 MICROFLUIDIC CHIP HAVING MULTI FLUORESCENCE MICROSENSORS FOR SPATIOTEMPORAL SENSING OF CULTURE ENVIRONMENTH. Maruyama¹, K. Takagi¹, T. Masuda¹, O. Suzuki², and F. Arai¹
¹Nagoya University, JAPAN and ²Tohoku University, JAPAN

We proposed on-chip spatiotemporal sensing for monitoring interactions between cells and environment using fluorescence multi-sensing. The microfluidic chip integrating optical sensor is used to construct the harmonious environment like in vivo to reconstruct high-quality organs in ex vivo. We demonstrated spatiotemporal variation of pH, Calcium ion was measured and during transformation of octacalcium phosphate (OCP) to hydroxyl apatite (HA) inside the microfluidic chip.

M-010 PLASMONIC-ELECTROCHEMICAL DUAL MODALITY MICROFLUIDIC SENSOR FOR CANCER BIOMARKER DETECTIONM.A. Ali, S. Tabassum, Q. Wang, Y. Wang, R. Kumar, and L. Dong
Iowa State University, USA

A dual-modality microfluidic immunosensor is reported for the detection of cancer biomarker using graphene oxide assembled periodic gold nanoposts array. The sensor provides both the electrochemical and surface plasmon resonance signatures of a biomarker. The dual modalities produced on a single platform can improve detection reliability, precision, and false alarm resilience. The detection of limit of the sensor for epidermal growth factor receptor 2 (ErbB2) is ~1.0 fM.

T-011 ODOR-SENSITIVE FIELD EFFECT TRANSISTOR (OSFET) BASED ON INSECT CELLS EXPRESSING INSECT ODORANT RECEPTORSD. Terutsuki, H. Mitsuno, Y. Okamoto, T. Sakurai, A. Tixier-Mita, H. Toshiyoshi, Y. Mita, and R. Kanzaki
University of Tokyo, JAPAN

We developed a novel bio-hybrid odorant sensor based on insect odorant receptors (ORs). This sensor can detect odorant responses of living cells expressing insect ORs as electrical output. The electrical output discriminated structurally similar odorants with high sensitivity and selectivity. The selectivity was consistent with odorant responses of insect ORs. The sensor can use various insect ORs and it could be applied to general odorants, such as foods, drugs, or harmful substances.

W-012 REAL-TIME MONITORING OF INSULIN USING A GRAPHENE APTAMERIC NANOSENSORZ. Hao^{1,2}, Y. Zhu¹, X. Wang¹, P. Rotti³, C. Dimarco¹, S. Lin¹, X. Zhao², J. Engelhardt³, J. Hone¹, and Q. Lin¹¹Columbia University, USA, ²Harbin Institute of Technology, CHINA, and ³University of Iowa Carver College of Medicine, USA

We present a new kind of electrical approach that employs a graphene-based Field-effect transistor (FET) nanosensor to real-time monitor insulin concentrations via affinity binding of insulin and insulin binding aptamer IGA3 that immobilized on graphene surface. The binding can promote the G-quadruplex formation of the aptamer, which structural conformation change will alter carrier density in the graphene, yielding continuous detectable signals.

M-013 SELF-ASSEMBLED GOLD NANOPARTICLE FILM FOR NANOSTRUCTURE-INITIATOR MASS SPECTROMETRY WITH PASSIVE ON-LINE SALT FRACTIONATIONT.A. Duncombe¹, P. Adams¹, A. Singh^{1,2}, and T. Northen¹¹Joint Bioenergy Institute, USA and ²Sandia National Laboratories, USA

Self-assembly of fluorinated-Au Nanoparticle films are a mass-producible fabrication methodology for generating nanostructure-initiator mass spectrometry substrates capable of high sensitivity detection of peptides (20 fmol). Further, through micropatterning of the fluorinated-Au Nanoparticle film to create discrete wettability, we passively fractionate the hydrophobic molecules of interest from high-salt background environments for robust and predictable mass spectrometry.

Biosensors and Bioreactors

- T-014 SPIRAL CHANNEL FOR FAST AND NOISE-FREE MICRORNA DETECTION**
S. Fujii¹, T. Osaki¹, N. Misawa¹, K. Kamiya¹, and S. Takeuchi^{1,2}
¹Kanagawa Academy of Science and Technology (KAST), JAPAN and
²University of Tokyo, JAPAN

We developed a microRNA detection device, which can be used for unpurified samples. Hybridization of microRNA with the complementary DNA ensures the detection in a sequence specific manner. Magnetic beads and magnetic field were applied to achieve the noise-free detection schematic. Finally, the spiral channel was used to enhance the hybridization rate of RNA-DNA, and the following digestion reaction by duplex-specific nuclease.

- W-015 SURFACE-ENHANCED RAMAN SPECTROSCOPY ANALYSIS OF DNA BASES USING ARRAYED AND SINGLE DIMER OF GOLD NANOPARTICLE**
K. Ikegami, K. Sugano, and Y. Isono
Kobe University, JAPAN

This paper reports ultrasensitive surface-enhanced Raman spectroscopy (SERS) detection of four kinds of DNA bases. The gold nanoparticle dimer was directionally arrayed on a substrate in order to achieve huge enhancement at all dimers. 10 pM limit of detection for four DNA bases and 0.1 s rapid detection for adenine were achieved. A single dimer was fabricated and we clarified single-molecule-level SERS detection of DNA bases was possible using the single dimer.

- M-016 VOLATILE ODORANT DETECTION BY CORNEAL EPITHELIAL CELLS USING PERFUSABLE FLUIDIC CHAMBER**
E. Nam^{1,2} and S. Takeuchi^{1,2}
¹University of Tokyo, JAPAN and
²Japan Science and Technology Agency (JST), JAPAN

This work presents a method to detect volatile odorant using corneal epithelial cells with olfactory receptors. We first fabricate a device that provides the air-liquid environment by (i) a dome shaped chamber to confine the air and (ii) channels to maintain humidity of the cells on the bottom of the device. Using the device, we successfully detected the volatile odorant using the fluorescence imaging of the corneal epithelial cells that were transfected with the mammalian olfactory receptors.

- T-017 μ RESPIROMETER TO DETERMINE THE OXYGEN CONSUMPTION RATE OF MAMMALIAN CELLS IN A MICROFLUIDIC CELL CULTURE**
F. Bunge¹, S. van den Driesche¹, A. Waite², U. Mirastschijski¹, and M.J. Vellekoop¹
¹University of Bremen, GERMANY and ²Alfred-Wegener-Institute, GERMANY

We present a novel μ respirometer to determine the oxygen consumption rate (OCR) of mammalian cells. The oxygen concentration is measured with the fluorescent dye PtTFPP in a polystyrene-matrix. This film is integrated into a closed microfluidic chip made out of only oxygen-impermeable materials like glass and silicon. This results in a low drift and allows long-term measurements with mammalian cells. With this chip, we determined the OCR of basophil RS-ATL8 cells as 32amol/(cell•s).



Bio and Medical MEMS**Manufacturing for Bio- and Medical MEMS****W-018 CARDIAC TOXICITY SCREENING USING POLYMERIC CANTILEVER INTEGRATED WITH CELL STIMULATORS**

N.E. Oyunbaatar, D.S. Kim, E.S. Kim, B.K. Lee, and D.W. Lee
Chonnam National University, KOREA

We describe a smart cantilever device to precisely monitor the drug-induced contraction forces of cardiac cells. The cantilever device is composed of two parallel microelectrodes and 3D micro-patterns on the surface. The unique biocompatible complex polymer sensor can effectively screen cardiac cell beating duration and contraction force difference which due to the various functional drug during the electrical stimulation.

M-019 A RAPID MICRO-MOLDING PROCESS FOR FABRICATING POLYMERIC BIODEGRADABLE 3D STRUCTURES USING HYDROPHOBIC ELASTOMERIC MOLDS

J. Zhou, M. Ochoa, S. Samaddar, R. Rahimi, V.D. Badwaik, D.H. Thompson, and B. Ziaie
Purdue University, USA

We have developed a diffusion-based micro-molding fabrication process for creating polymeric, biodegradable micro-structures (e.g., microneedles) which can be loaded with bio-active delicate therapeutic agents. As demonstration, fabricated gelatin microneedles loaded with a DNA complex using polydimethylsiloxane (PDMS) mold are sufficiently sharp to penetrate porcine skin and exhibit transfection of the DNA complex.

T-020 BIOINSPIRED VASCULAR STRUCTURES VIA 3D PRINTING AND SUSPENDED MICROFLUIDICS

J.G. Dawson¹, D.C. Hesley¹, N. Katagiri¹, C.P. Nguyen¹, S.A. Mannuel¹, T.G. Wun¹, A.B. Chow¹, N.R. Gupta², J.V. Bonventre^{2,3}, and R.D. Sochol¹
¹University of Maryland, College Park, USA, ²Brigham and Women's Hospital, Harvard Medical School, USA, and ³Harvard University, USA

We utilize a 3D-printed design and suspended microfluidics to manufacture a microscale device for modeling vascular structures with relevant biological architecture. An extracellular matrix analogue is embedded in the 3D-printed framework, and endothelial cells are seeded on the device interior to form a tubular monolayer. This design mimics vascular geometry while maintaining a permeable surface to allow for the characterization of transcellular molecular transport.

W-021 CROSS-SCALE MANIPULATIONS OF HETEROGENEOUS COMPONENTS WITH ARBITRARY SHAPES

J.-T. Liao, Y.-L. Chen, and S.-K. Fan
National Taiwan University, TAIWAN

Heterogeneous hydrogel microcomponents were constructed on an electromicrofluidic (EMF) device with the features and advantages of (1) manipulation prepolymer droplets and particles with EMF, (2) photo crosslinking with arbitrary light shapes through a DMD (digital micromirror device), and (3) assembly the crosslinked components with EMF.

M-022 ELECTRIC STRESS PRODUCES BILAYER LIPID MEMBRANES BY EXCLUSION OF EXCESSIVE OIL LAYER

Y. Matsunaga^{1,2}, T. Osaki², N. Misawa², S. Fujii², K. Kamiya², N. Miki^{1,2}, and S. Takeuchi^{2,3}

¹Keio University, JAPAN, ²Kanagawa Academy of Science and Technology (KAST), JAPAN, and ³University of Tokyo, JAPAN

This paper proposes a formation method for oil-layer-free bilayer lipid membranes (BLM) by using a compressive force of electric field. We examined a qualitative protocol for oil-layer-free BLM formation. We succeeded in BLM formation using a mixture of hexadecane and n-decane. The method would contribute to produce vivo-like membranes appropriate for membrane protein functionalities.

Manufacturing for Bio- and Medical MEMS**T-023 FABRICATION OF FLEXIBLE POLYMER BIO-MEMS WITH SUBMICRON FEATURES**

K. Scholten and E. Meng
University of Southern California, USA

We present and characterize a method for fabricating Parylene-based bioMEMS with submicron feature size and resolution, using electron beam lithography and nano-contact printing methods adapted for biocompatible, organic polymers. These techniques are used to produce a prototype, high-density flexible neural probe with trace spacing of 750 nm.

W-024 FROM 2D FLUIDIC ARRAY SCREENING TO 3D BACTERIAL CAPTURING STRUCTURES IN A POINT OF CARE SYSTEM FOR SEPSIS DIAGNOSIS

M.-A. Shahbazi, K. Kant, J.J. Kaplinsky, V. Aaydha Chidambara, D.D. Bang, and A. Wolff
Technical University of Denmark, DENMARK

A combined 2D microfluidic-microarray high throughput approach is used to identify universal bacterial capturing ligands that can be tethered on the surface of 3D sponges to concentrate bacteria in diagnosis devices. The developed platform allows for the first time the simultaneous monitoring of various ligands' affinities to different bacteria species in a dynamic condition in-vitro.

M-025 GENE TRANSFER BY CIRCULATING PLASMA BUBBLE FLOW

Y. Yamanishi^{1,2}, R. Tanaka¹, Y. Arakawa³, and Y. Nakatsu¹
¹Kyushu University, JAPAN, ²Japan Science and Technology Agency (JST), JAPAN and ³Shibaura Institute of Technology, JAPAN

We have succeeded in injection of plasmid to adherent cells which are suspended in the plasma-bubbles laden circulation flow in a chamber. High-speed plasma-bubbles are generated by glass electrode and the air-liquid interface has a stiction force which draws the gene. The circulating flow increased the chance for cells to contact air-liquid interface of bubbles which enclosed plasma or reactive gas. Finally, the high reactive interface enables gene(GFP) transfer to cells efficiently.

T-026 VERSATILE 3-D STACKING OF 2-D PAPER-BASED BIOBATTERIES

Y. Gao and S. Choi
State University of New York, Binghamton, USA

We demonstrate a novel fabrication technique of 2-D paper-based biobatteries that can be easily connected in series or parallel by folding the sheet or stacking several sheets of paper devices. A stackable, and 3-D manufactured bacteria-powered battery is developed by folding two functional layers (i.e. a conductive hydrophilic reservoir as an anode and a solid electron acceptor as a cathode) integrated into a single sheet of chromatography paper.

W-027 HIGH-YIELD INDIUM-BASED WAFER BONDING FOR LARGE-AREA MULTI-PIXEL OPTOELECTRONIC PROBES FOR NEUROSCIENCE

E. Klein, C. Gossler, O. Paul, U.T. Schwarz, and P. Ruther
University of Freiburg, GERMANY

We optimized the yield of an indium-based wafer-level bonding process for joining 4-inch sapphire and silicon wafers to realize neural probes for optogenetic research in neuroscience. The sapphire wafer comprise 50x50 μm^2 GaN-based LEDs. The yield is optimized by using an analytical model and experimental study varying the bond metal thickness and area. The stress-induced rupture is completely suppressed by employing up to 4- μm -thick indium with a lift-off process on up to 20% of the wafer area.

Manufacturing for Bio- and Medical MEMS

- M-028 NANO 3D PRINTING-ENABLED MICROPOST ARRAY GRADIENTS**
A. Mengis, R. Gopal, N. Feldman, N. Kedia, D. Hesley, J. Young,
T. Fobe, L. Fernandez, C. Anderson, and R.D. Sochol
University of Maryland, College Park, USA

We develop a two-photon Direct Laser Writing (DLW) strategy to create arrays of dual-structured microposts that vary in height (and therefore stiffness) from post-to-post for cell mechanobiological studies. To micromold polydimethylsiloxane (PDMS), we employ DLW to 3D print moldable structures with 100 nm layer height.

- T-029 A THERMORESPONSIVE ELECTROMECHANICAL MICROCHIP FOR TEMPERATURE CONTROL IN BIOMEDICAL SMART IMPLANTS**
A.L. Roy and K. Takahata
University of British Columbia, CANADA

We report a thermoresponsive electromechanical microchip targeting temperature regulation applications in electrothermal implants for their safe operation in vivo. Footprint downscaling is essential for implantable transducers to assist in greater integration density and biocompatibility which is achieved through chip design and fabrication to allow its integration with a variety of in vivo microsystems that require thermal management.

- W-030 WAFER-SCALE HIGH-RESOLUTION PATTERNING OF BIOSTRUCTURES USING SILK LIGHT CHAIN PROTEIN PHOTOLITHOGRAPHY**
W. Liu¹, S. Zhang¹, W. Lee¹, and T.H. Tao^{1,2}
¹*University of Texas, Austin, USA* and ²*Chinese Academy of Sciences, CHINA*

We report on wafer-scale high resolution patterning of bio-microstructures using silk fibroin light chain (L-fibroin) as the photoresist material. The enhanced patterning resolution, the improved etching selectivity and the inherent biocompatibility of such protein-based photoresist provides opportunities in fabricating large scale biocompatible functional microstructures.

Bio and Medical MEMS**Materials for Bio- and Medical MEMS**

- M-031 COMPARATIVE STUDY OF THE VISCOELASTICITY OF PARYLENE THIN FILMS FOR MEMS USING NANO-DMA AND MOLECULAR DYNAMICS**
W. Sui¹, M.S. Duvieusart¹, J. Zhao², Y.-C. Tai³, and Y.-K. Lee¹
¹*Hong Kong University of Science and Technology, CHINA,*
²*Jiangnan University, CHINA,* and ³*California Institute of Technology, USA*

We present a comparative study of the viscoelasticity of parylene C (PPC) by using Nano-DMA (Dynamical Mechanical Analysis) and Molecular Dynamics (MD) simulations. The predicted T_g determined from the MD model is consistent with the previous works. Furthermore, with Time-Temperature Superposition principle (TTSP), we successfully determined the master curve of PPC, for the first time, very important for bio-MEMS devices.

- T-032 GAS PERFUSABLE MICROFABRICATED MEMBRANES FOR HIGH-DENSITY CELL CULTURE**
C.A. Cook¹, Y. Liu¹, J. Lu², N. Chen², Y. Fong², and Y.-C. Tai¹
¹*California Institute of Technology, USA* and ²*City of Hope, USA*

We report the design, fabrication, and feasibility of a high-density cell culture system capable of cell substrate densities of 40 cm²/cm³, greater than 250x current commercially available systems. This design provides oxygen directly from gas perfusable membranes on which the cells are grown to overcome oxygen delivery limitations in traditional culture systems. Membranes are composed only of medical grade PDMS and Parylene to mitigate contaminant leaching concerns.

Materials for Bio- and Medical MEMS

W-033 GRAPHENE OXIDE COATED FABRIC LAYERS FOR THE EFFICIENT ISOLATION OF CIRCULATING TUMOR CELLSJ. Bu¹, Y.J. Kim¹, Y.-T. Kang¹, T.H. Lee¹, J. Kim², H. Kim², and Y.-H. Cho¹¹Korea Advanced Institute of Science and Technology (KAIST), KOREA and ²Se Hong Trading, KOREA

We present the fabric sheet layers, functionalized with graphene oxide (GO) for the sensitive isolation of circulating tumor cells (CTCs). Compared to the previous microfluidic-based CTC detection devices, which require complicated and long fabrication processes, the fabric sheet layers are simply fabricated by conventional textile manufacturing; thus the device is mass producible at extremely low-cost. Therefore, high sensitive CTC isolation is achieved with simple preparation.

M-034 MECHANICAL ENHANCED HYDROGEL FIBER ENCAPSULATING CELLS FOR LONG-TERM TRANSPLANTATION

F. Ozawa, J. Sawayama, and S. Takeuchi

University of Tokyo, JAPAN

This paper describes a core-shell hydrogel microfiber consisted of alginate and tetra-arm poly(ethylene glycol) (tetra-PEG) encapsulating rat insulinoma cells using a microfluidics process with a coaxial device and rapid gelation induced by diffusion of two different cross-linkers of barium ion and dithiothreitol in the laminar flow.

T-035 MICROFLUIDIC DETECTION OF SOIL NITRATE IONS USING NOVEL ELECTROCHEMICAL FOAM ELECTRODEM.A. Ali¹, K. Mondal², Y. Wang¹, N.K. Mahal¹, M.J. Castellano¹, and L. Dong¹¹Iowa State University, USA and ²North Carolina State University, USA

We report a microfluidic flow-through soil nitrate sensor integrating a nanocomposite of graphene foam-titanium nitride nanofibers (GO-TiN NFs) as a sensing interface. Synergistic effect from the integration of TiN NFs with GF into microfluidics is demonstrated, showing a great potential for improved sensing efficacy.

Bio and Medical MEMS

Medical Microsystems (Probes, Implantables, Imaging, Etc.)

W-036 SAMPLE-TO-ANSWER MOBILE MALARIA MOLECULAR DIAGNOSTIC SYSTEM FOR RESOURCE-LIMITING AREAS

G. Choi, D. Song, S. Shrestha, J. Miao, L. Cui, and W. Guan

Pennsylvania State University, USA

We develop a field-deployable, standalone, sample-in-answer-out molecular diagnostic system (AnyMDx) to enable real-time molecular analysis of blood-borne malaria disease at the point of need. The system seamlessly integrates all nucleic acid testing steps from sample preparation to real-time amplification and detection. Fully automated AnyMDx delivers ultra-sensitive and species-specific molecular answers to the patients within 40 minutes without any requirement of laboratory infrastructures.

M-037 A NOVEL BIOMEMS DEVICE FOR EFFICIENT ON-CHIP SINGLE CELL LOADING AND 3D ROTATION

L. Huang, P. Zhao, S. Bian, G. Shi, P. Liu, S. Zong, and W. Wang

Tsinghua University, CHINA

We report a novel microfluidic device that integrates mechanical constriction for single cell trap in the channels, which are enclosed by thick (or 3D) C-PDMS (carbon-black-PDMS) electrodes and bottom planar transparent electrode for dielectrophoretic (DEP) manipulation. Leveraging hydrodynamics and dielectrophoresis (DEP), this simple biomedical microsystem enables more efficient loading of one single cell in place and controllable 3D cell rotation than before.

Medical Microsystems (Probes, Implantables, Imaging, Etc.)

T-038 FLEXIBLE MULTI-MODAL MICRO-BIOSENSOR TOWARDS ACCURATE CANCER TISSUE TARGETING DURING BIOPSY PROCESS

J. Park, Y. Jeong, and I. Park

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

We report microscale flexible biosensor with multimodal sensing capabilities (electrical impedance, pH and glucose concentration) and application to the sensor integrated biopsy needle towards accurate cancer targeting during biopsy process. The sensor is thin enough to be integrated onto the surface of needle, which avoids additional tissue damage during the needle insertion. The sensor shows sensing performance that can cover the physical/chemical differences between cancer and normal tissues.

W-039 A MICRO LUNG CHIP TO ASSESS AIR POLLUTANT EFFECTS

S. Noh and H. Kim

University of Utah, USA

This paper reports an advanced μ -lung chip and its first time use in assessing the air pollutant effects on the lung cells, ultimately enabling the resultant toxicity evaluation with tracer permeation after the air pollution exposure. On the μ -lung chip it was demonstrated to culture lung cells on an inserted porous membrane; to monitor the cell growth over time by measuring TEER with integrated micro electrodes; and to allow a comprehensive evaluation of cell responses and tracer permeation.

M-040 FLEXIBLE CYLINDRICAL NEURAL PROBE WITH GRAPHENE ENHANCED CONDUCTIVE POLYMER FOR MULTI-MODE BCI APPLICATIONSM.-H. Wang¹, K. Nikaidon², Y. Kim², B.-W. Ji^{1,3}, H.-C. Tian¹, X.-Y. Kang^{1,4}, C.-S. Yang¹, B. Yang¹, X. Chen¹, X.-L. Wang¹, Y. Zhang², and J.-Q. Liu¹*¹Shanghai Jiao Tong University, CHINA, ²National Institute of Advanced Industrial Science and Technology (AIST), JAPAN, ³Northwestern University, USA, and ⁴École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND*

This paper reports a novel flexible neural probe fabricated by cylindrical substrates lithography to obtain high space selectivity for multi-mode Brain-Computer-Interface (BCI) applications. The probe was further modified with graphene enhanced conductive polymer composite by an electrochemical method to improve the interface performance. The results show the modified probe has high charge storage capacity (CSC), low impedance and good stability.

T-041 A PARYLENE CUFF ELECTRODE FOR PERIPHERAL NERVE RECORDING AND DRUG DELIVERYA.M. Cobo¹, B. Boyajian¹, C. Larson¹, K. Scholten¹, V. Pikov², and E. Meng¹*¹University of Southern California, USA and ²GlaxoSmithKline, UK*

Novel peripheral nerve electrode for recording and drug delivery. Micromachined interface consists of Pt electrodes embedded in Parylene microfluidics. Locking mechanism ensures snug fit to the nerve for localized drug delivery to induce axonal sprouting towards the electrodes. Here, we present fully functional Lyse-and-Attract Cuff Electrodes with initial testing of locking mechanism in vivo, improved microfluidic channel design, localized drug delivery, and low impedance recording electrodes.

