2018 IEEE Micro Electro Mechanical Systems (MEMS 2018)

Belfast, United Kingdom
21-25 January 2018

Pages 1-656

IEEE Catalog Number: CFP18MEM-POD
ISBN: 978-1-5386-4783-7

****** This is a print representation of what appears in the IEEE Digital Library. Some format issues inherent in the e-media version may also appear in this print version.***

IEEE Catalog Number:	CFP18MEM-POD
ISBN (Print-On-Demand):	978-1-5386-4783-7
ISBN (Online):	978-1-5386-4782-0
ISSN:	1084-6999

Additional Copies of This Publication Are Available From:

Curran Associates, Inc
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: (845) 758-0400
Fax: (845) 758-2633
E-mail: curran@proceedings.com
Web: www.proceedings.com

MEMS 2018 PROGRAM SCHEDULE

Sunday, 21 January

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

Monday, 22 January

Welcome Address
Auditorium, Ground & Level 1

08:00 **MEMS 2018 Conference Chairs**
Michel Despont, CSEM, SWITZERLAND
Jens Ducrée, Dublin City University, IRELAND

Plenary I
Session Chair:
J. Ducrée, Dublin City University, IRELAND
Auditorium, Ground & Level 1

08:50 **MICROSTRUCTURES TO SHAPE ACOUSTIC FIELDS AND CREATE COMPLEX MICROFLUIDIC FLOWS** **1**
Jonathan M. Cooper
University of Glasgow, UK

Session I – Biosensors
Session Chairs:
K. Cheung, University of British Columbia, CANADA
T. Cui, University of Minnesota, USA
Auditorium, Ground & Level 1

09:35 **HANDHELD NANOPORE-BASED BIOSENSING DEVICE** **2**
Y. Izawa[1,2], T. Osaki[2], K. Kamiya[2], S. Fujii[2], N. Misawa[2], N. Miki[1,2], and S. Takeuchi[2,3]
[1]Keio University, JAPAN, [2]Kanagawa Institute of Industrial Science and Technology, JAPAN, and [3]University of Tokyo, JAPAN

We developed a handheld device for long-term nanopore-based biosensing. Lipid bilayer is formed at the tip of a glass capillary, which is contained in the solution trapped in a cup-like reservoir. This format achieved (i) formation of a robust lipid bilayer for mobile use, (ii) solution exchange without rupturing the bilayer, and (iii) sustaining the small number of nanopores for long-term sensing. Our device successfully