W-042 A pH-SENSITIVE HYDROGEL-BASED SMART SWITCH FOR GI-TRACT PAYLOAD RELEASE

H. Jiang, W. Yu, J. Zhou, and B. Ziaie

Purdue University, USA

In this work, we developed a low-cost and tunable pH-change-driven smart switch based on the deflection of a conductive elastic membrane induced by the swelling of a pH-responsive hydrogel to achieve an electrical on-and-off switch. The described pH-responsive switch can be fabricated via scalable layer-by-layer approach and suitable of incorporation into ingestible capsules for pH-controlled localized drug release in the gastrointestinal (GI) tract.

Medical Microsystems (Probes, Implantables, Imaging, Etc.)**M-043 AN ELECTROSTATIC MEMS SCANNER WITH IN-PLANE AND OUT-OF-PLANE TWO-DIMENSIONAL SCANNING CAPABILITY FOR CONFOCAL ENDOSCOPIC IN VIVO IMAGING**

H.J. Li, X.Y. Duan, and T.D. Wang
University of Michigan, USA

This work presents an electrostatic MEMS scanner with in-plane and out-of-plane two-dimensional (2D) scanning capability, enabled by using a novel gimbal-like structure, for a compact side-viewing confocal endomicroscope collecting in vivo fluorescent images in horizontal and oblique planes of tissues. By employing this single scanner, real-time and large field of view (FOV) switchable horizontal/oblique in vivo imaging is achieved.

T-044 COMPACT OCT ENDOMICROSCOPIC CATHETER USING FLIP-CHIP BONDED LISSAJOUS SCANNED ELECTROTHERMAL MEMS FIBER SCANNER

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

We report a compact optical coherence tomography (OCT) endomicroscope with a Lissajous scanned electrothermal MEMS fiber scanner. The electrothermal MEMS fiber scanner was precisely designed and flip-chip bonded with a thin printed circuit board and completely packaged with 1.65 mm diameter housing tube, 1 mm diameter GRIN lens, and an optical fiber. Compact OCT catheter was successfully combined with a spectral-domain OCT system. 2D OCT images of a finger were successfully obtained.

W-045 HIGH ASPECT RATIO SILICON FIELD EMITTER ARRAYS (FEAS) AS MINIATURIZED STABLE ELECTRON SOURCE FOR CATHETER-BASED RADIOTHERAPY

X. Wang, G. Stemme, and N. Roxhed
KTH Royal Institute of Technology, SWEDEN

This paper aims at a miniaturized electron source based on high aspect ratio silicon field emitter arrays (FEAs) for generating x-rays in catheter-based radiotherapy applications. The carefully designed and fabricated $400\ \mu\text{m} \times 400\ \mu\text{m}$ silicon FEAs demonstrate sufficiently stable emission currents under moderate vacuum requirements. The experimental results are in line with the requirement of delivering relevant doses for cancer radiotherapy.

M-046 FIRST DUAL-COLOR OPTRODE WITH BARE LASER DIODE CHIPS DIRECTLY BUTT-COUPLED TO HYBRID-POLYMER WAVEGUIDES

M. Schwaerzle, P. Ringwald, O. Paul, and P. Ruther
University of Freiburg, GERMANY

We report on the design, fabrication, assembly as well as optical, electrical and thermal characterization of the first MEMS-based dual-color optrode with laser diodes (LDs) directly butt-coupled to waveguides for neuroscientific research. Integrated microelectrodes (EL) are aligned to the optical stimulation sites with application specific EL arrangements. Integrated Pt meanders positioned underneath the LD pads and along the probe shafts enable temperature measurements during system operation.

T-047 OPTICAL LOW ANGLE PASS FILTER FOR HIGH RESOLUTION ROBUST PHOTOPLETHYSMOGRAPHY MONITORING

C.-S. Hwang, S.-P. Yang, J.-W. Park, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We develop an optical low angle pass filter (OLAPF) for enhancing the signal-to-noise ratio (SNR) of the reflectance type photoplethysmography (PPG) using the slanted micro mirror array structure, which can reduce the noise of the PPG signal inside of the human tissue. The OLAPF can block the highly scattered light, which lost their directionality inside of the human skin, while transmitting the PPG signals from the capillary by allowing the low-angle incident light.

Medical Microsystems (Probes, Implantables, Imaging, Etc.)

W-048 PARYLENE BASED FLEXIBLE GLUCOSE SENSOR USING GLUCOSE-RESPONSIVE FLUORESCENT HYDROGEL

M. Kaiho, J. Sawayama, Y. Morimoto, and S. Takeuchi
University of Tokyo, JAPAN

We developed a flexible sensor for in vivo continuous glucose monitoring. This sensor has a glucose-responsive fluorescent hydrogel on a flexible parylene electrode with a wireless module. The flexibility of the sensor could reduce damage to tissues and organs of the patients. In the experiment, we implanted the sensor into the subcutaneous of a rat, and successfully performed the wireless measurement of glucose concentration in vivo.

M-049 PHOTOELECTRIC NEURAL INTERFACE COMBINING WIRE-BONDING μ LEDS WITH IRIIDIUM OXIDE MICROELECTRODES FOR OPTOGENETICS

B.-W. Ji^{1,2}, X.-Y. Kang^{1,3}, M.-H. Wang¹, B.-F. Bao¹, H.-C. Tian^{1,4},
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¹Shanghai Jiao Tong University, CHINA, ²Northwestern University, USA,

³École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND, and

⁴XD Power Systems Co., Ltd, CHINA

We design, fabricate, and test a novel photoelectric neural interface (PENI) which combines wire-bonded micro light emitting diodes array and iridium oxide microelectrodes array. The back-to-back assembly method is utilized to allow light through the aligned holes of both arrays with almost no attenuation. As an optogenetics tool, the device will be attached on the cortical surface of a mouse expressing ChR2 which can realize synchronized light modulating and neural signal recording.

T-050 PROSTHETIC ARACHNOID GRANULATIONS USING 3D PRINTING TECHNOLOGY

T.-L. Liu^{1,2}, S. Zahedi^{2,3}, R.J. Garling², F. Kralick⁴,
C.A. Harris², and M.M.-C. Cheng²

¹Chang-Gang University, TAIWAN, ²Wayne State University, USA,

³University of Toronto, CANADA, and ⁴Shore Physicians Group, USA

This paper investigates bead-based microfluidic diodes as self-regulated shunt valves for mimicking the physiological functions of arachnoid granulations, which acts as a one-way valve and allows cerebrospinal fluid (CSF) to exit the sub-arachnoid space and enter the blood stream in the brain. The prosthetic device has been fabricated using 3D printing (stereolithography), which allows layer-by-layer deposition of soft and biocompatible polymer with high precision.

W-051 MEMS 6-AXIS FORCE-TORQUE SENSOR ATTACHED TO THE TIP OF GRASPING FORCEPS FOR IDENTIFICATION OF TUMOR IN THORACOSCOPIC SURGERY

A. Nakai¹, K. Kuwana², K. Saito², T. Dohi², A. Kumagai³, and I. Shimoyama¹

¹University of Tokyo, JAPAN, ²Tokyo Denki University, JAPAN, and

³Touchence, Inc., JAPAN

We developed a MEMS 6-axis force-torque sensor attached to the tip of grasping forceps for identification of tumor in thoracoscopic surgery. To validate the grasping forceps with sensors, the gelatin in which a silicone sphere was embedded was grasped with it and the variations in 3-axis force and 3-axis torque depending on grasping positions were measured. The thickness and direction of the embedded object were derived from acquired data of normal force and 2-axis torque, respectively.

Medical Microsystems (Probes, Implantables, Imaging, Etc.)

M-052 SUBCELLULAR ELECTRODE ARRAYS FOR MULTISITE RECORDING OF DOPAMINE IN VIVO

H.N. Schwerdt, M. Kim, E. Karasan, S. Amemori, D. Homma, H. Shimazu, T. Yoshida, R. Langer, A.M. Graybiel, and M.J. Cima
Massachusetts Institute of Technology, USA

This abstract reports the fabrication and use of carbon fiber (CF) arrays with up to 8 recording electrodes with individual diameters of 8–10 μm (9–10 times smaller than conventional CF microelectrodes and other reported dopamine sensors) for electrochemical recording of dopamine and other neurochemicals from deep brain regions in a minimally invasive and high density manner.

T-053 ULTRA HIGH-ASPECT-RATIO NEUROPROBE: 5- μm -DIAMETER AND 400- μm -LENGTH NEEDLE DETECTS ACTION POTENTIALS IN VIVO

S. Yamagiwa, H. Sawahata, H. Oi, R. Numano, M. Ishida, K. Koida, and T. Kawano
Toyohashi University of Technology, JAPAN

This paper reports 5- μm -diameter and 400- μm -length ultra high-aspect-ratio needle electrodes for neuronal action potential recordings in vivo. The fabricated electrode shows the neural recording capabilities, as demonstrated in the in vivo recordings of action potentials from a mouse's cortex. To the author's knowledge, this is world's smallest extracellular recording needle, which will offer numerous electrophysiological recording applications while the brain tissue damage can be minimized.

W-054 WIRELESS INTRAOCULAR PRESSURE SENSOR USING STRETCHABLE VARIABLE INDUCTOR

M.H.M. Kouhani, A. Weber, and W. Li
Michigan State University, USA

We design, fabricate, and characterize a wireless, flexible, passive pressure sensor that enables real-time minimally invasive in-vivo intraocular pressure monitoring. It employs a novel approach which is measuring the strain on the sclera of eye-ball using integrated planar stretchable variable inductor. Comparing with the state-of-the-art devices which are based on variable capacitors, major reduction in fabrication complexity and higher stability for long-term measurements are achieved.

M-055 WORLD'S FIRST BIO-DEGRADABLE ACTUATOR FOR REMOVAL-FREE IMPLANTABLE MEMS

H. Sato, Y. Inoue, M. Ikeuchi, and K. Ikuta
University of Tokyo, JAPAN

A new concept of an implantable device made of bio-degradable polymers is proposed. Since the bio-degradable polymer is decomposed and absorbed in a human body, the surgery for taking out is not required after use. We succeeded to develop a "bio-degradable actuator" requiring no electric power. The prototype micro actuator was fabricated and the driving principle was verified successfully. Various applications for medicine can be conceivable.

Bio and Medical MEMS

Nanobiotechnology

T-056 CHARACTERIZATION OF BIOMOLECULES USING AN APTAMER-BASED GRAPHENE NANOSENSOR

X. Wang^{1,2}, Z. Hao¹, W. Zhang^{2,3}, and Q. Lin¹

¹Columbia University, USA, ²East China University of Science and Technology, CHINA, and ³University of Saskatchewan, CANADA

We report kinetic and energetic characterization of biomolecular interactions using, for the first time, a microfluidic aptameric graphene field-effect transistor (FET) nanosensor to yield insight into the pharmacologic basis of biomolecular recognition.

Nanobiotechnology

W-057 DYNAMIC MANIPULATION AND PATTERNING OF BREAST CANCER CELLS IN BIOSOLUTIONH. Jia¹, H. Tang¹, A. Rede^{1,2}, X. Liu¹, H. Liu¹, and P.X.-L. Feng¹¹Case Western Reserve University, USA and²Hathaway Brown School, USA

This work describes the first experimental exploration of non-invasive, fast and dynamic manipulation of breast cancer cells by harnessing multimode micromechanical resonators operated in biosolution. We demonstrate that groups of breast cancer cells are spatially manipulated into controlled microscale patterns, facilitated by the spatially rich multimode resonances.

M-058 FINE VIRTUAL CATHODE DISPLAY FOR BIOMOLECULES CONTROL AND CELL NANO SURGERYT. Hoshino¹, M. Yoshioka¹, A. Wagatsuma¹, H. Miyazako^{1,2}, and K. Mabuchi¹¹University of Tokyo, JAPAN and²Japan Society for the Promotion of Science, JAPAN

Electron beam (EB) induced fine virtual cathode (VC) on a 100-nm-thick SiN membrane has been developed using inverted-EB lithography (I-EBL). Here we present electrokinetic property of the VC for biological materials and instantly control their spatio-temporal responses using the VC. This technique was applied to pinpoint transmembrane molecules delivery and in-situ molecules patterning with any instant design. So we call this technique virtual cathode display for biomolecules.

T-059 NANOBLADE ARRAY FOR SPATIAL DISSECTION OF SINGLE CELLS AND TISSUESD. Kagawa¹, M. Kusumoto¹, Y. Takemura¹, H. Takao¹, F. Shimokawa¹, and K. Terao^{1,2}¹Kagawa University, JAPAN and²Japan Science and Technology Agency (JST), JAPAN

We propose a novel method for sampling single cells and intracellular biomolecules without losing spatial information in tissues or in single cells, using Si nano-blade array device. Pushing the device physically against cells or a sliced tissue allows us to dissect and keep them in the space walled by the blade structures. The biomolecules are extracted in each space are collected with ligand molecules immobilized on the blades or a micropipette approaching from the backside of the device.

W-060 ON-CHIP INTERNALIZATION PROCESS OF AN INTRACELLULAR NANOBOT INTO A SINGLE CELL

K. Ogawa, K. Uesugi, and K. Morishima

Osaka University, JAPAN

We develop an intracellular nanobot to stimulate organelles. The nanobot is made of a carbon nanocoil with a Ni layer, has a helical shape and can demonstrate corkscrew motion like flagella by a rotating magnetic field. In order to stimulate organelles of the specific cell and analyze some local biochemical reactions, a microfluidic device is used for internalization process of a nanobot into the cell.

M-061 ON-SITE MANIPULATION OF SINGLE DNA MOLECULES USING OPTICALLY-DRIVEN MICROCHOPSTICKSR. Inukai¹, H. Takao¹, F. Shimokawa¹, and K. Terao^{1,2}¹Kagawa University, JAPAN and²Japan Science and Technology Agency (JST), JAPAN

This paper reports a novel DNA manipulation technique for the analysis of single DNA molecules under a fluorescence microscope. We successfully manipulated single DNA molecules using two microstructures driven by two laser beams, where we handled them like 'chopsticks'. This manipulation technique allows the imaging of single DNA molecules with its intact state, which will lead to the nanotechnology-based DNA analysis.

Bio and Medical MEMS**Tissue Engineering****T-062 MICROFLUIDIC ENABLED RAPID BIOPRINTING OF HYDROGEL
μFIBER BASED POROUS CONSTRUCTS**M. Nie¹, P. Mistry², J. Yang², and S. Takeuchi¹¹University of Tokyo, JAPAN and ²University of Nottingham, UK

A rapid and high-resolution bioprinter based on a capillary coaxial microfluidic printer head and vacuum substrate, was conceived and built up in this work. We demonstrated the printing of porous (400 μm pitch) 3D bio-scaffold made up of calcium alginate microfibers with a printing resolution (i.e. fiber diameter) of ca. 150 microns, at a speed of 40 mm/s, which is approximated 10x faster than the existing ones with comparable resolution.

**W-063 ENGINEERING A THREE-DIMENSIONAL TISSUE MODEL WITH
A PERFUSABLE VASCULATURE IN A MICROFLUIDIC DEVICE**Y. Nashimoto¹, I. Kunita², A. Nakamasu³, Y. Torisawa¹, M. Nakayama¹,
H. Kotera¹, K. Nishiyama², T. Miura³, and R. Yokokawa¹¹Kyoto University, JAPAN, ²Kumamoto University, JAPAN, and³Kyushu University, JAPAN

We developed a microfluidic platform for a tissue model with a perfusable vasculature, which allows, for the first time, a perfusion in a tissue model. Our group previously reported that a spheroid of lung fibroblasts could induce angiogenesis from microchannels. In this study, we showed that the sprouts could connect with vessel-like structure in a spheroid and form a perfusable vasculature in a spheroid. This model opens up new techniques for tissue-culture.

**M-064 FORMATION OF VESSEL-LIKE CHANNEL USING ALGINATE FIBER
AS A SACRIFICIAL STRUCTURE**K. Nishimura¹, N. Mori¹, Y. Morimoto¹, and S. Takeuchi^{1,2}¹University of Tokyo, JAPAN and²Japan Science and Technology Agency (JST), JAPAN

This research reports a method to fabricate loop-shaped vessel-like channel for perfusion of culture medium in a cell-laden collagen gel. We used alginate fibers as sacrificial structures for construction of channels. By integration of a loop-shaped alginate fiber with tube connectors in a cell-laden collagen gel, we achieved perfusion of medium via a loop-shaped channel. We believe that this method will be useful for in vitro construction of 3D tissues with complex-shaped vessel-like channels.

**T-065 CELL COCULTURE WITHIN ELECTRICALLY PATTERNED CELLS
AND HYDROGEL STRUCTURES**

J.-H. Lee, Y.-T. Lo, and S.-K. Fan

National Taiwan University, TAIWAN

We report a new method that can pattern cells and hydrogels on two different scales to form a biomimetic in vitro liver tissue by electromicrofluidic (EMF) techniques. In this research, EMF, capable of simultaneous control of multiple fluids and particles with appropriate electrical signals, is used to construct heterogeneous hydrogel microstructure and pattern multiple cells on varied scales into an in vitro hepatic-lobule-like arrangement in one step on a single device.

Tissue Engineering**W-066 ON-CHIP CELL GYM**

M. Horade¹, C.-H.D. Tsai¹, H. Ito¹, N. Higashino¹, T. Akai¹, U. Yokoyama², Y. Ishikawa², S. Sakuma³, F. Arai³, and M. Kaneko¹

¹Osaka University, JAPAN, ²Yokohama City University, JAPAN, and

³Nagoya University, JAPAN

A novel microfluidic system for applying cyclic pressure to cells during incubation is developed. The cyclic pressure generates stress stimulus to the cells, and is named "Cell Exercise". To observe what happens during the cell exercise in real-time, "On-Chip Cell Gym" is fabricated. The chip composed of two parallel chamber arrays, so that we can directly observe the difference with and without Cell Exercise. Dramatic growth of cell stress fibers is observed in the group of cell exercise.

Bio and Medical MEMS**Other Bio and Medical MEMS****M-067 A MICROFLUIDIC DEVICE FOR ANTIMICROBIAL SUSCEPTIBILITY TESTING OF COMBINED ANTIBIOTICS BY USING BROTH DILUTION METHOD**

W.-B. Lee¹, W.-H. Chang¹, H.-L. You², M.S. Lee³, and G.-B. Lee¹

¹National Tsing Hua University, TAIWAN, ²Chang Gung University, TAIWAN, and ³Kaohsiung Chang Gung Memorial Hospital, TAIWAN

A simple microfluidic device which can perform antimicrobial susceptibility testing (AST) of combined antibiotics against antibiotics-resistant bacteria has been presented. A new approach to measure fractional inhibitory concentration (FIC) of two antibiotics by performing broth dilution automatically was proposed and its performance had a good agreement with manual operation.

T-068 A PRACTICAL SINGLE CELL ANALYSIS METHOD FOR MECHANICAL CHARACTERIZATION OF CANCER CELLS

T. Baëtens^{1,2}, G. Perret^{1,2}, Y. Takayama², M. Kumemura^{1,2},

L. Jalabert³, S. Meignan^{2,4}, C. Lagadec², F. Hiroyuki^{1,2},

D. Collard^{1,2}, and M.C. Tarhan²

¹University of Tokyo, JAPAN, ²University of Lille, FRANCE,

³LAAS-CNRS, FRANCE, and ⁴Centre Oscar Lambret, FRANCE

We integrated MEMS tweezers with a microfluidic device for single cell mechanical characterization. Automated tip insertion in a channel via a side opening was combined with controlled flow by a vacuum pump to achieve a practical method for single cell analysis. Two groups of breast cancer cells (live and fixed) were tested and distinguished. This is the first step towards a non-labeled method for multi-parameter mechanical characterization of cells targeting early detection of metastatic CTCs.

W-069 AN INKJET PRINTED PIEZORESISTIVE BACK-TO-BACK GRAPHENE TACTILE SENSOR FOR ENDOSURGICAL PALPATION APPLICATIONS

Y.-M. Fu¹, M.-C. Chou¹, Y.-T. Cheng¹, E.B. Secor², and M.C. Hersam²

¹National Chiao Tung University, TAIWAN and

²Northwestern University, USA

The paper presents a tactile sensor design mimicking human finger touch to differentiate tissue hardness for endosurgical palpation applications. The sensor comprises two inkjet printed piezoresistive graphene-based sensing elements back-to-back linked for force and displacement detection. The experimental result shows the sensor can exhibit 2.1 and 5.3 mN force feedback from the fat and muscle tissues of pig respectively, while it is pressed with the same 100 μ m displacement to the tissues.

Other Bio and Medical MEMS**M-070 C. ELEGANS IMMOBILIZATION USING DEFORMABLE MICROFLUIDICS FOR IN VIVO STUDIES OF EARLY EMBRYOGENESIS AND INTESTINAL MICROBIOTA**

L. Dong, J. Zhang, M. Cornaglia, X. Huang, T. Lehnert, and M. Gijs
Ecole Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This paper reports a new approach for on-chip immobilization of *C. elegans* nematodes. We present two microdevices, both taking advantage of the elastic properties of polydimethylsiloxane (PDMS), but optimized for different applications. Innovative features are: (i) thanks to size-tunable PDMS structures, the same chip can be used for long-term immobilization of worms or larvae at all development stages; (ii) on-chip high-resolution imaging capability of in vivo biological processes.

T-071 ELECTROCHEMICAL-MECHANICALLY TRIGGERED TRANSIENT ELECTRONICS

K. Sim, X. Wang, and C. Yu
University of Houston, USA

We report a new type of transient electronics triggered through electrochemical-mechanical manner with robust and reliable mechanical design, low triggering voltage and fast transient characteristics. Such device is constructed through integrating electrochemical-mechanically triggered MEMS module with functional electronics. The triggering mechanism in this device opens up new vistas for transient electronics designs. Various materials and different type of electronics has been demonstrated.

W-072 HYBRID FILM FOR SELF-ADHESION AND SHAPE-CONTROLLING

S. Shimbo¹, T. Fujie^{1,2}, and E. Iwase¹

¹*Waseda University, JAPAN and*

²*Japan Science and Technology Agency (JST), JAPAN*

We propose a hybrid film that is composed of "nanosheet" with a hundreds-of-nanometer-thick polymeric film and "punched film" with hundreds-of-micrometer-thick film. Because of the thickness, the nanosheet is able to adhere to biological tissues without glue, but is sometimes difficult to handling. Our hybrid film is established both adhesiveness of nanosheet and shape-controlling ability of punched film.

M-073 LIGHT CONTROLLED INTEGRATABLE SINGLE CELL MICRO ROTARY VANE PUMP

Y. Yalikun, N. Tanaka, A. Yusufu, and Y. Tanaka
RIKEN, JAPAN

We develop a light controllable single cell driven micro rotary vane pump for transport fluid in small space based on a new type of bio-actuator: *Euglena*. *Euglena* has features of both animals and plants, which will allow, for the first time, bio-actuator functioned in fresh and salt water and take nourishment through photosynthesis.

T-074 POLYMER MEMS SENSOR FOR FLOW MONITORING IN BIOMEDICAL DEVICE APPLICATIONS

A.G.P. Kottapalli¹, Z.Y. Shen¹, M. Asadnia², S. Tian³,
K. Tao³, J. Miao³, and M.S. Triantafyllou⁴

¹*Singapore-MIT Alliance for Research and Technology (SMART),*

SINGAPORE, ²Macquarie University, AUSTRALIA, ³Nanyang

Technological University (NTU), SINGAPORE, and ⁴Massachusetts
Institute of Technology, USA

This work reports the application of an all-polymer MEMS flow sensor that addresses the critical problems associated with flow sensing in intravenous (IV) infusion appliances. Infusion pumps that are used to deliver fluids intravenously currently have no means of accurately sensing the velocity of fluids, thereby erroneous dosages remain undetected. The liquid crystal polymer (LCP) MEMS flow sensors presented in this work detect 'live-rates' of infusions with an accuracy of 1 mL/hr.

Materials, Fabrication, and Packaging for Generic MEMS and NEMS**Generic MEMS and NEMS Manufacturing****W-075 MINIATURIZED FLEXIBLE SENSOR WITH REDUCED GRAPHENE OXIDE/CARBON NANO TUBE MODIFIED BISMUTH WORKING ELECTRODE FOR HEAVY METAL DETECTION**

X. Xuan and J.Y. Park
Kwangwoon University, KOREA

We develop an electrochemical heavy metal ions sensor based on reduced graphene oxide (rGO)/carbon-nanotube (CNT) composite modified working electrode. The Au/rGO/CNT electrode was successfully patterned on polyimide substrate using a lithography technique, followed by the in-situ plating bismuth on the surface of the Au/rGO/CNT electrode as working electrode. The fully integrated electrochemical microsensor was then measured and evaluated for the detection of cadmium and lead ions.

M-076 A UNIVERSAL STRUCTURE FOR SELF-ALIGNED IN SITU ON-CHIP MICRO TENSILE FRACTURE STRENGTH TEST

R. Li, F. Yang, J. He, L. Zhang, T. Guan, Z. Fan, L. Cheng, and D. Zhang
Peking University, CHINA

We develop a universal self-aligned in situ on-chip micro tensile fracture strength tester for tensile strength extraction and process evaluation, which provides great force (above 100mN) to in situ on-chip specimen without introducing precise instrument, especially suitable for bulk micromachining related tests. The whole structure and process is simple, so it meets the requirements of various processes. Its advantages also include self-position, self-measure and self-adaption for loading.

T-077 DESIGN OPTIMIZATION AND CHARACTERIZATION OF NANOGAP CRACK-JUNCTIONS

V. Dubois, F. Niklaus, and G. Stemme
KTH Royal Institute of Technology, SWEDEN

In this paper we present the first parameter study on the geometrical considerations of CJs in titanium nitride (TiN), which provides clear guidelines for reliable formation of TiN CJs with well-defined dimensions. We further provide the complete electrical characterization of 40 TiN CJs designed as electron tunnel junctions.

W-078 FABRICATION AND MEASUREMENTS OF AN INDIVIDUALLY ADDRESSABLE MICRO-PROBE ELECTRODE ARRAY USING SILICON THROUGH-GLASS VIA

Y.-M. Shin¹, Y.-K. Kim¹, S.-K. Lee², and J.-H. Park²
¹*Seoul National University, KOREA* and ²*Dankook University, KOREA*

This paper presents a novel fabrication method and measurement results of an individually addressable micro-probe electrode array using silicon through-glass vias. To detect local response or electrochemical reaction with higher electrical signal output, each micro-probe electrode should be individually addressed and isolated from other electrodes with spatial resolution in the chip level.

M-079 FABRICATION OF HIGH ASPECT ALUMINUM DOPED ZINC OXIDE NANOMECHANICAL STRUCTURES BY DEEP RIE AND ALD

N.V. Toan and T. Ono
Tohoku University, JAPAN

This work reports the patterning of high aspect aluminum doped zinc oxide (AZO) for nanowall hollows and capacitive resonators. Hollows with 50 nm-width and 15 μm -height as well as smooth surfaces have been achieved and their height-to-width aspect is as high as 300. Suspended AZO capacitive resonators have been successfully fabricated. Its resonant frequency is observed at 10.4 kHz and the quality factor (Q) is approximately 500.

Generic MEMS and NEMS Manufacturing

T-080 FABRICATION OF A MEMS BASED SYMMETRICALLY DEFORMABLE CONVEX MIRROR

M.M. Hossain, J.Y. Lee, and S.H. Kong
Kyungpook National University, KOREA

We fabricate an optimized designed MEMS deformable convex micromirror system in which a metalized polymer membrane is suspended on a uniform cylindrical air-filled cavity in order to obtain perfectly spherical convex shape, and a glass microstructure is used for easy adhesive bonding with PDMS membrane. It has been investigated that the micromirror device would be integrated in beam guiding optical systems.

W-081 FABRICATION OF NANOSCALE STRUCTURES WITH NANOMETER RESOLUTION AND SURFACE UNIFORMITY

F. Niroui, M. Saravanapavanantham, T.M. Swager,
J.H. Lang, and V. Bulovi
Massachusetts Institute of Technology, USA

Bottom-up and top-down fabrication approaches are integrated in this work to develop a method to fabricate nanoscale structures with nanometer resolution and sub-nanometer surface uniformity for active devices. Well-defined and electrically-addressable nanogaps as small as 10 nm are formed with sub-nm surface roughness and planarized profiles. In addition, <5 nm vertical resolution in controlling the height difference between neighboring nanoscale structures is achieved.

M-082 FABRICATION STRATEGY FOR MICRO SOFT ROBOTICS WITH SEMICONDUCTOR DEVICES INTEGRATION

T. Liu, X. Wen, Y.-C. Kung, and P.-Y. Chiou
University of California, Los Angeles, USA

We report a general method to fabricate miniaturized soft robots. A freestanding micro robotic tentacle has been realized by heterogeneous integration of soft material polydimethylsiloxane (PDMS), liquid metal (LM), and silicon chips. Our technique enables large area parallel manufacturing of micro soft robotics armed with distributed crystalline silicon, deformable microfluidic channels, and electrical interconnects.

T-083 HIGH ASPECT RATIO-TITANIUM DIOXIDE-STABILIZED ZINC OXIDE NANOWIRES FOR PHOTOCATALYTIC HYDROGEN GAS HARVESTER

H.S. Park, E. Kao, X. Zang, and L. Lin
University of California, Berkeley, USA

We present a Titanium Dioxide/Zinc Oxide nanowire array for use as a solar-powered hydrogen gas harvester. Three advancements have been accomplished in this work: (1) high aspect ratio Titanium Dioxide nanowires (2) improved stability over bare Zinc Oxide Nanowires during photocatalysis and (3) excellent voltage (bias voltage needed) to split water into Hydrogen and Oxygen gas.

W-084 HIGH-THROUGHPUT PULSED LASER MANUFACTURING ETCH PROCESS FOR COMPLEX AND RELEASED STRUCTURES FROM BULK 4H-SiC

E.H. Ransom¹, K.M. Dowling¹, D. Rocca-Bejar²,
J.W. Palko¹, and D.G. Senesky¹

¹Stanford University, USA and ²Florida International University, USA

We develop, document, and characterize the effectiveness of a one-step process for manufacturing complex and released structures from bulk silicon carbide (SiC) using a pulsed laser. A yttrium-orthovanadate laser is used to scribe a cross-hatch pattern in a 4H-SiC. Fabrication of a planetary gear assembly from 4H-SiC is demonstrated. The documented process is a step toward cheaply and efficiently manufacturing SiC microstructures in lieu of more expensive fabrication techniques.

Generic MEMS and NEMS Manufacturing**M-085 MICRO-TETHERING FOR IN-PROCESS STICTION MITIGATION OF HIGHLY COMPLIANT STRUCTURES**

I.B. Flader, Y. Chen, D.D. Shin, D.B. Heinz, L. Comenencia Ortiz, A.L. Alter, W. Park, K.E. Goodson, and T.W. Kenny
Stanford University, USA

This work demonstrates, for the first time, a post-fabrication technique for creating highly compliant structures inside a hermetic, wafer-scale encapsulation process. By tethering the large, free-moving, structure during fabrication it was possible to selectively detach devices post-fabrication to mitigate the in-process stiction. The tethers in this work were attached to a dual beam resonant accelerometer, and were designed for detachment by two methods: Joule heating and shear stressing.

T-086 HIGHLY REPRODUCIBLE AND SCALABLE TRANSPARENT PDMS THIN FILM WITH SUPER-HYDROPHOBIC SURFACE

J.H. Park and D.W. Lee
Chonnam National University, KOREA

We describe an extremely simple method of making an optically transparent super-hydrophobic PDMS thin film by using a reusable photo-curable polymer mold. The use of the photo-curable polymer as a mold provides a great advantage in mass production of the optically transparent super-hydrophobic PDMS thin film.

W-087 THE STUDY OF SELF-LIMITED STATE PROFILE AND LEVEL SET SIMULATION OF ANISOTROPIC WET ETCHING ON QUARTZ

Y. Xing, H. Zhang, P.P. Cai, and Y. Li
Southeast University, CHINA

We reports that the stable transitional and self-limited profile can be characterized by the inflection points on etch rate curve of crystal orientation zone from the etched hemisphere experiment in quartz etching. Combining with 3D level set method, this new approach does allow a quickly locating all the possible self-limited etch planes. It successfully predicts the facets on complex micro needle array and other micro structures.

M-088 RELIABLE FIELD EMISSION ARRAY FOR X-RAY GENERATION WITH INORGANIC FILLER TREATED BY HIGH TEMPERATURE VACUUM ANNEALING

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

We design, model, optimize and fabricate cold electron cathodes that are specifically designed for X-ray sources. Micromachining patterning process, which enhanced edge effect, significantly improved its emission performance. High bonding strength was achieved by a preferred high temperature annealing process, which results in the improvement of field emission properties. To check its practical application, the fabricated emitter was vacuum sealed and tested in a conventional X-ray tube.

T-089 TRANSPARENT ZNO/GLASS SURFACE ACOUSTIC WAVE DEVICES WITH ALUMINUM DOPED ZNO ELECTRODE

J. Zhou¹, X. Wu¹, D. Xiao¹, H. Jin², S. Dong², Y. Fu³, and J. Luo²
¹National University of Defense Technology, CHINA,
²Zhejiang University, CHINA, and ³University of Northumbria, UK

This paper reports the fabrication of transparent SAW resonators using AZO as the transparent electrodes. Transparent SAW resonators exhibited two types of wave modes: Rayleigh and Sezawa waves, and signal amplitudes up to 25 dB were obtained with the transparency above 80%. Temperature sensing and microfluidic tests have demonstrated their potential application in transparent electronics.

Generic MEMS and NEMS Manufacturing**W-090 THIN FILM PARTIALLY ATTACHED ONTO ELASTOMER SUBSTRATE FOR THREE-DIMENSIONAL MICROSTRUCTURE**A. Takei¹, M. Murano¹, M. Tani¹, H. Fujita², and K. Okumura¹¹*Ochanomizu University, JAPAN* and ²*University of Tokyo, JAPAN*

This paper presents a new method for making three-dimensional structure on the surface of an elastomer substrate. In general, micromachining based on lithography process is layer-by-layer fabrication, and the resulting structure is restricted to be two-dimensional. In this paper, we presented that three-dimensional structures were achieved by attaching a thin film partially onto an elastomer. The fabrication process and morphology are presented.

M-091 ULTRA HIGH ASPECT-RATIO AND THICK DEEP SILICON ETCHING (UDRIE)

Y. Tang, A. Sandoughsaz, and K. Najafi

University of Michigan, USA

We report a DRIE process for etching ultra-deep structures in thick Si wafers (>500 μ m) with high aspect ratio and straight sidewalls for a wide range of feature sizes and patterns, achieved by ramping DRIE parameters. 600-800 μ m deep trenches at 20-40 μ m wide are etched in 1mm thick Si, and can be etched through with thicker/higher selectivity masks. We also etch holes >500 μ m deep at 25 μ m in diameter. This ultra-deep DRIE will benefit IC integration and MEMS transducers at micro/mille-meter scale.

Materials, Fabrication, and Packaging for Generic MEMS and NEMS**Materials for MEMS and NEMS****T-092 AN ELASTOMER-BASED MEMS FABRY-PEROT INTERFEROMETER FOR PHYSICAL AND BIOLOGICAL SENSING BY DRY TRANSFER TECHNIQUE**K. Takahashi^{1,2}, T. Fujie^{2,3}, N. Sato³, S. Takeoka³, and K. Sawada¹¹*Toyohashi University of Technology, JAPAN*, ²*Japan Science and Technology Agency (JST), JAPAN*, and ³*Waseda University, JAPAN*

We developed an elastomer-based Fabry-Perot interferometer with 120-1080 nm gap between a freestanding thin film and a substrate using dry transfer technique. An elastomeric nanosheet using a polystyrene-polybutadiene-polystyrene triblock copolymer (SBS) can be formed by dry transfer technique owing to the high adhesiveness of the SBS nanosheet. With the pressure change, the freestanding membrane was found to deform with good adhesion between the dry transferred SBS and the substrate.

W-093 COMPOSITE MATERIALS WITH CONTROLLABLE MACROMECHANICAL PROPERTIES BASED ON MEMS-ASSISTED STRUCTURAL MANIPULATION OF LOW-DIMENSIONAL SUBCOMPONENTSM. Kim¹, J. Kim², and M.G. Allen¹¹*University of Pennsylvania, USA* and²*Georgia Institute of Technology, USA*

We report a general approach toward composite materials with wide-ranging macroscale mechanical properties through the three-dimensional structural manipulation of low-dimensional subcomponents. The composites possess multilayer structures comprising alternating metal and elastomeric materials within which patterned pores are present. By controlling the pore geometries and the individual layer thicknesses in microscale, in- and out-of-plane mechanical properties are substantially tailored.

Materials for MEMS and NEMS

M-094 CONTROLLED ENERGY RELEASE BASED ON EXPLOSIVE POROUS SILICON

S. Keshavarzi, W. Kronast, F. Lima, and U. Mescheder
Furtwangen University, GERMANY

This paper reports on a novel method to release the huge amount of energy stored in functionalized porous silicon on a Si chip in a controlled manner. This is achieved by adjusting size and separation distance between locally defined areas of porous silicon. Such an approach allows multiple sequential or single explosions on a single Si chip with defined energy output.

T-095 DURABLE SUPER-HYDROPHOBIC NICKEL SURFACES WITH A HIGH RUBBING RESISTANCE AND THEIR APPLICATION IN TRIBOELECTRIC NANOGENERATORS

K. Jung^{1,2}, Y. Jung¹, C. Choi¹, B. Park¹, S. Kim¹, and J. Ko¹
¹*Pusan National University, KOREA and*
²*Korea Marine Equipment Research Institute, KOREA*

A nanostructured surface that is highly robust against strong and repetitive rubbing has been developed. Carbon nanotubes (CNTs) were implanted into nickel so that they could not be easily detached from the surface; these CNTs were able to maintain their superhydrophobicity despite harsh rubbing condition using sandpaper. In addition, a Triboelectric nanogenerator was developed using a CNTs+nickel plate as its rotating electrode and showed excellent durability in a sustainability test.

W-096 NANOCOMPOSITE RUBBER ELASTOMER WITH PIEZORESISTIVE DETECTION FOR FLEXIBLE TACTILE SENSE APPLICATION

J.-J. Wang, C.-E. Lu, J.-L. Huang, R. Chen, and W. Fang
National Tsing Hua University, TAIWAN

This work presents flexible tactile sensor using piezoresistive nanocomposite rubber elastomers: Carbon-black powders filled into PDMS using solvent-wetting methods with n-Hexane to produce well-dispersed conductive polymeric nanocomposites. The C-PDMS nanocomposites are utilized to measure resistance changes. In application, the C-PDMS is casted and stacked into PDMS substrate and gold films deposited with MPTMS adhesion layers as bond pads to implement flexible polymer-based devices

M-097 EXTRACTED NATURAL SILK FIBROIN AS A DUAL-TONE PROTEIN RESIST FOR ECO-FRIENDLY ELECTRON BEAM LITHOGRAPHY

S. Zhang¹, N. Qin², and T.H. Tao¹
¹*University of Texas, Austin, USA and*
²*Chinese Academy of Sciences, CHINA*

We report on the ability to reshape extracted natural silk fibroin with energetic electrons and on the application of advanced spectroscopic imaging for nanoscale structural analysis. Silk fibroin films under electron irradiation at various dosages has been performed using infrared scattering near-field optical microscopy (s-SNOM), which provides important guidelines for utilizing silk fibroin as a dual-tone protein resist for all-water-based eco-friendly electron beam lithography (EBL).

T-098 SILICON NANOWIRE ARRAYS THERMOELECTRIC POWER HARVESTER

A.A. Tahrir, A. Ahmad, and M.S. Mohamed Ali
Universiti Teknologi Malaysia, MALAYSIA

The p-type and n-type silicon nanowire arrays (SiNWAs) thermoelectric power harvesters are fabricated using metal-assisted chemical etching technique. The heat flow across SiNWAs devices exhibits higher temperature difference between hot and cold junctions than bulk silicon devices. Compared to bulk silicon, SiNWAs thermoelectric device shows higher voltage generation and Seebeck coefficient. The voltage rises as the temperature difference between the junctions increases.

Materials for MEMS and NEMS

- W-099 TENSILE PROPERTIES OF SINGLE-CRYSTAL-SILICON FULLY COATED WITH SUBMICROMETER-THICK PECVD DLC**
W. Zhang, A. Uesugi, Y. Hirai, T. Tsuchiya, and O. Tabata
Kyoto University, JAPAN

We reports on the improvement of tensile strength of silicon microstructures fully coated with sub-micrometer thick diamond like carbon (DLC) film using PECVD. The released specimens with the dimensions of $120 \times 4 \times 5 \mu\text{m}$ thick were coated by the all side at the thickness of 150 nm simultaneously. The tensile strength improved up to 53.5% by the full coatings depending on deposition bias voltage. In addition, the deviation in strength reduced significantly compared to bare silicon specimen.

- M-100 THERMO-MECHANICAL CHARACTERIZATION OF MATERIALS AT MICRO/NANOSCALE UNDER BENDING**
M. Elhebeary and M.T.A. Saif
University of Illinois, Urbana Champaign, USA

We present a new method for testing materials at the microscale at high temperature under bending in situ in SEM. It consists of a straining stage with built-in force and displacement sensors attached to a heating stage inside the SEM. The method revealed strengthening of SCS under bending compared to that under uniform tension. The study further reveals significant reduction in the Brittle to Ductile Transition temperature of SCS micro-beams compared to their bulk counterparts.

- T-101 ULTRA-THIN ALD MGO MEMBRANES AS MEMS TRANSMISSION DYNODES IN A TIMED PHOTON COUNTER**
V. Prodanovic^{1,2}, H.W. Chan^{1,2}, A.U. Mane³, J.W. Elam³,
H. v.d. Graaf^{1,2}, and P.M. Sarro¹
¹*Delft University of Technology, NETHERLANDS,*
²*International Institute for Subatomic Physics, NETHERLANDS, and*
³*Argonne National Laboratory, USA*

We fabricated and characterized large arrays of ultra-thin (5-25 nm) free-standing MgO membranes. ALD is employed as the most apt technique for growing MgO films of good quality with excellent control over thickness and extremely low surface roughness. The exceptional mechanical, chemical and electrical properties of MgO make this material a very attractive candidate for numerous MEMS applications, as the MEMS transmission dynodes in a novel timed photon counter, demonstrated here.

Materials, Fabrication, and Packaging for Generic MEMS and NEMS**Packaging and Assembly**

- W-102 300 μm DEEP THROUGH SILICON VIA IN LASER-ABLATED CMOS MULTI-PROJECT WAFER FOR COST-EFFECTIVE DEVELOPMENT OF INTEGRATED MEMS**
Y. Suzuki¹, H. Fukushi¹, M. Muroyoma¹, Y. Hata², T. Nakayama³,
R. Chand¹, H. Hirano¹, Y. Nonomura², H. Funabashi², and S. Tanaka¹
¹*Tohoku University, JAPAN,* ²*Toyota Central R&D Labs., Inc., JAPAN, and*
³*Toyota Motor Corporation, JAPAN*

We for the first time fabricated deep TSVs in a laser-ablated multi-project CMOS-LSI wafer, and demonstrated CMOS-MEMS integration by wafer bonding. The largest challenge was how to manage the fragility and roughness of the laser-ablated area. 300 μm deep TSVs were fabricated in a TSMC0.18 CMOS-LSI MPW. All TSVs showed good electrical characteristics. "Tohoku TSV CMOS-MEMS platform" reported here gives many chances for cost-effective development of integrated MEMS.

Packaging and Assembly

M-103 A LOW TEMPERATURE INKJET PRINTING AND FILLING PORCESS FOR LOW RESISTIVE SILVER TSV FABRICATION IN A SU-8 SUBSTRATET.-H. Yang^{1,2}, Z.-L. Guo^{1,2}, Y.-M. Fu¹, Y.-T. Cheng¹, Y.-F. Song^{1,2}, and P.-W. Wu^{1,2}¹National Chiao Tung University, TAIWAN and²National Synchrotron Radiation Research Center, TAIWAN

The abstract presents a low temperature inkjet printing process to realize low resistive Ag TSV (Through Substrate Vias) with the aspect ratio of via diameter to depth from 2:1 up to 5:1 in a flexible substrate potential for flexible microsystem applications. Combining humidity control and layer-by-layer Ag mirror reaction, the resistivity of the filled vias can exhibit a resistivity of <450 ohm-cm. Further process optimization for conventional TSV fabrication can be expected.

T-104 MASKLESS MANUFACTURING OF THROUGH GLASS VIAS (TGVs) AND THEIR TEST STRUCTURESM.J. Laakso¹, J. Liljeholm^{1,2}, A.C. Fischer^{1,3}, G. Stemme¹, T. Ebefors², and F. Niklaus¹¹KTH Royal Institute of Technology, SWEDEN,²Silex Microsystems AB, SWEDEN, and³Karlsruhe Institute of Technology (KIT), SWEDEN

We report a novel through glass via (TGV) structure that is fabricated exclusively by maskless methods. These methods include femtosecond-laser direct-ablation together with magnetic-field-assisted self-assembly and they demonstrate an attractive possibility for fast prototyping and product development. The resistances of TGV pairs were measured using four-point measurements and showed a median resistance of 161 mΩ for two TGVs in series.

MEMS Actuators and PowerMEMS

Actuator Components and Systems

W-105 A PIEZOELECTRIC BEAM ACTUATOR WITH A PURE TWISTING RESPONSEI.H. Grinberg, N. Maccabi, A. Kassie, and D. Elata
Technion - Israel Institute of Technology, ISRAEL

We present for the first time ever, a piezoelectric beam actuator that is directly driven in pure torsion (i.e. twisting deformation with no bending).

M-106 A FAST-MOVING ELECTROSTATIC CRAWLING INSECTM. Qi^{1,2}, Y. Zhu¹, Z. Liu¹, X. Zhang^{1,4}, X. Yan^{1,3,4}, and L. Lin²¹Beihang University, CHINA, ²University of California, Berkeley, USA,³Collaborative Innovation Center of Advanced Aero-Engine, CHINA, and⁴National Key Laboratory of Science and Technology, CHINA

We report an insect-size crawling robot with fast moving speed for the first time driven by electrostatically induced self-vibration. Under an applied DC voltage, the robot with a total mass of 47mg has achieved a forward crawling speed up to 30mm/s (1.5 body lengths per second). Using an integrated on-board capacitor, it can move freely without electrical powering wires for up to 10s with a speed of 2mm/s. The simple structural design could open up new directions for microbot research.

T-107 ANNULAR ULTRASONIC MICROMOTORS FABRICATED FROM BULK PZT

P. Hareesh and D.L. DeVoe

University of Maryland, College Park, USA

We report a new class of bulk PZT traveling wave ultrasonic micromotor fabricated from a single sheet of bulk PZT. This fabrication process requires only two lithography steps, greatly simplifying manufacture while improving device performance and fabrication costs. A novel actuation scheme termed differential quadrature drive causes the input to be enhanced through the use of transverse interdigitated electrodes. Bidirectional rotary motion of glass rotors has been successfully demonstrated.

Actuator Components and Systems

W-108 ELECTROWETTING-ON-DIELECTRIC ACTUATION OF A SPATIAL AND ANGULAR MANIPULATION MEMS STAGE

D.J. Preston, A. Anders, B. Barabadi, E. Tio, Y. Zhu, D.A. Dai, and E.N. Wang
Massachusetts Institute of Technology, USA

We demonstrate a MEMS translational stage that uses electrowetting-on-dielectric as the actuating mechanism. Our stage is capable of linear translation with resolution of 10 μm over a maximum range of 130 μm and angular deflection of approximately $\pm 1^\circ$ while eliminating solid-solid contact. The range and resolution can be readily improved via higher base contact angle and lower contact angle hysteresis as indicated by the detailed modeling accompanying the experimental demonstration.

M-109 HYDRO-IONIC MICROTHRUSTER FOR LOCOMOTION IN LOW REYNOLD'S NUMBER IONIC FLUIDS

D.L. Magley, V. Narasimhan, and H. Choo
California Institute of Technology, USA

We have demonstrated a fast, extremely power-efficient, hydro-ionic microthruster using electro-osmotic propulsion for operation in a low Reynolds-number ionic environment. Powered by an onboard power supply, the microthruster achieves speeds up to 5.24cm/s (175 body-lengths/s) while consuming less than 3.68 μW . It is 75% faster and 68 times more energy-efficient than previous designs, opening up new possibilities for various implantable bio-fuel cell powered biomedical applications.

T-110 LATERAL MOVING OF AN ARTIFICIAL FLAPPING-WING INSECT DRIVEN BY LOW VOLTAGE ELECTROMAGNETIC ACTUATOR

Z. Liu¹, X. Yan^{1,3,4}, M. Qi^{1,2}, Y. Yang¹, X. Zhang¹, and L. Lin²
¹*Beihang University, CHINA*, ²*University of California, Berkeley, USA*,
³*Collaborative Innovation Center of Advanced Aero-Engine, CHINA*, and
⁴*National Key Laboratory of Science and Technology, CHINA*

We present an artificial flapping-wing insect driven by a low voltage electromagnetic actuator to move laterally along a horizontal guide rail for the first time. Three distinctive achievements have been accomplished: (1) only 90mg in weight with wing span of 3cm for the prototype; (2) high peak to peak flapping amplitude of 100.4° at 51.3Hz under a low driving voltage of 5V; and (3) measured 116.5 μN average lift force to move on a horizontal guide rail.

W-111 MULTIFUNCTIONAL LIQUID LENS (MLL) FOR VARIABLE FOCUS AND VARIABLE APERTURE

J. Lee, Y. Park, S.H. Oh, and S.K. Chung
Myongji University, KOREA

We present a novel multifunctional liquid lens (MLL) for miniature cameras. MLL firstly offers variable-focus and variable-aperture in a single lens system using a sole electrowetting-on-dielectric (EWOD) actuation for simultaneously controlling the curvature and aperture of MLL. The proposed MLL offers a simple design structure to be easily miniaturized but covers a wide range of variable lens curvatures and apertures for the high optical performance of miniature cameras.

M-112 OPEN LOOP, SELF-EXCITATION IN A BISTABLE MICROMECHANICAL BEAM ACTUATED BY A DC ELECTROSTATIC LOAD

L. Medina¹, R. Gilat², B.R. Ilic³, and S. Krylov¹
¹*Tel-Aviv University, ISRAEL*, ²*Ariel University, ISRAEL*, and
³*National Institute of Standards and Technology (NIST), USA*

We demonstrate an open-loop self-excitation response in a curved, bistable beam under a time-independent electrostatic load. The self-excitation is triggered by placing a high value resistor in series with a beam that is on the verge of bistability. The voltage deflection curve of such a beam contains an inflection point, where the slope of the curve is approximately zero. Our results show, that actuation at a voltage corresponding to the inflection point induces stable self-oscillations.

Actuator Components and Systems

- T-113 SHOCK-RESISTIBILITY OF INERTIAL MICROSWITCH UNDER REVERSE SENSITIVE DIRECTIONAL ULTRA-HIGH G ACCELERATION**
Q. Xu, Z. Yang, Y. Sun, M. Zhao, J. Li, G. Ding, and X. Zhao
Shanghai Jiao Tong University, CHINA

This paper reports a novel inertial microswitch with multi-directional compact constraint structures for improving the shock-resistibility. Its shock-resistibility in the reverse sensitive directional ultra-high g acceleration (~hundreds of thousands) is simulated and analyzed. The testing comparison indicates that spurious trigger is easier to happen if without constraint structure, and the designed constraint structures can effectively improve the shock-resistibility.

- W-114 TRANSPARENT PIEZOELECTRIC TRANSDUCERS FOR LARGE AREA ULTRASONIC ACTUATORS**
D. Sette, S. Girod, N. Godard, N. Adjeroud, J.-B. Chemin,
R. Leturcq, and E. Defay
Luxembourg Institute of Science and Technology, LUXEMBOURG

This work focuses on the fabrication of transparent piezoelectric transducers on glass substrates. The actuator is used in d_{33} mode offering high transduction capabilities, while an interdigital electrodes design allows for increasing the area of the actuator in the cm^2 range. The results demonstrate that fully transparent actuators with ultrasonic range resonant frequency can be fabricated on glass substrates. Direct applications of these actuators are haptic devices for tactile sensation.

- M-115 TWO NOVEL MEMS ACTUATOR SYSTEMS FOR SELF-ALIGNED INTEGRATED 3D OPTICAL COHERENT TOMOGRAPHY SCANNERS**
A. Jovic¹, G. Pandraud¹, N. Sanchez², J. Sancho², K. Zinoviev³,
J.L. Rubio², E. Margallo², and P.M. Sarro¹
¹*Delft University of Technology, NETHERLANDS*,
²*MedLumics SL, SPAIN*, and ³*imec, BELGIUM*

We present two novel MEMS actuator systems for a new self-aligned integrated 3D optical coherent tomography (OCT) scanner. The integration of a silicon microlens, an optical waveguide and a MEMS system on a single chip, provides a decrease in optical losses thanks to the intrinsic alignment obtained during fabrication, while reducing the complexity and time that assembly and packaging of separate components demand, therefore making fully integrated, miniaturized 3D OCT scanners possible.

MEMS Actuators and PowerMEMS

Manufacturing for Actuators and PowerMEMS

- T-116 3D PRINTED, PROGRAMMABLE OSMOTIC ACTUATORS FOR ORTHODONTIC APPLICATION**
H. Hsu, L.-Y. Liu, and Y.-C. Su
National Tsing Hua University, TAIWAN

We have successfully demonstrated (1) a 3D manufacturing/packaging scheme that readily converts hydraulic actuators into autonomous osmotic actuators, and (2) a new type of osmotic actuators that can generate desired locomotion and force outputs for orthodontic treatment. The actuators are osmotically pressurized to guide the teeth into proper alignment. Besides pumping, it is demonstrated for the first time that osmotic actuation can be tailored to realize sophisticated functions.

Manufacturing for Actuators and PowerMEMS**W-117 FLEXIBLE THERMOELECTRIC POWER GENERATORS BASED ON ELECTROCHEMICAL DEPOSITION PROCESS OF BI₂TE₃ AND SB₂TE₃**

N.H. Trung, N.V. Toan, and T. Ono
Tohoku University, JAPAN

This work demonstrates a new approach of an electrochemical deposition to fabricate self-endurance flexible thermoelectric generators (FTEGs) without top and bottom sustaining substrates. Two proposed structures together with new fabrication processes are developed to complete high performance devices. Ideas and results from this work can precipitate the development of wearable electronics devices that would be used in biosensors, health care instruments, and mobiles devices, etc.

M-118 FREESTANDING SOLID-STATE MICRO-SUPERCAPACITOR BASED ON LASER-PATTERNED NANOFIBERS

Y. Song¹, X. Chen¹, H. Chen¹, X. Cheng¹, J. Zhang¹, Z. Su¹, L. Miao¹, B. Meng³, Q. Yuan², and H. Zhang¹
¹*Peking University, CHINA*, ²*Chinese Academy of Sciences, CHINA*, and ³*Beijing Micro Energy Technology Co., Ltd, CHINA*

We present a simple and scalable fabrication for freestanding solid-state micro-supercapacitor (MSC), which, for the first time, combines electrolyte transferring with laser patterning process. With in-planar and electrolyte-substrate layout, MSC could be greatly decreased. Taking advantage of nanofibers and CNTs, the optimized line-width of MSC exhibits high areal capacitance. Therefore, such freestanding MSC shows potentials to satisfy the requirements of energy systems and wearable devices.

T-119 PASSIVELY SELF-ALIGNED ASSEMBLY OF COMPACT BARREL HINGES FOR HIGH-PERFORMANCE, OUT-OF-PLANE MEMS ACTUATORS

X. Xie and C. Livermore
Northeastern University, USA

We present a two-stage, passively self-aligned, assembly-based process for rapidly creating micro-barrel hinges with unconstrained rotation and reduced clearance. The hinges' ease of fabrication and functional advantages are demonstrated through implementation and characterization of a motion-amplifying, out-of-plane actuator. Most significantly, the two-stage passive alignment of the barrel-hinged approach provides rapid, straightforward manufacture of complex, out-of-plane MEMS architectures.

W-120 REALIZATION OF TRIBOELECTRIC ENERGY HARVESTERS USING STEEL-POLYMER MICROFABRICATION METHODS

E. Iseri and S. Mutlu
Bogazici University, TURKEY

Triboelectric nanogenerators (TENG) are developed for wireless and batteryless keyboard applications, using steel-polymer microfabrication methods including lithography, electrochemical etching, hot embossing and thermo-compression bonding. Triboelectric effect between polydimethylsiloxane (PDMS) and steel surfaces is characterized. Crab leg shaped design is applied on 50 μm thick steel film to harvest energy. Maximum instantaneous power density of 1.1 $\mu\text{W}/\text{cm}^2$ is achieved for 1 mm displacement.

MEMS Actuators and PowerMEMS

Materials for Actuators and PowerMEMS

M-121 A 1000-VOLT PLANAR MICRO-SUPERCAPACITOR BY DIRECT-WRITE LASER ENGRAVING OF POLYMERSX. Li^{1,2}, Y. Cui¹, M. Qi¹, H. Wu¹, Y. Xie¹, X. Zang¹, D. Wen¹, K.S. Teh^{1,3}, J. Ye⁴, Z. Zhou², Q.-A. Huang², W. Cai^{1,4}, and L. Lin¹¹University of California, Berkeley, USA, ²Southeast University, CHINA,³San Francisco State University, USA, and⁴South China University of Technology, CHINA

A 1000V, high-voltage planar micro-supercapacitor has been constructed to successfully power an electrostatic cantilever resonator for more than 1 minute. Direct-write laser engraving of Kapton tape has been used to make the micro supercapacitor patterns for the first time. The laser engraving technique provides a unique way to make portable, lightweight and cheap high-voltage energy storage devices for various applications.

T-122 DC-DRIVEN ACRYLATE-COPOLYMER-BASED ELECTROTHERMAL OSCILLATOR AND ITS APPLICATION IN THERMOPNEUMATIC DIFFUSER PUMP

S.-W. Chen, C.-C. Yeh, and Y.-J. Yang

National Taiwan University, TAIWAN

This work presents a novel electrothermal oscillator driven by a fixed DC voltage, and its application in thermopneumatic diffuser pump. The proposed device employs ultra-sensitive temperature sensing material which was made by dispersing acrylate copolymer with graphite particles. The periodic electric current switching for activating a nozzle-diffuser valveless thermopneumatic pump with the electrothermal oscillator was demonstrated by supplying a constant DC voltage.

W-123 HIGH EFFICIENCY PIEZOELECTRIC MEMS VIBRATION ENERGY HARVESTERS USING (100) ORIENTED BIFE03 FILMSM. Aramaki, K. Izumi, T. Yoshimura, S. Murakami, and N. Fujimura
Osaka Prefecture University, JAPAN

We have developed a design principle to fabricate of high efficient piezoelectric MEMS vibrational energy harvesters (PVEHs) from the viewpoints of materials science and MEMS. We propose BiFeO₃ films as the piezoelectric films. To maximize the conversion efficiency of pVEHs, the microstructure and thickness of BiFeO₃ films were optimized. pVEHs using the BiFeO₃ films exhibit the output power of 2.8 μW/mm²/G₂ which corresponds 80% of the theoretical limitation of the fabricated pVEH.

M-124 HIGHLY EFFICIENT PIEZOELECTRIC MICRO-ENERGY HARVESTERS WITH ALN THIN FILMS GROWN DIRECTLY ON FLEXIBLE TI FOILS

L. Van Minh and H. Kuwano

Tohoku University, JAPAN

This work presents highly efficient, micromachined energy harvester using lead-free piezoelectric AlN thin films grown directly on Ti foils. AlN films with (002)-preferred orientation were grown on Ti foils by an AC reactive magnetron sputter with Ar/N₂ gas and Al target. The rocking FWHM of (002)-AlN peak was 2.3°. AlN/Ti-based microenergy harvesters achieved the highest normalized power density of 1.494 mW·g⁻²·cm⁻³ among the published lead-free metallic energy harvesters.

Materials for Actuators and PowerMEMS

T-125 STIMULI-RESPONSIVE HYDROGEL MICROSPRINGS FOR MULTIPLE AND COMPLEX ACTUATIONK. Yoshida¹, S. Nakajima¹, R. Kawano², and H. Onoe¹¹Keio University, JAPAN and²Tokyo University of Agriculture and Technology, JAPAN

This paper describes stimuli-responsive hydrogel microsprings (SR springs) to achieve multiple and complex actuation. SR springs, made of double network hydrogel of p(NIPAM-co-AAc) and calcium alginate, were formed by using a bevel-tip capillary. The size, pitch and cross-sectional pattern of SR springs were variable by controlling flow rate, buoyancy force and laminar-flow pattern. By heating single-layered or patterned SR springs, we achieved five different types of complex spring movements.

MEMS Actuators and PowerMEMS

PowerMEMS Components and Systems

W-126 ALN WIDEBAND ENERGY HARVESTERS WITH WAFER-LEVEL VACUUM PACKAGING UTILIZING THREE-WAFER BONDING

N. Wang, C. Sun, L.Y. Siow, H. Ji, P. Chang, Q. Zhang, and Y. Gu

Agency for Science, Technology and Research (A*STAR), SINGAPORE

We design, fabricate, and characterize an AlN MEMS energy harvester (EH) with an operation bandwidth of 64.6Hz (859.9Hz – 924.5Hz, 7.24%), peak output open-circuit voltage of 4.43V, and an output power of 82.24 μ W that yields a power density of 0.734mW/cm³ with its size of 0.8 \times 0.8 \times 0.175cm³, packaged using a novel wafer-level vacuum packaging scheme which employs two times of eutectic Al-Ge bonding to bond the device wafer to both the top cap wafer and the bottom cap wafer.

M-127 TRIBOELECTRIFICATION BASED ACTIVE SENSOR FOR LIQUID FLOW AND BUBBLE DETECTING

X. Cheng, L. Miao, H. Chen, Y. Song, Z. Su, X. Chen, H. Wang,

M. Zhang, and H.X. Zhang

Peking University, CHINA

We present an active liquid flow sensor using the effect of contact-electrification between water and solid interface. C₄F₈ plasma treated PDMS with wrinkle pattern is employed to contact with water to enhance the electric performance. The utilization of interdigital electrode enables this sensor to detect the liquid flow direction and velocity, while the grounded branch makes it capable to detect bubble. This active sensor has a promising application in microfluidic sensor system.

T-128 BIPOLAR ELECTROSTATIC DRIVING FOR HIGH-RESOLUTION ISOLATED BATTERY VOLTAGE SENSORN. Nobunaga¹, S. Kumagai¹, H. Ishihara², M. Ishii², and M. Sasaki¹¹Toyota Technological Institute, JAPAN and ²Yazaki Corporation, JAPAN

Si resonator is applied for measuring the voltage in a highly isolated manner. The resonant frequency shift being affected by the electrical field from the high voltage (supposing the battery) is the working principle. Here, the resonator is electrically floated for the isolation and the outside driving voltage is set to be bipolar. This new method stabilizes the resonant frequency realizing 0.25V accuracy at 80V. Feasibility for measuring the high voltage up to 420V is demonstrated.

PowerMEMS Components and Systems**W-129 BROADBAND ROTATIONAL ENERGY HARVESTING USING BISTABLE MECHANISM AND FREQUENCY UP-CONVERSION**

H. Fu and E.M. Yeatman
Imperial College London, UK

This paper presents the electromechanical dynamics of a broadband rotational piezoelectric energy harvester using bi-stability and frequency up-conversion. The power extraction capability of different oscillating modes was analysed theoretically. The keys to maintain the operation in high energy orbit were investigated. The design is implemented experimentally, showing a significant improvement in output power over a wide bandwidth compared to a harvester without bi-stability.

M-130 NEW COMB GEOMETRY OF CAPACITIVE VIBRATION ENERGY HARVESTERS MINIATURIZING THE AIR DAMPING EFFECT

Y. Lu¹, F. Marty¹, D. Galayko², and P. Basset¹
¹*Université Paris-Est, FRANCE* and ²*UPMC-Sorbonne Université, FRANCE*

We report a hierarchical comb geometry of MEMS capacitor for electrostatic vibration energy harvesters, where the lossy air damping effect is greatly reduced. The bandwidth of the device with new comb shape is expanded in air from 80~160 Hz to 10~180 Hz without the need of external mass. The energy extracted in air during each cycle of external excitation reaches 85 times higher @15Hz/2g than that of the classical gap-closing electrodes, and is no less than 33 times higher within 10~40 Hz.

T-131 PREPARING 3D GRAPHENE NANOWALL-NICKEL HYBRID ELECTRODE ON QUARTZ GLASS FOR ON-CHIP MICRO-SUPERCAPACITORS

J. Li and T. Ono
Tohoku University, JAPAN

We report micro-supercapacitors built on 3D graphene nanowall (GNW)/Ni core-shell electrode via standard MEMS technique. As the growth of GNW on quartz glass was rationally revealed, a uniform coating of Ni on GNW was realized to simultaneously serve as a shadow mask for patterning and an active material for capacitance augment. With 10-fold larger capacitance of 337 F/cm³ than pure GNW and Ni, the novel hybrid electrode enabled a high energy and power density delivery of micro-supercapacitors.

W-132 TRIBOELECTRIC ENERGY HARVESTER USING FREQUENCY UP-CONVERSION TO GENERATE FROM EXTREMELY LOW FREQUENCY STRAIN INPUTS

H.-J. Ko, D.-S. Kwon, and J. Kim
Yonsei University, KOREA

We developed a flexible triboelectric energy harvester that consists of Al-coated PVC cantilever with one-end anchored to the PVC substrate and Al-coated PET film placed between them. The other end of cantilever can be bound to the substrate due to the permanent magnets. When the cantilever is released by the strain inputs, it vibrates at its natural frequency, causing repeated contact and relative motion of the cantilever and film, which generates high frequency oscillation of voltage output.



Las Vegas Strip from the Bellagio: 2014 ©Brian Jones

PowerMEMS Components and Systems

M-133 STRETCHABLE THIN-FILM GENERATOR WITH DUAL WORKING MODES FOR BODY MOTION ENERGY HARVESTINGX. Chen¹, Y. Song¹, H. Chen¹, J. Zhang¹, Z. Su¹, X. Cheng¹,
B. Meng², and H. Zhang¹¹Peking University, CHINA and²Beijing Micro Energy Technology, Co., Ltd., CHINA

We develop a novelty stretchable thin-film generator (TFG) based on electrification for effectively harvesting body motion energy. The TFG has two working modes, the folding mode and the contact-separation mode, under the same circuit connection. Electrospinning PU nanofibers are employed to integrate electrodes, making it not only flexible but also highly stretchable up to 100%. The film structure makes the device very convenient be attached onto cloth or skin as a wearable energy harvester.

MEMS Actuators and PowerMEMS

Other Actuators and PowerMEMS

T-134 DEMONSTRATION OF TUNABLE ENERGY PROPAGATION USING MAGNETO-MECHANICAL OSCILLATOR ARRAYSR.E. Carroll¹, J.A. Little², B.P. Mann², and D.P. Arnold¹¹University of Florida, USA and ²Duke University, USA

This work reports a MEMS testbed platform that not only demonstrates complex energy propagation behaviors in periodic arrays of coupled oscillators, but also a technique to alter those behaviors externally, post fabrication. Using the devices, we show frequency bandgaps, bandgap and their dependence on oscillator compliance. Additionally, the ability to modify those bandgap responses via altering the inter-oscillator coupling forces is demonstrated.

W-135 MULTI-FUNCTION AND CASCADABLE MEMS LOGIC DEVICE

S. Ilyas, N. Jaber, and M.I. Younis

King Abdullah University of Science and Technology, SAUDI ARABIA

We present a reprogrammable Microelectromechanical systems MEMS logic device that can perform the fundamental logic gate AND, the universal logic gate NAND, and the tri-state logic gate using mixed-frequency excitation. The concept is based on exciting combination resonances due to the mixing of two or more input signals. Benefiting from unified input and output signals, we also present a possibility of cascading these devices to perform complex computing.

M-136 ENHANCED PHOTOCATALYTIC OF ORGANIC POLLUTANTS USING HIGH-ASPECT-RATIO SI/ITO/WO₃ MICROPOST PHOTOELECTRODES

X. Jiang, M. Liu, D. Zheng, X. Zhao, W. Wang, and G. Sun

Nankai University, CHINA

We report an enhanced photocatalysis system for organic pollutants decomposition, using high-aspect-ratio (HAR) Si/ITO/WO₃ micropost photoelectrode. Compared with traditional TiO₂, Tungsten trioxide (WO₃) coupled with Si can absorb more visible light. Our preliminary Methylene Blue (MB) (C16H18ClN3S) decomposition testing shows that about ~83.4% of MB can be decomposed within 30 mins.

MEMS for Electromagnetics

DC and Low Frequency Magnetic and
Electromechanical Components and Systems**T-137 AN EFFECTIVE TEMPERATURE COMPENSATION ALGORITHM FOR CMOS-MEMS THERMAL-PIEZORESISTIVE OSCILLATORS WITH SUB PPM/°C THERMAL STABILITY**A.A. Zope¹, R.H. G.¹, J.-H. Chang², C.-C. Chen¹,
D.-J. Yao¹, and S.-S. Li¹¹National Tsing Hua University, TAIWAN and²United Microelectronics Corporation, TAIWAN

A temperature compensation algorithm for CMOS-MEMS Thermal-Piezoresistive Oscillator (TPO) using constant resistance (constant-R) control with two-point calibration is proposed. The method achieves sub-ppm/°C level temperature co-efficient of frequency (TCf) compared to 8ppm/°C with constant-R reported earlier. Measurement at only two temperature points is required for effective compensation, thus avoiding the expensive look up table approach.

W-138 CORRECTED SQUEEZED-FILM DAMPING SIMULATION VALIDATED WITH A LORENTZ-FORCE MAGNETOMETER OPERATING IN VACUUMA. Sinding¹, I.E. Ocak², W.U. Syed³, A.N. Chatterjee⁴, C. Welham¹,
S. Liu⁵, J. Yan⁵, S. Breit⁵, H.-K. Chang², I.M. Elfadel³, and Z. Sbiaa⁴¹Coventor, SARL, FRANCE, ²Agency for Science, Technology and Research (A*STAR), SINGAPORE, ³Masdar Institute of Science and Technology, UAE, ⁴GLOBALFOUNDRIES Inc., SINGAPORE, and⁵Coventor, Inc., USA

We implemented and validated a corrected squeezed film gas damping simulation for common MEMS structures, electrostatic comb fingers, under various vacuum levels. Q factors were measured for the sensing mode of a Lorentz-force magnetometer. At its typical operating pressure, 10Pa, corresponding to Knudsen number $Kn \sim 670$, the simulated Q factor is within +/-25% of the measured value. This simulation predicts, for the first time, Q factors for MEMS sensors such as gyroscopes and magnetometers.

M-139 INDUCTANCE ENHANCEMENT OF A MEMS INDUCTOR WITH SELF-ALIGNED MAGNETIC NANOPARTICLESJ.-S. Lee¹, S.-D. Ko², C.-H. Han³, Y.-H. Yoon¹,
M.-H. Seo¹, and J.-B. Yoon¹¹Korea Advanced Institute of Science and Technology (KAIST), KOREA,²Georgia Institute of Technology, USA, and ³SK Hynix Inc., KOREA

We report a novel method to integrate magnetic nanoparticles (MNPs) with a MEMS inductor. The proposed method is based on a self-alignment of MNPs, and the alignment process results in an optimal MNP distribution maximizing inductance. Consequently, with only 1wt% MNP mixture and simple planar spiral inductor structure, the proposed method has yielded a significant inductance gain over 50%, which is comparable to the state of the art inductance gain achieved by MNPs in any method whatsoever.



MEMS for Electromagnetics**Free Space Optical Components and Systems
(Displays, Lenses, Detectors)****T-140 MICROMIRROR BASED OPTICAL PHASED ARRAY FOR
WIDE-ANGLE BEAMSTEERING**

Y. Wang and M.C. Wu
University of California, Berkeley, USA

We develop and fabricate a novel MEMS micromirror based optical phased array (OPA) for beamsteering. The one-dimensional OPA has a fine pitch of $2.4\mu\text{m}$, the smallest ever demonstrated and made possible by integrating vertical combdrive actuators underneath the mirror, a 22° field-of-view at 905nm wavelength, $< 2\mu\text{s}$ response time and $< 10\text{V}$ actuation voltage. These properties together with its wavelength- and modulation-agnostic properties make it an attractive choice for LIDAR applications.

MEMS for Electromagnetics**Material for Electromagnetic Transducers****W-141 RAPID MANUFACTURING OF OSTE POLYMER RF-MEMS COMPONENTS**

S. Rahiminejad¹, J. Hansson^{2,3}, E. Köhler¹, W. van der Wijngaart²,
T. Haraldsson², S. Haas^{1,2}, and P. Enoksson¹
¹*Chalmers University of Technology, SWEDEN*, ²*KTH Royal Institute of Technology, SWEDEN*, and ³*Mercene Labs AB, SWEDEN*

We report the first RF-MEMS component in OSTE polymer. The 280 GHz ridge gap resonator was fabricated by direct, high aspect ratio, photostructuring of OSTE, followed by gold coating. The OSTE-based device was compared with Si-, SU8- and CNT-based devices of equal design: 1) the OSTE-based process is significantly faster, can be performed outside the cleanroom, and at lower cost; 2) the OSTE-based device performance is on par with the other alternatives in terms of frequency, Q-factor and loss.

MEMS for Electromagnetics**MEMS for Timing and Frequency Control****M-142 CW-POWERED SQUEGGING MICROMECHANICAL CLOCK GENERATOR**

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

A mechanical circuit has been demonstrated that harnesses squegging to convert -50dBm of input continuous-wave (CW) energy into a local 1-kHz clock output while consuming three orders less local battery power than a typical real-time clock (RTC). By dispensing with the need for positive feedback sustaining amplifiers, this CW-powered clock generator operates with only 0.8nW of battery power when outputting a triangle-wave into 0.8pF , which is $1250\times$ lower than the $1\mu\text{W}$ of a typical RTC.

**T-143 DISTRIBUTED LAMÉ MODE RESONATORS FOR
TEMPERATURE-STABLE HIGH FREQUENCY
MEMS OSCILLATORS**

A. Daruwalla, C.-S. Liu, H. Wen, and F. Ayazi
Georgia Institute of Technology, USA

We develop a Distributed Lamé mode resonator that takes the advantages of a square Lamé mode with doping-dependent TCF and extends it to a distributed arrangement to allow efficient transduction while up-scaling the resonance frequency with high temperature turnover point. DLM shows one of the highest $f\text{-}Q$ for SCS resonators at 167MHz . With DLM, one can build temperature stable SCS oscillators at high frequencies comparable to quartz oscillators suitable for HF military and consumer applications.

MEMS for Timing and Frequency Control

W-144 HIGH Q LOW IMPEDANCE WLCSP RESONATOR FOR SUB-100 MHZ PROGRAMMABLE OSCILLATOR APPLICATIONG. Wu, J. Xu, X. Zhang, N. Wang, D. Yan, J.L.K. Lim,
Y. Zhu, W. Li, and Y. Gu*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

A wafer level chip scale packaged (WLCSP) aluminum nitride (AlN) on silicon resonator is reported. The fabricated piezoelectric resonator achieves a Q of 9517 and an impedance of 51 Ohm at its resonant frequency of 27.19 MHz. The measured frequency drift is within 30 ppm after 1000 thermal cycles (-45 ~ 85 °C). The piezoelectric resonator based oscillator shows an overall frequency drift of 3 ppm over the temperature range of -20 °C to 70 °C with the temperature compensation approaches.

M-145 FREQUENCY TRIMMING OF SILICON RESONATORS AFTER PACKAGE WITH INTEGRATED MICRO-EVAPORATORS

W. You, H. Yang, B. Pei, K. Sun, and X. Li

Chinese Academy of Sciences, CHINA

This paper presents for the first time a novel method to trim the resonant frequency of a silicon bulk acoustic resonator after package with an integrated micro-evaporator, which is bonded to the silicon resonator face to face. During trimming, an electric power is applied to heat the micro-evaporator locally to evaporate the top aluminum layer to trim the resonant frequency of MEMS resonator permanently. The average trimming rate can be adjusted from -0.3 ppm/min to -12.2 ppm/min.

T-146 PHASE NOISE SUPPRESSION EFFECT AT THE TURNOVER TEMPERATURE IN OVEN CONTROLLED MEMS OSCILLATOR

W. You, H. Yang, K. Sun, B. Pei, and X. Li

Chinese Academy of Sciences, CHINA

An obvious phase noise suppression effect is reported for the first time at the turnover temperature of a degenerately phosphorus-doped silicon oscillator. The resonant frequency of an N++ [100] bulk mode single crystal silicon resonator reached the maximum at the turnover temperature. Our experiments show that the phase noise also reaches the minimum at the turnover temperature. More than 20 dB drops of the phase noise in low offset frequencies has been observed.

W-147 HIGH Cx/CO 13nm-CAPACITIVE-GAP TRANSDUCED DISK RESONATOR

J. Naghsh Nilchi, R. Liu, and C.T.-C. Nguyen

University of California, Berkeley, USA

Electrode-to-resonator gaps of 13.2nm achieved on a 59.5MHz disk resonator have enabled a measured electromechanical coupling $C_x/CO > 1.62\%$ at a V_p of only 5.5V, which exceeds that of any competing technology at similar VHF frequencies, all while retaining a Q of 29,640. This combination of high C_x/CO and Q stands to not only cut VHF oscillator power consumption, but now creates opportunities for the RF filter market, where 10nm gap with higher V_p should allow 6% C_x/CO at GHz frequencies.

MEMS for Electromagnetics

NEMS for Electromagnetic Transducers

M-148 DEVELOPMENT OF GRAPHENE DRUM RESONATOR WITH NANOCAVITY BY LOW-PRESSURE DRY TRANSFER TECHNIQUE

H. Ishida, T. Iwata, K. Sawada, and K. Takahashi

Toyohashi University of Technology, JAPAN

We developed cavity-sealed single-layer graphene drum resonator by using low-pressure dry transfer technique. Maximum diameter of 45 μm with gap length of 810 nm was obtained. We demonstrated fundamental resonance frequency ranges of 0.74-1.36 MHz with a quality factor of about 300 with 30-45 μm in diameter.

MEMS for Electromagnetics**Photonic Components and Systems**

- T-149 A FAST UNCOOLED INFRARED NANOBOLOMETER FEATURING A HYBRID-PLASMONIC CAVITY FOR ENHANCED OPTICAL RESPONSIVITY**
F. Ottonello Briano, M. Colangelo, C. Errando-Herranz, H. Sohlström, and K.B. Gylfason
KTH Royal Institute of Technology, SWEDEN

We demonstrate the first uncooled single-nanowire-based infrared bolometer to detect sub-mW optical signals up to MHz frequencies. The bolometer consists of a Pt nanowire on a suspended silicon hybrid-plasmonic cavity and exhibits enhanced optical responsivity. The high speed of our nanobolometer enables advanced modulation schemes as well as power saving by pulsed operation. Furthermore, its simple integration and small footprint make it a cost effective detector for sensing applications.

- W-150 A NOVEL LOW-LIGHT-LEVEL OPTICAL SWITCH BY USING NANO-OPTO-MECHANICS TECHNOLOGY**
J. Tao, H. Cai, L.Y.T. Lee, and Y. Gu
*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

An all-optical switch that controls strong light with a weak one based on nonlinear cavity enhanced optomechanical effect is demonstrated by use of NOMS technology. The switch working at a low-light-level is studied through a combination of modelling and experiment. Potential applications include optical memories, on-chip optical signal processing, etc.

- M-151 ZERO-POWER LIGHT-ACTUATED MICROMECHANICAL RELAY**
Z. Qian, S. Kang, V. Rajaram, C. Cassella, N.E. McGruer, and M. Rinaldi
Northeastern University, USA

This paper reports on the demonstration of a passive light-actuated micromechanical relay. Differently from any existing switches, the proposed LMR relies on a plasmonically-enhanced thermomechanical coupling to selectively harvest the impinging energy of light, in a specific spectral band of interest, and use it to mechanically create a conducting channel between the device terminals without the need of any additional power source, which directly translates into a zero standby power consumption.

MEMS for Electromagnetics**RF MEMS Components and Systems**

- T-152 5 GHZ LITHIUM NIOBATE MEMS RESONATORS WITH HIGH FOM OF 153**
Y. Yang, A. Gao, R. Lu, and S. Gong
University of Illinois, Urbana Champaign, USA

We develop a new class of super-high frequency (SHF) MEMS resonators operating at 5 GHz range. The SHF resonances have been achieved by employing the first order antisymmetric mode in suspended Z-cut Lithium Niobate thin film. The fabricated device has demonstrated a high electromechanical coupling of 29% and a high quality factor of 527, which marks the first time that MEMS resonators at SHF were demonstrated with an extremely high figure of merit of 153.

RF MEMS Components and Systems**W-153 A HIGH PERFORMANCE AND ULTRA WIDE TUNED CAPACITOR USING NETTED MEMBRANE STRUCTURES FOR RECONFIGURABLE RF SYSTEMS**

J.W. Kim, H.O. Cho, and J.Y. Park
KwangWoon University, KOREA

This paper reports an wide tuned RF MEMS tunable capacitor using netted membrane structures for highly miniaturized and reconfigurable RF devices and systems applications. The proposed capacitor is also designed to achieve high linearity and capacitance values. Since the netted membrane structure is stuck to the dielectric layer of bottom electrode not at once but each in turn as the actuation voltage is increased, it provides extremely superior linearity and wide tuning range.

M-154 AN INNOVATIVE PIEZO-MEMS CHANNEL-SELECT FILTER DESIGN BASED ON NON-MONOTONIC COUPLED MODES

C.-Y. Chen¹, M.-H. Li¹, G. Pillai¹, J.M.-L. Tsai², and S.-S. Li¹
¹*National Tsing Hua University, TAIWAN* and ²*InvenSense Inc., USA*

This work proposes a novel mechanically-coupled filter design which combines two distinct physical vibration modes, including LE and degenerate IPS modes in a single filter structure, fabricated using InvenSense AlN-on-silicon platform. The proposed non-monotonic coupled mode filter simultaneously features a nodal-point positioned filter coupler and a differential operation, hence enabling narrow-band filtering and significant feedthrough reduction toward channel-select applications.

T-155 EFFECTS OF HETEROSTRUCTURE STACKING ON ACOUSTIC DISSIPATION IN COUPLED-RING RESONATORS

A. Peczalski¹, X.-Q. Zheng², J. Lee², P.X.-L. Feng²,
and M. Rais-Zadeh^{1,3}
¹*University of Michigan, USA*,
²*Case Western Reserve University, USA*, and
³*California Institute of Technology, USA*

We report on quantifying effects of heterostructures layer stacking on measured dissipation and quality (Q) factors of AlN-on-Si coupled-ring breathing mode micromechanical resonators. For the first time, we realize resonators of the same lateral dimensions but in different stacking layers (Si, AlN/Si, and Al/AlN/Si). We measure the resonance and its Q values, compare and model the observed energy dissipation. The results show that charge redistribution loss is a possible limiting mechanism.

W-156 DIRECT MEASUREMENT OF DISSIPATION IN PHONONIC CRYSTAL AND STRAIGHT TETHERS FOR MEMS RESONATORS

V.J. Gokhale^{1,2} and J.J. Gorman¹
¹*National Institute of Standards and Technology (NIST), USA* and
²*University of Michigan, USA*

This paper presents optical measurements of the dynamic strain profiles along tethers found in microelectromechanical resonators and relates them to quality factor. Our experiments present the first systematic comparison between the best-performing conventional straight-beam tethers with one-dimensional phononic crystal (PnC) tethers for silicon bulk acoustic resonators, and demonstrate more than 3× improvement in mechanical quality factor (Q) when the PnC tethers are used.

RF MEMS Components and Systems

M-157 INTEGRATION OF BOTTOM ELECTRODE IN Y-CUT LITHIUM NIOBATE THIN FILMS FOR HIGH ELECTROMECHANICAL COUPLING AND HIGH CAPACITANCE PER UNIT AREA MEMS RESONATORS

A. Kochhar, L. Colombo, G. Vidal-Álvarez, and G. Piazza
Carnegie Mellon University, USA

For the first time, we report the integration of a bottom electrode in thin films of Y-cut lithium niobate (LN) on silicon to demonstrate high performance lamb-wave (SO-mode) and thickness-shear-mode (TSM) resonators. The resonators attained high coupling $>6\%$ when excited in SO-mode and $>30\%$ when excited in TSM. Our demonstration enables MEMS designers to fully harness the high coupling of thin LN film, and have a transformative impact on reconfigurable and ultra-low-power communication systems.

T-158 LATERALLY VIBRATING LITHIUM NIOBATE MEMS RESONATORS WITH 30% ELECTROMECHANICAL COUPLING COEFFICIENT

F.V. Pop^{1,2}, A.S. Kochhar¹, G. Vidal-Álvarez¹, and G. Piazza¹
¹*Carnegie Mellon University, USA* and ²*University of Udine, ITALY*

We demonstrated laterally vibrating lithium niobate (LN) MEMS resonators operating at 500 MHz with an electromechanical coupling coefficient (kt^2) of 30% (theoretical limit), the highest ever attained for this class of resonators. This accomplishment is made possible by the use of direct bonding of bulk X-cut LN wafers to high resistivity silicon and a resonator electrode layout to harnessing the full capabilities of the film. A maximum figure of merit ($FoM=kt^2*Q$) of 219 is attained.

MEMS for Electromagnetics

THz MEMS Components and Systems

W-159 A TUNABLE TERAHERTZ METAMATERIAL BASED ON A MICRO-CANTILEVER ARRAY

X. Zhao¹, J. Schalch², J. Zhang², H.R. Seren¹, G. Duan¹,
R.D. Averitt², and X. Zhang¹
¹*Boston University, USA* and ²*University of California, San Diego, USA*

This paper reports a mechanically tunable terahertz metamaterial based on an array of electrostatic actuated cantilevers. This metamaterial realizes the capacity to electrically switch the transmission terahertz waves from circular polarization to linear polarization, which is demonstrated for the first time.

M-160 A UNCOOLED MULTI-BAND METAMATERIAL DETECTOR FOCAL PLANE ARRAY FOR REAL-TIME MULTI-SPECTRAL TERAHERTZ WAVE SENSING AND IMAGING

Z. Zhou, H. Li, J. Cao, and H. Tao
Chinese Academy of Sciences, CHINA

We have designed, fabricated, and characterized an uncooled, multi-band sub-wavelength metamaterial detector focal plane array (FPA) for real-time multi-spectral terahertz (THz) wave sensing and imaging. A rise in temperature due to the resonant absorption by split ring resonators (SRRs) leads to an increase in the interconnected SRR array's resistance, which can be readily read out electrically. We achieved a triple band THz detector FPA working at 2.5 THz, 3.4 THz, 4.3 THz, respectively.

MEMS Physical Sensors

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

- T-161 A PASSIVELY TEMPERATURE-COMPENSATED DUAL-FREQUENCY ALN-ON-SILICON RESONATOR FOR ACCURATE PRESSURE SENSING**
Q. Xie, N. Wang, C. Sun, A.B. Randles, P. Singh, X. Zhang, and Y. Gu
*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

We report a passively temperature-compensated dual-frequency AlN-on-Silicon micromachined resonator which has been experimentally demonstrated to provide highly accurate and linear pressure sensing. Thanks to its high temperature stability over a wide temperature range, this device is significantly more sensitive to differential pressure change, hence exhibiting huge potential for application in ruggedized environments where large temperature fluctuation is a concern.

- W-162 A SILICON CARBIDE DIFFERENTIAL OUTPUT PRESSURE SENSOR BY CONCENTRICALLY MATCHED CAPACITANCE**
L. Beker¹, A. Maralani², L. Lin¹, and A.P. Pisano²
¹*University of California, Berkeley, USA and*
²*University of California, San Diego, USA*

One of the major problems in geothermal and aerospace applications is to transfer small capacitance changes through cables. We present a SiC micromachined harsh-environment pressure sensor that utilizes concentrically matched capacitance to have differential capacitance output; thus noise stemming from cables can be reduced. Experimentally, it is verified that the sensors can provide a differential output. They can be mounted to km-long cables to without any active electronics.

- M-163 DRIE TRENCHES AND FULL-BRIDGES DESIGN FOR SENSITIVITY IMPROVEMENT OF MEMS SILICON THERMAL WIND SENSOR**
Y. Ye, Z. Yi, M. Qin, and Q.-A. Huang
Southeast University, CHINA

A MEMS silicon thermal wind sensor with improved sensitivity is demonstrated based on DRIE trenches and full-bridges design. Firstly, DRIE trenches are fabricated to suppress lateral heat loss between the heater and the thermistor. Moreover, eight thermistors forming two Wheatstone full-bridges enable about 50% increase of the sensitivity with respect to four thermistors. Based on these two designs, this device achieves sensitivity improvement of about 226%, compared with the traditional sensor.

- T-164 A WAFER-LEVEL ENCAPSULATED CMOS MEMS THERMORESISTIVE CALORIMETRIC FLOW SENSOR WITH INTEGRATED PACKAGING DESIGN**
W. Xu¹, B. Gao¹, M. Ahmed¹, M. Duan¹, B. Wang¹, A. Bermak^{1,2}, S. Mohamad¹, and Y.-K. Lee¹
¹*Hong Kong University of Science and Technology, CHINA and*
²*Hamad Bin Khalifa University, QATAR*

We present a wafer-level encapsulated Thermoresistive Micro Calorimetric Flow (TMCF) sensor with the integrated packaging by using proprietary InvenSense CMOS MEMS technology. The pulsed operated TMCF sensor achieved a normalized sensitivity of 112.4uV/(m/s)/mW. The measured TMCF sensor response time (<3.63ms) shows good agreement with a theoretical model. With the pulsed operation, the proposed TMCF sensor will be a promising digital CMOS MEMS flow sensor for IoT.

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

W-165 ENVIRONMENT-FRIENDLY WEARABLE THERMAL FLOW SENSORS FOR NONINVASIVE RESPIRATORY MONITORING

T. Dinh, H.-P. Phan, A. Qamar, T.-K. Nguyen, P. Woodfield,
Y. Zhu, N.-T. Nguyen, and D.V. Dao
Griffith University, AUSTRALIA

We report an eco-friendly and wearable flow sensor for noninvasive monitoring of human respiration. The sensor can be manufactured in-house using pencil graphite as a sensing layer and cellulose paper as a substrate, without using any cleanroom facilities. The sensor offers excellent performance such as high sensitivity and high signal-to-noise ratios. We further demonstrate a patch-type wearable sensor for monitoring human respiration, which finds applications in personal healthcare.

M-166 HIGH-THROUGHPUT AND LABEL-FREE PARASITEMIA QUANTIFICATION AND STAGE DETERMINATION FOR PLASMODIUM FALCIPARUM-INFECTED RED BLOOD CELLS

X. Yang^{1,2}, Z. Chen¹, G. Choi¹, J. Miao¹, L. Cui¹, and W. Guan¹
¹*Pennsylvania State University, USA* and ²*Zhengzhou University, CHINA*

This paper reports a highly sensitive, label-free cell deformability sensor for quantitative and high-throughput parasitemia measurement and stage determination for plasmodium falciparum-infected red blood cells (Pf-iRBCs). By analyzing more than 6000 RBCs within 1 min, parasitemia detection limit of 0.024% was achieved. In addition, the sensor can also distinguish the population for different stages.

T-167 MEMS WITH AN EMBEDDED FLUIDIC MICROCHANNEL FOR SENSITIVE WEIGHING OF LIQUID SAMPLES

C. Hadji¹, L. Viro¹, C. Picard², F. Baléras¹, and V. Agache¹
¹*CEA/LETI, FRANCE* and ²*University Grenoble, FRANCE*

This paper reports hollow MEMS plate oscillators for the characterization of liquid samples, with a one-fold improvement in both Q-factor and Allan deviation compared to previous alike structures, and fluidic constriction larger than 1 μm . These new characteristics make the devices amenable for the first time to liquid weighing with a 100 Hz $(\text{g}\cdot\text{L}^{-1})^{-1}$ sensitivity and a few $\text{g}\cdot\text{L}^{-1}$ detection floor.

W-168 THERMAL BASED FLOW SENSOR WITH NEARLY ZERO TEMPERATURE DEPENDENCE AND MID-BASED FLOW CHANNEL

F.T. Krogmann, C.J. Hepp, M. Lehmann, and J. Holoubek
Innovative Sensor Technology - IST AG, SWITZERLAND

A flow sensor is presented which shows nearly zero temperature dependence of the output signal between temperatures of 5 to 55°C. This allows without the need of temperature calibration an accuracy in the flow signal of less than 5% of the reading. The sensor is embedded into a MID (metal-interconnecting device) housing, which forms the fluidic channel and enables an easy mounting of the fluidic connection as well as a direct soldering of the sensor to a PCB.

M-169 THERMOELASTIC QUALITY-FACTOR ENHANCED DISK RESONATOR GYROSCOPE

X. Zhou, D. Xiao, Z. Hou, Q. Li, Y. Wu, D. Yu, W. Li, and X. Wu
National University of Defense Technology, CHINA

This paper demonstrates enhancing the thermo elastic quality-factor of a disk resonator gyroscope by hanging lumped mass on the frame structure. Our enhanced DRG shows a two-fold improvement in quality-factor and five-fold improvement in decay time constant compared with the conventional pure frame DRG. Hanging lumped mass could greatly reduce the resonant frequency whereas hardly affect the relaxation rate.

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

- T-170 TWO-STEP PROCEDURE FOR MULTI-MODE MEMS RESONATOR-BASED SENSING OF FLUID PROPERTIES**
G. Pfusterschmied¹, M. Kucera¹, C. Weinmann¹, M. Schneider¹,
A. Bittner¹, J.L. Sánchez-Rojas², and U. Schmid¹
¹Technische Universität Wien, AUSTRIA and
²University de Castilla, La Mancha, SPAIN

In this paper, a novel approach for the determination of densities and viscosities of fluids, using a multi-mode MEMS resonator, is introduced. Thereby a self-actuating/self-sensing piezoelectric MEMS-resonator is fabricated such, so that lateral as well as transversal bending modes can be excited within one measurement cycle. This unique evaluation principle is based on a two-step procedure, thus achieving deviations lower than 3%.

MEMS Physical Sensors

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

- W-171 A SIMPLE METHOD TO IMPLEMENT AND FURTHER PERFORMANCES ENHANCEMENT OF THE SHEAR FORCE SENSOR**
H.-Y. Chen, C.-Y. Huang, W.-C. Lai, R. Chen, and W. Fang
National Tsing Hua University, TAIWAN

We provide a simple approach in both design and process to change performances of the proposed shear force sensor. The sensor consists of SOI substrate and PDMS filler, with the latter transmitting force as the interface layer and protects suspended sensing units. With experimental supports, the performance of the shear force sensor can be improved by varying the cavity size of sensing cantilevers, indicating the sensitivity increases for 4-fold from the measurement results.

- M-172 AN IN-SITU PREPARED SYNCHRONOUS SELF-COMPENSATED FILM STRAIN GAGE FOR HIGH TEMPERATURE**
S. Yang, C. Zhang, H. Wang, and G. Ding
Shanghai Jiao Tong University, CHINA

This paper reports a novel temperature compensation method for PdCr strain gage. A suspended PdCr film and PdCr film adherent to the substrate with the same layout were fabricated. The temperature coefficient of resistance (TCR) for the suspended PdCr film and PdCr film adherent to the substrate has been measured up to 380°C so that the effect of temperature on the resistivity is known. Meanwhile, the gage factor K for PdCr film has been calculated for different temperature.

- T-173 STRETCHABLE, TRANSPARENT AND WEARABLE SENSOR FOR MULTIFUNCTIONAL SMART SKINS**
J. Zhang¹, Y. Song¹, H. Chen¹, X. Cheng¹, X. Chen¹,
B. Meng^{1,3}, Q. Yuan², and H. Zhang¹
¹Peking University, CHINA, ²Chinese Academy of Sciences, CHINA, and
³Beijing Micro Energy Technology Co., Ltd, CHINA

This paper reports a novel body motion sensor with PDMS-AgNWs structure, which is not only highly sensitive to detect static gestures by strain-resistance response, but also self-powered to recognize body motion based on triboelectrification and electrostatic induction synchronously for the first time. Attaching the sensor on skin directly, the motion could be reconstructed in real time. Particularly, the sensor can work as part of smart skins for its great stretchability and transparency.

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

W-174 FLEXIBLE TACTILE SENSOR ARRAY UTILIZING MICROSTRUCTURED PDMS BUMPS WITH PEDOT: PSS CONDUCTIVE POLYMER

S.-J. Fang¹, S. Husson², C.-K. Fu², and C.-H. Lin¹

¹National Sun Yat-sen University, TAIWAN and

²Metal Industries Research & Development Center, TAIWAN

This paper presents a novel flexible tactile sensor array fabricated with PEDOT:PSS conductive polymer modified micro-structured PDMS bumps. The micro-structures on PDMS bumps are produced by replicating the formed thermal bubble cavities during laser ablation of PMMA substrate. The micro-structures on the PDMS bumps greatly enhance the small force response such that the developed sensor exhibits a good response for detecting forces ranging from 0.2~0.7 N.

M-175 EVALUATION OF GROUND SLIPPERY CONDITION DURING WALK OF BIPEDAL ROBOT USING MEMS SLIP SENSOR

T. Okatani, H. Takahashi, T. Takahata, and I. Shimoyama

University of Tokyo, JAPAN

This paper reports an evaluation method of ground slippery condition using a MEMS slip sensor. The sensor can discriminate slippery and nonslippery conditions of ground in dynamic motions of a bipedal robot, which enables the robot to prevent a slip during walking. The fabricated sensor chip was attached to sole of the robot. Then, we demonstrated that ground slippery condition was determined by the sensor outputs during walking motion.

T-176 BIOINSPIRED MICROPOROUS ELASTOMER WITH ENHANCED AND TUNABLE STRETCHABILITY FOR STRAIN SENSING DEVICE

Z. Su¹, X. Chen¹, H. Chen¹, Y. Song¹, X. Cheng¹, B. Meng^{1,2},

Z. Song¹, and H. Zhang¹

¹Peking University, CHINA and

²Beijing Micro Energy Technology Co., Ltd., CHINA

Inspired by the muscle fiber networks in tongue of lizards, we report a large-area, microporous PDMS membrane with maximum enhancement of fracture strain by 210% over the bulk PDMS film. The three-dimensional microporous structures are fabricated by removing monodisperse polystyrene sphere arrays in PDMS matrix. Integrated with the capacitive strain sensor, the as-fabricated membrane is demonstrated as stretchable substrate for large or even extreme strain detection and human motion recognition.

W-177 MEMS FORCE AND DISPLACEMENT SENSOR FOR MEASURING SPRING CONSTANT OF HYDROGEL MICROPARTICLES

S. Kohyama¹, H. Takahashi¹, S. Yoshida², H. Onoe², K.H. Shoji¹,

T. Tsukagoshi¹, T. Takahata¹, and I. Shimoyama¹

¹University of Tokyo, JAPAN and ²Keio University, JAPAN

We developed a method to detect spring constant by a force and displacement sensor which consists of two sidewall doped piezoresistive cantilevers in the ranges of μN and μm . One cantilever pushes a target to wall to measure the restoring force of the target. Another cantilever pushes the wall directly to measure the displacement. By measuring both force and displacement on the same sensor chip, the spring constant of targets can be obtained accurately on from the sensor output.

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

- M-178** **SURFACE MICRO-STRUCTURED, STRETCHABLE STRAIN SENSOR TOWARDS BIAXIAL SENSITIVITY AND PERFORMANCE ENHANCEMENT**
M.S. Kim, D. Kwon, S. Kim, K. Kim, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We develop stretchable strain sensor based on a micro-structured polydimethylsiloxane (PDMS) and carbon nanotube (CNT) film deposited on its surface. Due to the microdome structures of the PDMS substrate, applied stress is concentrated between the microdomes and cracks of CNT film are only positioned at those regions. These phenomena enable the sensor to have both improved sensitivity and characteristic of a biaxial sensing.

- T-179** **VERTICAL INTEGRATION OF CAPACITIVE AND PIEZO-RESISTIVE SENSING UNITS TO ENLARGE THE SENSING RANGE OF CMOS-MEMS TACTILE SENSOR**
S.-Y. Tu, W.-C. Lai, and W. Fang
National Tsing Hua University, TAIWAN

We present a tactile sensor design to enlarge the sensing range by vertically integrated capacitive and piezo-resistive sensing units. The smaller loads are detected by the relatively sensitive capacitive sensing unit with deformable electrode of lower stiffness. The larger loads are detected by the piezo-resistive sensing units attached to a relatively stiff supporting structure. Thus, the sensing range of tactile sensor is improved.

MEMS Physical Sensors**Gas and Chemical Sensors**

- W-180** **A PHOTONIC MICROSYSTEM FOR HYDROCARBON GAS ANALYSIS BY MID-INFRARED ABSORPTION SPECTROSCOPY**
N.P. Ayerden¹, J. Mandon², M. Ghaderi¹, F.J.M. Harren², and R.F. Wolffenbuttel¹
¹*Delft University of Technology, NETHERLANDS* and
²*Radboud University, NETHERLANDS*

We present a gas-filled LVOF as the on-chip functional integration of a wideband optical filter and a gas cell. By using the resonator cavity of the filter also as a gas cell, the μm -level physical cavity length is elongated to a mm-level effective absorption path length through multiple reflections. The microspectrometer is designed using the Fizeau model and fabricated in a CMOS compatible process. The selectivity and sensitivity are demonstrated in the mid-IR with actual gas measurements.

- M-181** **A PORTABLE MINIATURIZED Pb^{2+} DETECTOR USING ION-RESPONSIVE HYDROGEL WITH WIRELESS INTERROGATION CAPABILITY**
C.-C. Yeh and Y.-J. Yang
National Taiwan University, TAIWAN

This paper presents a passive wireless Pb^{2+} sensor by employing ion-responsive hydrogel with an inductor-capacitor (L-C) resonator. When water passes through the device flowing into the hydrogel cavity, the hydrogel swells and changes the capacitance of the integrated L-C resonator, which in turn changes the resonant frequency that can be remotely detected by the phase-dip technique.

Gas and Chemical Sensors

T-182 AN ALN TWO-DIMENSIONAL ACOUSTIC WAVE HUMIDITY SENSOR WITH GRAPHENE OXIDE AS SENSING LAYER

X. Le and J. Xie
Zhejiang University, CHINA

In this paper, we firstly report an AlN thin film two-dimensional acoustic wave humidity sensor with graphene oxide (GO) as sensing layer. The sensor with small sensing area shows high sensitivity up to 218.6 kHz/10%RH with a wide detection range from 10% to 90%RH. The sensor has excellent performance in terms of repeatability and stability. The TCF of the sensors is about -15.8 ppm/°C, much smaller than conventional humidity sensors.

W-183 HIGHLY INTEGRATED SnO₂ NANOTUBES USING TEMPLATED ZNO NANOWIRES FOR LOW POWER GAS SENSORS

I. Cho, K. Kang, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper reports highly sensitive, low power gas sensors consisting of beam-shaped, suspended microheaters and locally synthesized 1-D metal oxide nanostructures. We directly synthesized sensitive SnO₂ nanotubes on suspended microheaters through low cost, fast and low-temperature liquid-phase process. It allows facile integration of sensing nanomaterials on selective microscale spots, which is difficult by using other conventional deposition methods.

M-184 HIGH PERFORMANCE HYDROGEN SENSOR BASED ON AN ARRAY OF SINGLE SUSPENDED CARBON NANOWIRES SELECTIVELY FUNCTIONALIZED WITH PALLADIUM NANOPARTICLES

J. Seo, Y. Lim, and H. Shin
Ulsan National Institute of Science & Technology (UNIST), KOREA

We report a novel hydrogen sensor based on an array of single suspended carbon nanowires ($\phi \sim 200$ nm, length ~ 100 μ m) decorated with various sizes (10 \sim 50 nm) of Pd nanoparticles (NPs) enabling room temperature H₂ gas sensing with high sensitivity, wide sensing range and full recovery in 5 s via low power consumption.

T-185 THE EXPLORATION OF MESOPOROUS SILICA AS A STATIONARY PHASE SUPPORT FOR SEMI-PACKED MICRO-FABRICATED GAS CHROMATOGRAPHIC (GC) COLUMNS

F. Luo, F. Feng, L. Hou, W. You, P. Xu, X. Li, X. Ge, and Y. Wu
Chinese Academy of Sciences, CHINA

This paper reports the use of mesoporous silica as a stationary phase support for serpentine semi-packed micro GC columns. Herein, OV-101 is used as the stationary phase. It is demonstrated that gaseous alkane C1-C4 can be well separated by using the micro-fabricated GC columns in 2 m, rather than the 25-30m of conventional capillary columns. Besides, the chromatographic resolution of mesoporous silica column for C1-C2 is 150 % higher than that of the same GC column without mesoporous silica.

W-186 MOF (METAL-ORGANIC FRAMEWORK) NANOMATERIAL FOR 400ppb-CONCENTRATION DETECTABLE XYLENE GAS SENSORS

P. Xu¹, T. Xu², H. Yu¹, D. Zheng², and X. Li¹
¹*Chinese Academy of Sciences, CHINA and*
²*Shanghai Institute of Technology, CHINA*

In this paper, MOF is explored as xylene sensing-material for resonant-cantilever gas sensor. Sensing experiment with the MOF nano-material of HKUST-1 demonstrates that 400ppb xylene can be detected. This LOD has been lower than the human olfactory threshold. The sensing mechanism is identified as the interaction between MOF and xylene. The specificity of HKUST-1 MOF to xylene is originated from the Cu²⁺ induced moderate Lewis acidity and like-dissolves-like interaction of benzene-ring.

Gas and Chemical Sensors

M-187 ULTRA-LOW POWER HYDROGEN SENSOR BY SUSPENDED AND PALLADIUM COATED SILICON NANOWIREJ. Yun¹, J.-H. Ahn², Y.-K. Choi¹, and I. Park¹¹Korea Advanced Institute of Science and Technology (KAIST), KOREA and²Kwangwoon University, KOREA

We developed a silicon nanowire decorated with palladium nanoparticles for hydrogen detection with self-heating. Self-heating of the Pd-SiNW reduces the response and recovery times by consuming low power without any significant change of sensitivity. Power consumption is further reduced by suspending the Pd-SiNW from substrate. Humidity effect on hydrogen sensing was also reduced by Joule heating. The sensor device has advantages of mass production and integration with electric circuit.

T-188 ULTRASENSITIVE MICRO SENSOR BASED ON LAYER-BY-LAYER SELF-ASSEMBLED GRAPHENE AND BISMUTH NANOPARTICLES FOR TRACE LEAD IONS DETERMINATIONZ. Wu¹, G. Jing¹, and T. Cui²¹Tsinghua University, CHINA and ²University of Minnesota, USA

For the first time, an ultra-sensitive micro sensor for the detection of trace lead (II) is fabricated by mixed dispersion solution of bismuth nanoparticles and PDDA, and layer-by-layer self-assembled with graphene suspension solution on a micro gold electrode.

MEMS Physical Sensors

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

W-189 A 3-BIT DIGITALLY OPERATED MEMS ROTATIONAL ACCELEROMETERV. Kumar¹, A. Ramezany¹, S. Mazrouei¹, R. Jafari², and S. Pourkamali¹¹University of Texas, Dallas, USA and ²Texas A&M University, USA

This work presents an electrostatically tunable MEMS rotational acceleration switch and its operation as a 3-bit digital rotational accelerometer. A rotational acceleration switch with a 49 rad/s² resolution has been fabricated and tested which requires only bias voltages for its operation enabling significant power reduction. Following a simple algorithm to activate different actuators, a binary search can be performed by a digital controller to find the rotational acceleration.

M-190 A MICROMACHINED THREE-AXIS GAS INERTIAL SENSOR BASED ON BIDIRECTIONAL THERMAL EXPANSION FLOW

B. Nie, W. Wang, F. Ye, and H. Chang

Northwestern Polytechnical University, CHINA

This paper reports a novel micromachined three-axis gas inertial sensor based on the bidirectional thermal expansion flow. Eight heaters and eight thermistors form a "cross-shape" network to generate bidirectional thermal expansion flows for the thermos-resistive sensing of each thermistor. Thus the Z-axis angular rate and X/Y-axis acceleration can be sensed simultaneously. Furthermore, the coupling between different axes can be suppressed very well.

T-191 AMBIENT PRESSURE DRIFT REJECTION OF MODE-LOCALIZED RESONANT SENSORS

H. Zhang, J. Zhong, W. Yuan, J. Yang, and H. Chang

Northwestern Polytechnical University, CHINA

This paper demonstrates the ambient pressure drift rejection capability in the full measurement range of mode-localized sensors. Based on a mode-localized resonant stiffness sensor, the experimental results show that the maximum measurement error of the amplitude ratio readout is ~2.74% whereas that of the frequency readout is ~21.63% with a pressure range of [2.6, 20] Pa.

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

- W-192 AN IMPROVED-SENSITIVITY RESONANT ACCELEROMETER WITH FISHBONE-SHAPED RESONATORS OF HIGHER VIBRATION MODES**
H. Ding and J. Xie
Zhejiang University, CHINA

This paper reports an improved-sensitivity resonant accelerometer with fishbone-shaped resonators of higher vibration modes. The higher vibration modes have a higher frequency sensitivity, and the proposed fishbone-shaped resonator can realize the mode selection and frequency-tuning function according to the location and number of driving and sensing electrodes. So this resonant accelerometer has sensitivity improvable and adjustable function compared to state of the art.

- M-193 DYNAMICALLY BALANCED DEGENERATE MODE GYROS WITH SUB-HZ FREQUENCY SYMMETRY AND TEMPERATURE ROBUSTNESS**
J. Giner¹, Y. Zhang¹, D. Maeda¹, K. Ono¹, A.M. Shkel², and T. Sekiguchi¹
¹*Hitachi Ltd. R&D Group, JAPAN and* ²*University of California, Irvine, USA*

GPS-less navigation applications require low drift gyroscopes. Dynamically balanced, mode-degenerate MEMS gyroscopes are ideal candidate due to its low noise, high Q factor and its capability to be operated as a Rate Integrating Gyroscope (RIG). Here we present XY symmetric dynamically balanced gyro with a new concentrated springs architecture that mitigates fabrication imperfections and provides as-fabricated frequency symmetry of less than 0.2Hz leading to a temperature robustness of 50mHz in a 120°C.

- T-194 EIGENMODE OPERATION AS A QUADRATURE ERROR CANCELLATION TECHNIQUE FOR PIEZOELECTRIC RESONANT GYROSCOPES**
M. Hodjat-Shamami, A. Norouzpour-Shirazi, and F. Ayazi
Georgia Institute of Technology, USA

This paper presents a quadrature error cancellation technique based on the virtual alignment of the gyroscope electrodes to the direction of vibration mode shapes in the presence of fabrication non-idealities. The proposed method, referred to as eigenmode operation, enables all-piezoelectric modal alignment of resonant gyroscopes. Also, for the first time, gyroscopic operation of a piezoelectric annulus structure which utilizes high-frequency in-plane flexural vibration modes is demonstrated.

- W-195 EPITAXIALLY-ENCAPSULATED QUAD MASS RESONATOR WITH SHAPED COMB FINGERS FOR FREQUENCY TUNING**
P. Taheri-Tehrani¹, M. Defoort¹, Y. Chen², I. Flader²,
D.D. Shin², T.W. Kenny², and D.A. Horsley¹
¹*University of California, Davis, USA and* ²*Stanford University, USA*

We present an epitaxially-encapsulated 2mm by 2mm quad-mass resonator (QMR) with shaped comb fingers for frequency tuning. The device has a very high quality factor ($Q=100,000$) which, without the shaped electrodes, results in undesirable nonlinear behavior such as amplitude-frequency dependence. We demonstrate that through the shaped comb finger design, both frequency tuning (over 90Hz) and large amplitude oscillation (1 μ m amplitude) are possible using Stanford epi-seal process.

- M-196 ENHANCED FREQUENCY STABILITY IN A NON-LINEAR MEMS OSCILLATOR EMPLOYING PHASE FEEDBACK**
B. Sun^{1,2}, C. Zhao², G. Sobreviela-Falces², S. Du², F. Han¹,
X. Zou^{2,3}, and A. Seshia²
¹*Tsinghua University, CHINA,* ²*University of Cambridge, UK, and*
³*Chinese Academy of Sciences, CHINA*

We demonstrate an optimal low noise point for a nonlinear MEMS oscillator where phase noise to frequency noise conversion is minimized. A closed loop oscillator consisting of a digitally controlled phase shifter is implemented and measurements of frequency stability are conducted under different phase feedback conditions. Measurement results show for a specific value of feedback phase, the enhanced frequency stability is achieved when the resonator is biased in the non-linear regime.

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

T-197 FULLY-DIFFERENTIAL SINGLE RESONATOR FM/WHOLE ANGLE GYROSCOPE USING CW/CCW MODE SEPARATOR

T. Tsukamoto and S. Tanaka
Tohoku University, JAPAN

This paper reports a fully-differential frequency modulated (FM) gyroscope where two degenerated eigenmodes are independently controlled but superposed on a single resonator. FM gyroscope operation with excellent $\Delta f - \Omega$ linearity was obtained and the scale factor had a very small temperature coefficient of -52 ppm/K. Whole angle detection was also demonstrated, and excellent $\theta - \Theta$ linearity was observed.

W-198 HIGH-G (>20,000g) INERTIAL SHOCK SURVIVABILITY OF EPITAXIALLY ENCAPSULATED SILICON MEMS DEVICES

D.B. Heinz, V.A. Hong, Y. Yang, C.-H. Ahn, and T.W. Kenny
Stanford University, USA

We demonstrate high-frequency (1.2MHz) MEMS tuning fork resonators and lower frequency (39kHz) MEMS devices capable of withstanding high-G inertial shocks. These devices reliably function after repeated shocks exceeding 20,000g. The device performance, and the robust, pure silicon encapsulated environment are both preserved. High frequency, single anchored devices show no measureable change in properties, and low frequency devices have high survival rates with small changes in surface adhesion.

M-199 HONEYCOMB-LIKE DISK RESONATOR WITH HIGH IMMUNITY TO FABRICATION ERROR FOR GYROSCOPIC APPLICATION

D. Xiao¹, X. Zhou¹, Q. Li¹, Z. Hou¹, Y. Wu¹, W. Li¹, X. Wang¹,
J. Zhang^{2,3}, and X. Wu¹

¹National University of Defense Technology, CHINA,

²University of Chinese Academy of Sciences, CHINA, and

³State Key Laboratory of Transducer Technology, Shanghai, CHINA

This paper reports a novel honeycomb-like disk resonator for gyroscopic application. Compared to the state of the art nested-rings disk resonator, the honeycomb-like disk resonator can provide much higher immunity to the fabrication error, much higher robustness to the environment disturbance, and lower Brownian noise floor.

T-200 MANIPULATION OF HEAT FLUX PATHS IN THERMO-ELASTICALLY DAMPED RESONATORS FOR Q OPTIMIZATION

D.D. Gerrard, J. Rodriguez, L. Comenencia Ortiz, S.A. Chandorkar,
I.B. Flader, Y. Chen, D.D. Shin, and T.W. Kenny
Stanford University, USA

We demonstrate how to identify regions of major thermo-elastic dissipation (TED) in MEMS resonators and reduce this energy loss by modifying the device geometry. To demonstrate this, various geometries of a disk resonating gyroscope (DRG) are used. We fabricate and test these DRGs to show that they are TED limited and Q can be increased using this geometric manipulation methodology.

W-201 MICROSCALE PIERCED SHALLOW SHELL RESONATORS: A TEST VEHICLE TO STUDY SURFACE LOSS

B. Hamelin, V. Tavassoli, and F. Ayazi
Georgia Institute of Technology, USA

This paper reports on energy loss in micro-scale pierced shallow shell resonators (PSSRs). PSSRs are useful to study the contribution of surface loss to the overall energy damping. Measurements confirm mode confinement. Surface loss is the main dominant damping mechanism of trapped modes in $2.6\mu\text{m}$ thick SiO_2 PSSRs. SiO_2 surface loss parameters are extracted. Quality factors as high as 111,000 have been measured, which corresponds to a 30% improvement compared to state-of-the-art.

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

M-202 NON-LINEAR EFFECTS FOR FREQUENCY TUNING AND QUADRATURE COMPENSATION OF A PZT SELF-CALIBRATION COMPATIBLE Z-AXIS GYROSCOPES. Nadig, V. Pinrod, and A. Lal
Cornell University, USA

This work presents frequency tuning and quadrature cancellation of a bulk-PZT gyroscope. PZT piezoelectric ceramics have non-linear elasticity versus strain dependence. We leverage material non-linearity of PZT and lateral PZT bimorph design, for frequency and quadrature tuning. Frequency and quadrature tuning is demonstrated with DC voltage control, as broadband control is desirable for closed loop operation using ASIC.

T-203 ON CROSS-TALK BETWEEN GYROSCOPES INTEGRATED ON A FOLDED MEMS IMU CUBEA. Efimovskaya¹, Y.-W. Lin¹, Y. Yang², E. Ng³, Y. Chen⁴, I. Flader⁴, C.H. Ahn³, V. Hong⁵, T.W. Kenny⁴, and A.M. Shkel¹¹University of California, Irvine, USA, ²Integrated Device Technology, Inc., USA, ³InvenSense, Inc., USA, ⁴Stanford University, USA, and ⁵Apple, Inc., USA

We report a miniature IMU implemented using a folded MEMS approach. Electrical signals from the sensors are transferred through the dense network of metal traces on parylene, thus enabling the integration with signal processing electronics. For the first time, we characterized cross-talk between sensors on the IMU sidewalls and provided evidence that the folded IMU process is advantageous to a single-die approach.

W-204 PULLED MICROCAPILLARY TUBE RESONATORS FOR HIGH PRECISION MICRODROPLET SIZE MEASUREMENTSD. Lee¹, S. Kauh¹, and J. Lee²¹Seoul National University, KOREA and ²Sogang University, KOREA

We develop the high-precision microdroplet size measurement using a pulled microcapillary tube resonator (PμTR) which is fabricated by a microfabrication-free approach-pulling a glass capillary and fixing it on top of a machined jig. The pulled section in the middle makes simple contact with a piezoactuator and quartz tuning fork (QTF). Overall, typical off-the-shelf parts simply constitute a resonant mass sensing system along with a convenient electrical readout.

M-205 SHOCK-PROTECTION OF NANO-GAP CAPACITIVE MEMS ACCELEROMETERS USING SLOPED ELECTRODE DESIGNY. Jeong^{1,2}, M. Foster², J. Chae², D.E. Serrano², and F. Ayazi^{1,2}¹Georgia Institute of Technology, USA and ²Qualtré Inc., USA

Following paper presents on a novel sloped electrode that enables implementing shock stops in MEMS sensor, which uses sacrificial layer to define its capacitive nano-gaps. By sloping interdigitated fingers, travelling range larger than sacrificial layer thickness can be attained, enabling increased sensing gap than shock stop without additional fabrication steps. Proposed scheme is used to design accelerometer, and characterizations were done to verify survivability under high-g condition.

T-206 SHOALING VIBRATION AMPLIFIER WITH FLATTENED TRANSFER FUNCTION AND SUPPRESSED SPURIOUS MODESV. Maiwald, M. Müller, C. Ritz, C. Roman, and C. Hierold
ETH Zurich, SWITZERLAND

A vibration sensor with off-resonant band-pass displacement amplification and a differential capacitive read-out is presented. We show that the transfer function can be flattened by adjusting the pressure in the measurement chamber. The measured minimum amplification is 16 dB over the frequency band from 3-13 kHz and shows less than 10% decrease over a pressure range from 6.3 to 64 mbar. The device can be used for low-power detection of broadband vibration signals e.g. for structural monitoring.

Inertial Sensors (Gyros, Accelerometers, Resonators, Etc.)**W-207 TRI-MODE OPERATION OF HIGHLY DOPED SILICON RESONATORS FOR TEMPERATURE COMPENSATED TIMING REFERENCES**

Y. Chen, D.D. Shin, I.B. Flader, and T.W. Kenny
Stanford University, USA

In this work, we propose a novel temperature compensation method that utilizes a tri-mode operation scheme to generate a temperature-stable frequency reference over a large temperature range. Three resonant modes are excited simultaneously on a highly doped silicon MEMS resonator. A linear combination of the three frequencies with unique TCf characteristics is shown to eliminate the temperature dependence up to second order and produce a temperature-insensitive frequency output.

MEMS Physical Sensors**Manufacturing for Physical Sensors****M-208 ALL-SOFT PHYSICAL AND CHEMICAL MICROSYSTEMS BASED ON LIQUID METAL FOR WEARABLE ELECTRONICS APPLICATIONS**

M.-G. Kim, H. Alrowais, and O. Brand
Georgia Institute of Technology, USA

This paper introduces all-soft physical and chemical sensing systems for wearable electronics applications comprising soft microsensors and soft functional circuits using EGaln and PDMS. An advanced EGaln thin-line patterning technique enables size-scalable, high density, and residue-free liquid metal patterns that form the base for the demonstrated physical microsystem for strain measurement and microfluidic chemical sensing platform for liquid-phase VOC detection.

T-209 FACILE FABRICATION OF MULTIPLE HYDROGEL ATOMIC FORCE MICROSCOPE CANTILEVERS VIA CAPILLARY FILLING AND ULTRAVIOLET CURING IN AN ALIGNED PDMS MOLD PAIR

S. Kim, J. Song, and J. Lee
Sogang University, KOREA

This paper reports the facile fabrication of multiple hydrogel (Polyethyleneglycol diacrylate; PEGDA) atomic force microscope (AFM) cantilevers via capillary filling and ultraviolet (UV) curing in an aligned polydimethylsiloxane (PDMS) mold pair for the first time. Fabricated PEGDA AFM cantilevers are thoroughly characterized and used for nanoscale imaging of HeLa cells, calibration gratings, and DVD media.

W-210 ULTRA CONFORMAL HIGH ASPECT-RATIO SMALL-GAP CAPACITIVE ELECTRODE FORMATION TECHNOLOGY FOR 3D MICRO SHELL RESONATORS

J. Cho, T. Nagourney, A. Darvishian, and K. Najafi
University of Michigan, USA

We report a new fabrication technology to form capacitive sense/drive electrodes with large area and narrow, uniform, and controllable gaps around a 3D micro shell resonator. The process utilizes electroplated photoresist (EP) to form a conformal sacrificial layer on the 3D shell, and electroplated metal (EM) to grow drive/sense electrodes towards the resonator until they touch the sacrificial layer and stop.

MEMS Physical Sensors

Nanoscale Physical Sensors

M-211 ENGINEERING MINIATURIZED HAIR CELL SENSORS FOR AUDITORY SYSTEM

M. Asadnia¹, A.G.P. Kottapalli², M.E. Warkiani³,
J.M. Miao⁴, and M.S. Triantafyllou⁵

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for Research and Technology (SMART), SINGAPORE,

³University of New South Wales, AUSTRALIA,

⁴Nanyang Technological University, SINGAPORE, and

⁵Massachusetts Institute of Technology, USA

We report the development of a new class of miniature all-polymer flow sensors that closely mimic the intricate morphology of the mechanosensory ciliary bundles in biological hair cells in human auditory system. An artificial ciliary bundle is achieved by fabricating bundled polydimethylsiloxane (PDMS) micro-pillars with graded heights and electrospinning polyvinylidene fluoride (PVDF) piezoelectric nanofiber tip links.

T-212 FABRICATION OF NANOMECHANICAL RESONATOR WITH NON-LOCAL SPIN VALVE STRUCTURE FOR SPIN DETECTION AND CONTROL

Y.-J. Seo^{1,2}, K. Harij^{1,3}, R. Takahashi^{1,3}, H. Chudo^{1,3}, K. Oyanagi¹,
T. Ono¹, Y. Shiomi¹, and E. Saitoh^{1,2,3}

¹Japan Science and Technology Agency (JST), JAPAN,

²Tohoku University, JAPAN, and ³Japan Atomic Energy Agency, JAPAN

There has been considerable interest in studying spin transport properties of ferromagnetic and non-magnetic hybrid structures because of their potential applications as spin-electronic devices. We have fabricated an ultra-sensitive nanomechanical resonator with integrated non-local spin valve structure. The obtained sensitivity of the resonator is 87 aN, which indicates the fabricated resonator is able to demonstrate the detection and control of spins by torque measurement of spin diffusion.

MEMS Physical Sensors

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

W-213 A MUTLI-AXIS PIEZORESISTIVE MEMS SENSOR FOR ACOUSTIC EMISSION

N. Matsuda, N. Minh Dung, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

In this study we present an approach for three-dimensional acoustic emission (AE) sensing based on the liquid-on-piezoresistive structure. The sensor has three orthogonal piezoresistive beams, covered with silicone droplets to produce directivity for three-dimensional AE. The piezoresistor-based principle allows our sensor to be downscaled to 2.8mm × 2.8mm × 2.8mm. Experiment results demonstrate that the device measures both in-plane and out-of-plane AE and that it has a bi-directional pattern.

M-214 BROADBAND RING-SHAPED PMUTS BASED ON AN ACOUSTICALLY INDUCED RESONANCE

B.E. Eovino¹, S. Akhbari², and L. Lin¹

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

We report on the unprecedented bandwidth achieved by appropriately designed ring-shaped PMUTs in liquid media. The increase in bandwidth is due to a second resonance peak that, rather than being caused by an additional vibration mode as is typical, is caused by interactions with the acoustic medium that reduce loading on the PMUT at specific frequencies. This previously unreported phenomenon could improve PMUT systems in applications ranging from medical imaging to non-destructive evaluation.

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

T-215 HIGH SENSITIVITY AND HIGH S/N MICROPHONE ACHIEVED BY PZT FILM WITH CENTRAL-CIRCLE ELECTRODE DESIGNJ.-L. Huang¹, S.-C. Lo¹, J.-J. Wang¹, C.-E. Lu¹, S.-H. Tseng², M.-C. Wu², and W. Fang¹¹National Tsing Hua University, TAIWAN and ²GlobalMEMS Co., Ltd., TAIWAN

This study based on piezo-electric sensing principle to develop a high S/N ratio MEMS microphone. The patterned PZT and electrode designed implemented above the clamped diaphragm to generate high stress concentration on PZT and Si bimorph diaphragm. The proposed design also provides a smooth stress distribution across electrode to tolerate more process variation such as offset from double-side alignment and boundary change by DRIE undercut.

W-216 INTER-ELEMENT COUPLING EFFECTS IN PULSE-ECHO ULTRASONIC FINGERPRINT SENSORSX. Jiang¹, H.-Y. Tang¹, Y. Lu², E.J. Ng³, J.M. Tsai³, M.J. Daneman³, B.E. Boser¹, and D.A. Horsley²¹University of California, Berkeley, USA,²University of California, Davis, USA, and³Invensense, Inc., USA

Ultrasonic fingerprint sensors based on micromachined ultrasound transducers require very high pitch to achieve high resolution imaging. We investigate a 110 × 56 PMUT array based on monolithic eutectic bonding to CMOS. To achieve high fill-factor, the PMUTs are anchored through small eutectic pillars, resulting in a high degree of mutual coupling. Using experiment and modeling, we show that the pulsed transmit-receive response can be understood as a combination of various array mode-shapes.

M-217 ON-DEMAND, HEATLESS EJECTION OF SUB-MM-SIZED LIQUID DROPLETS

Y. Tang, L. Wang, Y. Wang, and E.S. Kim

University of Southern California, USA

This paper reports a nozzle-less, heatless droplet ejector built on a 1 mm thick PZT sheet covered by Fresnel acoustic lens formed with annular rings of air cavities. With 450 V_{pp} 2.2 MHz pulsed sinusoidal drive, the device consistently ejects large liquid droplets of 285 μm in diameter with a volume of 12.1 nL. With a driving pulse width of 81.81 μs, the ejected droplet travels 30 cm against gravity before falling down and the corresponding initial velocity of the ejected droplet is 2.42 m/s.

T-218 PIEZOELECTRIC ALN CANTILEVER ARRAY ON A SU-8 SUBSTRATE FOR FLEXIBLE ARTIFICIAL BASILAR MEMBRANEJ. Jang¹, J.H. Jang², and H. Choi¹¹Daegu Gyeongbuk Institute of Science and Technology (DGIST), KOREA and ²Ajou University College of Medicine, KOREA

This paper reports for the first time a piezoelectric aluminum nitride (AlN) cantilever array on a flexible SU-8 substrate. The deposited AlN thin film exhibited highly c-axis orientation on the cured SU-8 film. The fabricated AlN cantilever array demonstrated piezoelectric characteristics with mechanical frequency selectivity, which is a vital function for artificial basilar membrane (ABM).

W-219 WIDEBAND AIR-COUPLED PZT PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER THROUGH DC BIAS TUNINGY. Kusano¹, Q. Wang¹, R.Q. Rudy², R.G. Polcawich², and D.A. Horsley¹¹University of California, Davis, USA and²US Army Research Laboratory, USA

We report an air-coupled piezoelectric micromachined ultrasonic transducer (PMUT) with a high displacement sensitivity and a high 3dB bandwidth, achieved through dc bias tuning which controls the polarization and intrinsic stress of the PMUT's PZT layer. The two closely spaced resonance modes nearly overlapped at ±6V dc bias, resulting in broad bandwidth and shorter decay time, important for achieving short pulse transmission and reception in pulse-echo imaging.

MEMS Physical Sensors

Other Physical Sensors

M-220 ELECTROSTATIC CHARGE SENSOR BASED ON MICRO RESONATOR WITH SENSING SCHEME OF EFFECTIVE STIFFNESS PERTURBATION

D. Chen, J. Zhao, Y. Wang, and J. Xie
Zhejiang University, CHINA

We report a micro resonant electrostatic charge sensor with new sensing scheme to measure small quantity of electric charge. The sensing scheme utilizes input charge to produce lateral electrostatic force to perturb the effective stiffness of double ended tuning forks resonator, and lead to a resonant frequency shift. The electrostatic charge sensor based on lateral force perturbation scheme has high sensitivity compared with the traditional axial strain modulation type charge sensor.

T-221 A SINGLE-CHIP SCANNING PROBE MICROSCOPE ARRAY

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

We report the first single-chip atomic force microscope (sc-AFM) array that simultaneously acquires multiple sub-10nm images of a sample. Four AFM cantilevers share an electrothermal lateral scanning stage while each AFM cantilever is independently driven, sensed, and controlled. This sc-AFM array represents the first step towards massively parallel scanning probe microscopy (pSPM), a new class of metrology instrumentation that is poised to achieve unprecedented imaging throughput.

W-222 A MINIATURIZED AEROSOL SENSOR IMPLEMENTED BY A SILICON-BASED MEMS THERMAL-PIEZORESISTIVE OSCILLATOR

C.-C. Chu¹, T.-Y. Liu¹, T.-M. Chen², W.-T. Hsu³, C.-H. Weng³,
and S.-S. Li¹
¹*National Tsing Hua University, TAIWAN*,
²*Industrial Technology Research Institute, TAIWAN*, and
³*TXC Corporation, TAIWAN*

A real-time aerosol sensor utilizing an SOI-MEMS thermal-piezoresistive oscillator (TPO) has been demonstrated in this work with calibration by a commercial optical aerosol sensor (OAS). As compared to the self-sustained TPO, the DC power and operating temperature of the device can be significantly reduced by integrating MEMS resonators and sustaining circuits, which leads to a longer lifetime with lower power consumption and makes it a viable candidate for environmental sensing applications.

M-223 FILTERLESS NON-DISPERSIVE INFRA-RED GAS DETECTION: A PROOF OF CONCEPT

A. De Luca¹, S.Z. Ali², R.H. Hopper², S. Boual²,
J.W. Gardner³, and F. Udrea^{1,2}
¹*University of Cambridge, UK*, ²*AMS AG Group, AUSTRIA*, and
³*University of Warwick, UK*

We demonstrate the detection of carbon dioxide using a non-dispersive-infra-red (NDIR) technique that does not require an expensive optical filter. This is achieved by employing a CMOS MEMS differential IR thermopile detector with micro-engineered (plasmonic) optical properties. The concept illustrated here represents a milestone in low-cost gas sensing spectroscopy, and has the potential to profoundly impact in the entire IR field and enable NDIR use in many consumer electronics applications.

Other Physical Sensors

W-224 MULTIFUNCTIONAL SPACEBORNE BLACKBODY SYSTEM FOR ON-BOARD CALIBRATION OF IMAGE SENSORST. Kim¹, B.-G. Chae¹, Y. Ryu², H.-U. Oh¹, and J. Lee²¹Chosun University, KOREA and ²Hanbat National University, KOREA

We develop multifunctional spaceborne blackbody system to improve the estimation accuracy of the measuring object by integrating with micro-heaters, micro-coolers, and micro-temperature sensors for space applications. We realize a lightweight, low power consumption, high accuracy blackbody system. The precise temperature uniformity is achieved so that the exact representative temperature of the blackbody could be provided for the wide-range temperature calibration of image sensors.

M-225 NOVEL ABSORBER MEMBRANE AND THERMOCOUPLE DESIGNS FOR CMOS-MEMS THERMOELECTRIC INFRARED SENSORK.-C. Chang¹, Y.-C. Lee¹, C.-M. Sun², and W. Fang¹¹National Tsing Hua University, TAIWAN and ²PixArt Imaging Inc., TAIWAN

This study designs and implements a thermoelectric IR sensor using TSMC 0.35 μ m 2P4M standard CMOS process. The novel design has three major concerns: heat conduction of the absorber membrane, distribution of the thermocouple, and etching release holes for post-CMOS process. Proposed design significantly increase the thermal resistance and responsivity of IR sensor. As compare with the reference design, the presented design could increase the responsivity for 6-fold at 25mtorr working pressure.

T-226 PATTERNING HIGH ASPECT SILICON PILLARS ON CANTILEVER BY METAL ASSISTED CHEMICAL ETCHING FOR HUMIDITY SENSING

N.V. Toan, M. Toda, T. Hokama, and T. Ono

Tohoku University, JAPAN

The first time used of the pillar patterned by MACE process as a post process on an AFM silicon cantilever for a humidity sensing presented in this work. Although the AFM cantilever is very fragile, patterning structures on this cantilever have been successfully demonstrated.

W-227 ZERO-POWER SENSORS WITH NEAR-ZERO-POWER WAKEUP SWITCHES FOR RELIABLE SENSOR PLATFORMS

V. Pinrod, L. Pancoast, B. Davaji, S. Lee, R. Ying, A. Molnar, and A. Lal

Cornell University, USA

The first ever zero-power sensor node solution is presented with piezoelectric sensors and DC tunable threshold electrostatic switches. A sensor suite measuring acceleration, rotation, and magnetic field, with lateral NEMS switches is used for the detection of the desired signal pattern and generating a wake up trigger. NEMS switches, with threshold voltages in the mV to 10V range, are capable of combining multiple sensor outputs through multi-gate actuation to detect desired event features.

Micro- and Nanofluidics

Biological and Medical Microfluidics and Nanofluidics

M-228 AN ARTIFICIAL CILIA BASED MICROMIXER FOR SUPERIOR ZEBRAFISH SPERM ACTIVATION

C.-Y. Chen, P.-Y. Huang, and B. Panigrahi

National Cheng Kung University, TAIWAN

The objective of this study is to propose an artificial cilia based microfluidic device for efficient activation of zebrafish sperm by controlling the hydrodynamics induced on the zebrafish sperms from the artificial cilia beating.

Biological and Medical Microfluidics and Nanofluidics

T-229 AN INTEGRATED MICROFLUIDIC DEVICE FOR C. ELEGANS EARLY EMBRYOGENESIS STUDIES AND DRUG ASSAYSL. Dong, R. Jankele, J. Zhang, M. Cornaglia, T. Lehnert,
P. Gönczy, and M. Gijs*École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND*

We report the first an integrated microfluidic approach for *C. elegans* early embryogenesis studies with unprecedented accuracy and throughput. Our device presents the following innovative features: (i) on-chip embryo extraction from gravid nematodes; (ii) fast and reliable on-chip immobilization of fragile permeable embryos; (iii) on-chip high-resolution live imaging of very early events in embryogenesis; (iv) well-controlled microfluidic pharmacological assays on early embryos.

W-230 MECHANICAL CHARACTERIZATION OF CYANOBACTERIA UNDER OSMOTIC STRESSS. Sakuma¹, D. Chang¹, F. Arai¹, K. Kera², and N. Uozumi²¹*Nagoya University, JAPAN* and ²*Tohoku University, JAPAN*

We report the evaluation results of Young's modulus of two *Synechocystis* sp. PCC 6803 groups; wild type and mutant type, which was knocked out mechanosensitive channels. They are placed in two different mediums; normal and high-osmolality condition. We confirmed that the measurement system will contribute to clarify unknown function of ion channels of cyanobacteria based on relationship between environmental stress and mechanical characteristics on single cell level.

M-231 DIRECT PCR AMPLIFICATION AND IN SITU IMAGING BASED ON ALGINATE DROPLETS

L. Li, L. Yu, and T. Wu

Chinese Academy of Sciences, CHINA

A droplet based microfluidic system encapsulating PCR reagent into alginate beads as a new digital PCR solution has been developed, which avoided droplet coalescence and enabled efficient DNA amplification and high-throughput fluorescent imaging. We also compared two trapping methods using hydrodynamic traps and micro sieves, and indicated the advantages of latter for higher trapping rate and no droplet clogging. These results provide new insights and tools for on-chip digital PCR.

T-232 MULTI-MODAL IMPEDANCE SPECTROSCOPY DEVICE FOR SIMULTANEOUS MEASUREMENT OF ELECTRICAL AND MECHANICAL PROPERTIES OF CELLSK. Mahesh¹, K. Parate², C.M. Shah³, M.M. Varma¹, and P. Sen¹¹*Indian Institute of Science, INDIA*, ²*Iowa State University, USA*, and³*Royal Melbourne Institute of Technology, AUSTRALIA*

We demonstrate a novel microfluidic platform based on electrical impedance spectroscopy (EIS) which independently measures the electrical properties of cells and also simultaneously estimates their mechanical properties through measurement of transit times across a constriction. The proposed technique offers more versatility compared to existing EIS techniques and enables multi modal analysis of cellular properties.

W-233 PULSED LASER ACTIVATED CELL SORTER WITH DIELECTROPHORETIC SINGLE STREAM SHEATHLESS FOCUSINGX. Zhu¹, Y.-C. Kung¹, T.-H. Wu², M.A. Teitell¹, and P.-Y. Chiou¹¹*University of California, Los Angeles, USA* and ²*NantWorks, LLC, USA*

We report a sheathless microfluidic FACS utilizing 3D DEP single stream focusing and pulsed laser activated cell sorting (PLACS). DEP forces are provided along a 4cm-long channel sandwiched by electrodes that focuses particles into a single stream regardless of sizes at high flow speeds. Pulsed laser-induced cavitation bubbles are used to provide rapid (~30 μs) and precise fluid perturbation to sort out fluorescent particles. 91% purity is achieved at a throughput of 1,500 particles sec⁻¹.

Biological and Medical Microfluidics and Nanofluidics

M-234 TUMOR CELL ISOLATION IN MICROFLUIDIC DEVICES FOR CANCER TREATMENT MONITORING

Z.H. Fan, J.I. Varillas, J. Zhang, K. Chen, and T.J. George, Jr.
University of Florida, USA

We have developed microfluidic devices for isolating circulating tumor cells (CTCs) in blood samples of pancreatic cancer patients. The device consists of micromixers or micropillars, and their surfaces have been modified using an assemble of antibodies and aptamers. We found that the CTC number can be used for monitoring the treatment responses of cancer patients.

Micro- and Nanofluidics

Generic Microfluidics and Nanofluidics

T-235 A LOW-COST FLEXIBLE ELECTROCHEMICAL ACCELEROMETER USING GRAPHENE-INTEGRATED MICROCHANNEL

Y.X. Zhang, Z. Li, K. Xu, C. Gao, Y. Hao, F. Meng, and Y. Gui
Peking University, CHINA

This paper reports a novel electrochemical accelerometer for wearable systems and smart skins. A flexible accelerometer based on graphene electrodes and PDMS microchannel on polyimide flexible print circuit has been achieved by low-cost fabrication process. Instead of expensive platinum electrode, graphene layer was transferred to FPC to function as chemical inertness sensitive electrode, and microchannel on FPC was obtained without lithography process by using screen printing PDMS lines.

W-236 GRAVITY-DRIVEN PULSATILE MICROMIXER WITHOUT USING DYNAMIC OFF-CHIP CONTROLLERS

Z. Li and S.-J. Kim
Konkuk University, KOREA

We develop a pulsatile micromixer without the need for external controllers and only relies on constant water-head pressure. The device is composed of self-actuated oscillator and mixer units. The oscillator unit generates pulsatile pressure to drive the mixer unit, thereby producing narrow periodic fluidic bands of two solutions for rapid mixing. The micromixer achieves up to 95% mixing efficiency in the flow rate and flow switching frequency of 2–20 $\mu\text{L}/\text{min}$ and 14–20 Hz, respectively.

M-237 LIPID BILAYER AT VERTICALLY ALIGNED NANOLITER DROPLETS GENERATED BY TWO-LAYERED MICROFLUIDIC CHANNELS

T. Osaki¹, T. Kaminski², K. Kamiya¹, S. Fujii¹, N. Misawa¹,
P. Garstecki², and S. Takeuchi^{1,3}

¹*Kanagawa Academy of Science and Technology (KAST), JAPAN,*

²*Polish Academy of Sciences, POLAND, and* ³*University of Tokyo, JAPAN*

We propose a microfluidic device for observable lipid bilayer formation between a pair of vertically aligned droplets. The device feature would include visibility of the bilayer and variable volume of the droplets, together with sub-microliter aqueous volume and time-course observation. We demonstrated a bilayer formation using the device and observed crystallization of potassium ferricyanide caused by water permeation through the bilayer.

T-238 MICROFLUIDIC PARTICLE CLUSTERING DEVICE FOR CROSS-CONTAMINATION-FREE MULTIPLEX ANALYSIS

S. Lee, H. Kim, W. Lee, and J. Kim

Pohang University of Science and Technology (POSTECH), KOREA

We present a microfluidic device that facilitates a multiplex analysis via an interaction of heterogeneous particles within microchamber array. A novel mechanism for particle clustering in a desired order was developed via a multi-step "trapping-releasing-storing-and-repeating" method using a tunable trapping barrier. With a two-phase aqueous/oil isolation method of multiple chambers incorporating particle clusters, a cross-contamination-free multiplex analysis strategy is demonstrated.

Generic Microfluidics and Nanofluidics

W-239 PARALLEL TRAPPING OF SINGLE MOTILE CELLS USING VIBRATIN-INDUCED FLOW ON MICROFLUIDIC CHIP

T. Hayakawa, Y. Akita, and F. Arai
Nagoya University, JAPAN

We propose parallel trapping method of single motile cells on microfluidic chip. The method enables parallel trapping of large motile cell, that is difficult to be trapped with conventional methods. We realized it by using vibration-induced flow, which is induced by simply applying vibration to the microfluidic chip having micropillars on its surface. The induced flow generates localized flow pattern to trap a single motile cell. We succeeded in trapping single *Euglena* with proposed method.

M-240 NANO-ELECTROKINETIC RADIAL PRECONCENTRATOR/EXTRACTOR BASED ON ION CONCENTRATION POLARIZATION

S. Lee, S. Park, N. Jeon, and S.J. Kim
Seoul National University, KOREA

We developed the radial preconcentrator/extractor in a micro/nanofluidic platform based on ion concentration polarization (ICP) phenomena. The device was designed without complex channel network and one can complete sample preparation steps from the preconcentration of samples to recovery of concentrated samples with this single platform. This simple device would serve a key component for point-of-care-test applications and biomedical analysis tools.

T-241 PARALLEL MICROARRAYING OF MICROFLUIDIC DROPLETS FOR HIGH-THROUGHPUT INTEGRATION WITH MATRIX-ASSISTED LASER DESORPTION IONIZATION MASS SPECTROMETRY

T.A. Duncombe¹, P. Adams¹, A. Singh^{1,2}, and T.R. Northen¹
¹*Joint Bioenergy Institute, USA* and ²*Sandia National Laboratories, USA*

Current droplet microfluidics to mass spectrometry integration approaches, to our knowledge, all introduce a serial rate limiting step. To address this bottleneck we leveraged a simple microwell array to enable a parallel process of droplet microarraying, droplet sample deposition through surfactant removal, and thermally actuated device disassembly for facile integration with MALDI mass spectrometry analysis.

Micro- and Nanofluidics

Manufacturing for Micro- and Nanofluidics

W-242 3-D PRINTED MINIATURIZED DIAPHRAGM VACUUM PUMP

A.P. Taylor¹ and L.F. Velásquez-García²
¹*Edwards Vacuum LLC, USA* and
²*Massachusetts Institute of Technology, USA*

We report the first demonstration of a fully additively manufactured, miniature diaphragm vacuum pump. Using polyjet 3-D printing technology, a single-stage vacuum pump design with active valves that has 1 cm³ in total pumping volume and 5% dead volume was realized. The devices consistently pumped down from atmosphere to 330 Torr in under 50 seconds (8.7 cm³/min effective flow rate), which is >300X the highest reported flow rate from a diaphragm vacuum pump made with standard microfabrication.

Manufacturing for Micro- and Nanofluidics

M-243 PACKAGING TECHNIQUE FOR A TUNABLE MINIATURE LIQUID IRIS OPERATED BY ELECTROWETTING ACTUATIONJ.B. Chae¹, S. Park², J.-H. Chang³, J. Yang², and S.K. Chung²¹*Amkor Technology Korea Inc., KOREA,*²*Myongji University, KOREA, and*³*Samsung Electronics Co., Ltd., KOREA*

This paper presents a simple ultraviolet (UV) chemical sealant aided packaging technique for a tunable liquid iris actuated by electrowetting-on-dielectric (EWOD) principle. To verify the proposed packaging technique the high temperature test of the iris sample applied by the UV chemical sealant aided packaging technique is conducted in the temperature chamber. The result shows that the iris sample applied to the UV chemical sealant aided packaging technique shows no liquid leakage and remains as it was.

T-244 A SMART MICROFLUIDIC SYSTEM INTEGRATED WITH PRESSURE SENSORS AND FLOW SENSOR BASED ON ELECTROCHEMICAL IMPEDANCE METHODSL. Tang, J. Liu, W. Hong, T. Wang, X. Wang, X. Chen, B. Yang,
and C. Yang*Shanghai Jiao Tong University, CHINA*

We report on a smart microfluidic system with multiple micro sensors integrated in its channel. It consists of a standard PDMS channel and a smart substrate which has six bubble pressure sensors and a flow sensor all based on electrochemical impedance methods. This system will allow, for the first time, directly and simultaneously monitoring of multiple parameters in the channel of microfluidic systems, including the monitoring of local pressure, flow rate, particles, cells, and so on.

W-245 IN SITU NANO 3D PRINTING OF A MICROFLUIDIC DIODE

A.C. Lamont, E.C. Reggia, and R.D. Sochol

University of Maryland, College Park, USA

We develop a three-dimensional (3D) printing process for generating micro/nano scale structures in situ within 50 μm x 120 μm fluidic microchannels. This method is scaleable, and the functional components of the designs could also be fabricated in much smaller channels using the same techniques. This fabrication technique has enabled the structures to be generated at scales an order of magnitude smaller than previously existing devices while also remaining cost and labor efficient.

M-246 MORPHOLOGY CONTROL OF MICROCHANNEL CROSS-SECTION USING SACRIFICIAL SPINNING FIBER

Y. Zhang, H. Jing, K. Xu, C. Gao, Y. Hao, F. Meng, Y. Gui, and G. Chen

Peking University, CHINA

This paper presents a novel method to manufacture specific cross-section microchannel by spinning profiled fiber. With spinning process, HIPS (High Impact Polystyrene) fibers with high profile degree have been drawn from a shaped spinneret orifice, and those fibers act as sacrificial mold to build microchannel with specific cross-section in PDMS. A PDMS swelling method has also been developed to remove large length-diameter ratio HIPS fiber inside PDMS rapidly without mechanical extraction.

T-247 HIGHLY EFFICIENT FORMATION OF DROPLET INTERFACE BILAYERS BY USING A MICROPERFORATED SEPARATORN. Misawa¹, S. Fujii¹, K. Kamiya¹, T. Osaki^{1,2}, and S. Takeuchi^{1,2}¹*Kanagawa Academy of Science and Technology (KAST), JAPAN and*²*University of Tokyo, JAPAN*

This study reports an efficient droplet interface bilayer (DIB) formation using an open chamber with an attachable separator that can divide an aqueous solution to two regions. This approach facilitates reagent saving and simplification of the device fabrication. We are assured of this method's availability for various research and development fields based on DIB applications.

Manufacturing for Micro- and Nanofluidics**W-248 FABRICATION OF A TRANSPARENT STRUCTURED SUPEROMNIPHOBIC SURFACE USING A MULTIPLE PARTIAL EXPOSE METHOD**

M.-S. Lee, P.-H. Wu, and W. Hsu
National Chiao Tung University, TAIWAN

A fabrication method to form a transparent structured superomniphobic surface is proposed, which involves only one standard lithography process without depositing hydrophobic material. This low-cost and rapid fabrication method also has the potential to integrate with either flexible or nonflexible substrate for different applications.

Micro- and Nanofluidics**Materials for Micro- and Nanofluidics****M-249 DISPLAY MEDIUM WITH PARTICLE MANIPULATIONS IN AN EMULSION DROPLET ARRAY**

J.-J. Gao, M.-T. Chang, and S.-K. Fan
National Taiwan University, TAIWAN

A self-assembled and packaged display medium is fabricated using microfluidic emulsion technology to encapsulated droplets of particles solutions in a curable continuous phase, which greatly simplify the packaging process. After photo crosslinking, we obtain an emulsion droplet array of regularly and densely arranged droplets containing uniformly dispersed particles that are further addressable by the externally applied electric field to alter the reflectivity and perform as a display medium.

Micro- and Nanofluidics**Other Micro- and Nanofluidics****T-250 AUTOMATED PAPER-BASED DEVICES BY MICROFLUIDIC DELAY AND TIMING-VALVE FOR COMPETITIVE ELISA**

Y.-T. Lai, J.-S. Tsai, J.-C. Hsu, and Y.-W. Lu
National Taiwan University, TAIWAN

We present a microfluidic timing-valve on a paper-based device to conduct competitive ELISA procedures. The device consists of multiple channels, where timing-valves regulate each individual liquid flow, to automate sequential steps. Imidacloprid (small molecule pesticide) is tested in our proposed device, while the results validate a simplified fluidic manipulation procedure and permits only single-step application of the sample solution for on-site detection.

W-251 COMBINATION OF OPTICAL MANIPULATION OF PARTICLE AND PATTERNING OF HYDROGELS FOR DEMONSTRATION OF DIGITAL DRUG COCKTAILS

K.-C. Chung, W.-B. Lee, C.-Y. Fu, C.-H. Wang, and G.-B. Lee
National Tsing Hua University, TAIWAN

This study presents an integrated microfluidic system combining two techniques, including an optically-induced dielectrophoresis (ODEP) module for manipulation of drug particles and an UV-direct-writing module capable of patterning of hydrogel. This system was able to provide an automatic and customized production of drug cocktails. Moreover, hydrogel, PEGDA was used for the first time as a medium in the ODEP module. A drug cocktail could be formed in less than 30~60 seconds.

Other Micro- and Nanofluidics

- M-252 EWOD SYSTEM DESIGNED FOR OPTICAL SWITCHING**
S. Günther¹, C. Endrödy¹, S. Si¹, S. Weinberger², R. Claes³,
Y. Justo³, H. D'heer⁴, A. Neft⁵, and M. Hoffmann¹
¹Technische Universität Ilmenau, GERMANY,
²X-FAB MEMS Foundry Itzehoe GmbH, GERMANY,
³Chemstream, BELGIUM, ⁴Ghent University, BELGIUM, and
⁵Bartels Mikrotechnik GmbH, GERMANY

We present an EWOD cell comprising a novel biphasic liquid system actuated in a standard EWOD configuration. The liquids feature a high difference in refractive indices and a low absorption in the telecommunication wavelength range which opens up new fields for optical electrowetting systems. Utilizing this novel liquid system, an EWOD structure for a bistable optical switch is presented and the EWOD actuation of the new liquid system is proven by successfully demonstrating the droplet movement.

- T-253 INDUCED LATERAL ELECTRIC FIELD (ILEF) DC DIGITAL MICROFLUIDICS**
M.E. Razu and J. Kim
Texas Tech University, USA

This paper reports a low voltage DC digital microfluidics device working in air filler by inducing lateral electric field (ILEF), which enables manipulation of various positively charged and negatively charged polar solutions for biomedical applications. Sensitivity of threshold voltage (minimum required voltage for droplet motion) to the polarity of actuation potential and the polarity of droplet solution is also reported for the first time in this paper.

- W-254 OBSERVATION OF CELL PINBALL THROUGH HIGH SPEED SWITCHING BETWEEN REFLECTION INTERFERENCE AND PHASE CONTRAST**
R. Murakami¹, A. Yamamoto², H. Ito¹, C.-H.D. Tsai¹, M. Horade¹,
M. Tanaka³, and M. Kaneko¹
¹Osaka University, JAPAN, ²Kyoto University, JAPAN, and
³University of Heidelberg, GERMANY

In "Cell Pinball" phenomenon, rotating red blood cells (RBCs) move like elastic balls inside a microchannel. The goal of this work is to clarify where the rotational axis is through the comparison between the contour and contact shapes of a moving RBC. By switching the reflection interference contrast and the phase contrast microscopes, we could observe that the distance between the each centroid is less than 0.8 [μm]. This result suggests an asymmetric contact force distribution.

- M-255 3-DIMENSIONAL FLUID FLOW PROFILE ON A STRUCTURED PDMS SURFACE**
A. Rockenbach and U. Schnakenberg
RWTH Aachen University, GERMANY

We present a device capable of transporting fluid in an open system along a wall without rotating parts using cilia-like comb rows. For the first time, we show a 3-dimensional image of the flow field along the rows with velocity profiles and mid velocities for all three propagation types obtained in our device, symplectic, antiplectic, and synchronous flow. We show the influence of secondary flow on the device. The methods used allows us to simplify our experiment to just a quarter of data.

- T-256 RESEARCH ON MICRO-FABRICATED GAS CHROMATOGRAPHIC COLUMNS WITH EMBEDDED ELLIPTIC CYLINDRICAL POSTS**
B. Tian, F. Feng, L. Hou, F. Luo, X. Li, X. Ge, and Y. Wu
Chinese Academy of Sciences, CHINA

This paper reports a newly developed micro-fabricated gas chromatographic (μGC) column with embedded elliptic cylindrical posts (ECP), which has higher surface area and less zero velocity zones compared to the state of the art. The 2 m and 4 m columns can separate methane and ethane with 0.66 and 1.02 resolution, which are obviously higher than that of the μGC column with embedded cylindrical posts (CP).

Other Micro- and Nanofluidics**W-257 REVERSIBLE LOW VOLTAGE ELECTROWETTING WITH SiO₂ CAPILLARY WINDOW FOR OPTICAL IMAGING**N.V. Toan¹, S. Sangu², Y. Ansaï², and T. Ono¹¹*Tohoku University, JAPAN and*²*Ricoh Institute of Future Technology, JAPAN*

This work reports the reversible low voltage electrowetting and liquid oscillation with SiO₂ capillary window for optical imaging. The optical window with and without Glycerol liquid penetration into SiO₂ capillaries has been demonstrated.

M-258 WIRELESS VALVING FOR CENTRIFUGAL MICROFLUIDIC PLATFORM USING FIELD FREQUENCY MODULATIONM.A. Zainal¹, P.S. Chee^{1,2}, and M.S. Mohamed Ali¹¹*Universiti Teknologi Malaysia, MALAYSIA and*²*Universiti Tunku Abdul Rahman, MALAYSIA*

This paper reports a selective wireless active valve mechanism for centrifugal microfluidic CD operated using field frequency modulation techniques. The reported technique offers a further advancement in centrifugal microfluidic field by enabling full control on the liquid flow. We use localized and selective RF wireless heating of paraffin wax active valves to control the liquid flow in centrifugal CD. Vacuum/compression valving (VCV) and mixing applications are also demonstrated in this work.

T-259 TRANSPORT VELOCITY OF DROPLETS ON RATCHET CONVEYORS IS DETERMINED BY QUANTIZED STEP PROBABILITY

H.R. Holmes and K.F. Böhringer

University of Washington, USA

We report the first characterization of the transport velocity for droplets driven on ratchet conveyors. We determined that the minimum vibration amplitude to initiate droplet transport does not occur at the largest movement of the droplet edges and is thus not simply a resonance effect. We have also discovered that the transport velocity is correlated with the vibration amplitude, but ultimately determined by the probability of the droplet edges advancing by a discrete number of steps.

Technical Topics on MEMS Products**Barriers to Commercialization & Research Needs for Future Products****M-260 PRESSURE + X/Z TWO-AXIS ACCELERATION COMPOSITE SENSORS MONOLITHICALLY INTEGRATED IN NON-SOI WAFER FOR UPGRADED PRODUCTION OF TPMS (TIRE PRESSURE MONITORING SYSTEMS)**J. Wang¹, Z. Ni¹, J. Zhou², X. Shi², T. Wan², and X. Li¹¹*Chinese Academy of Sciences, CHINA and* ²*AutoChips Co. Inc., CHINA*

Reported is a low-cost batch fabrication technique for monolithically integrated pressure plus two-axis (X/Z) acceleration composite sensors. The newly added X-axis accelerometer is used for automatically identifying and positioning each of the four wheels. Benefited from the single-wafer front-side fabrication technique, the sensor has the advantages of small chip-size and compatible process with IC-foundries. Testing results of the sensor meet the requirements of upgraded TPMS application.

Technical Topics on MEMS Products

MEMS vs. Macro: Pros and Cons of Miniaturization in Actual Products

W-261 THE BENEFITS OF MINIATURIZATION OF AN ATOMIC FORCE MICROSCOPE

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

We have developed a single-chip Atomic Force Microscope (sc-AFM) that integrates all of the scanners, sensors, and sharp tip of a conventional AFM onto a single 1x1mm CMOS MEMS device. This miniaturization offers many performance advantages over conventional instruments, including reduced size (1,000x), reduced cost (100x), vibration immunity, and improved versatility. The small, portable system enables new applications for AFM, and makes this popular nanotechnology tool accessible to everyone.



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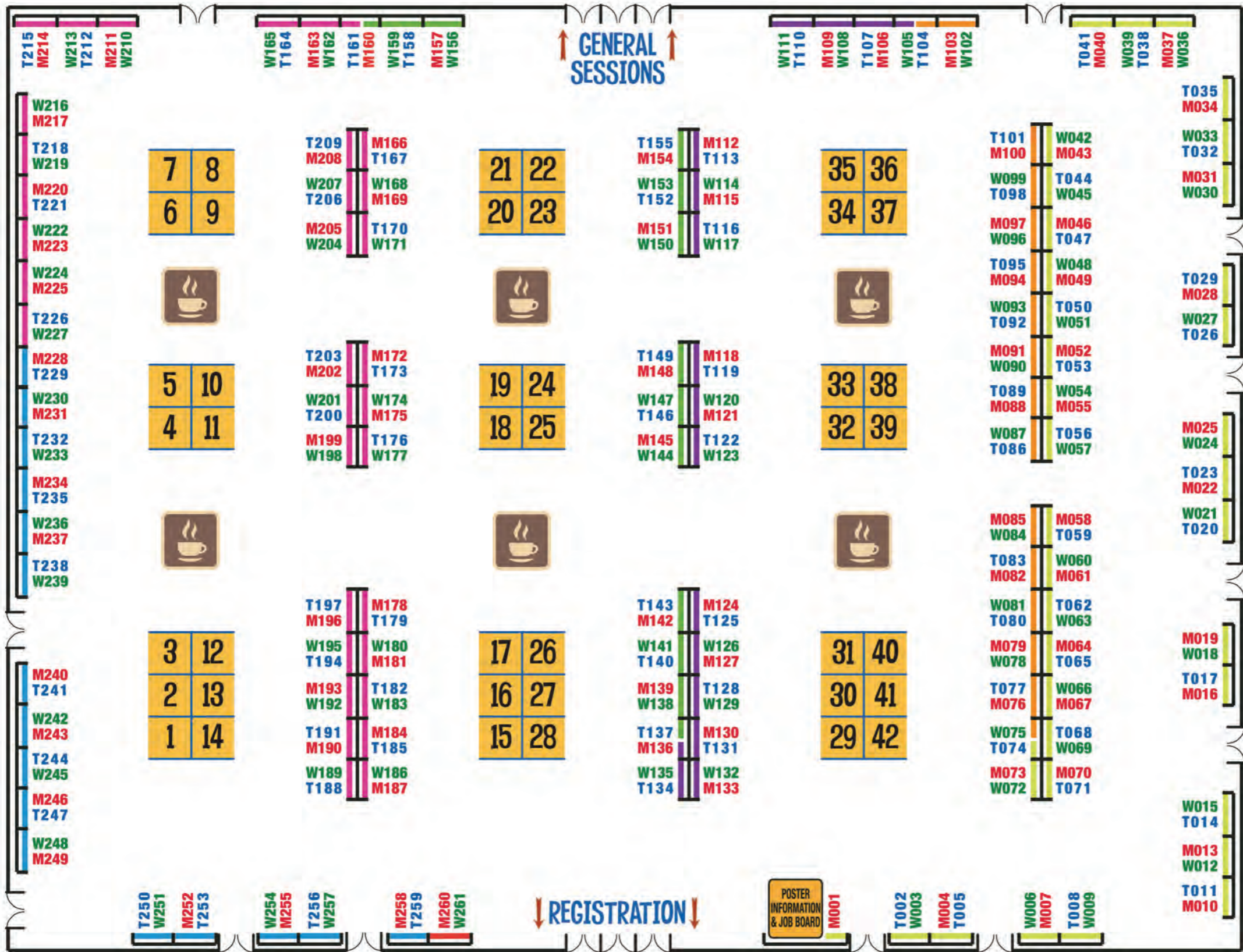
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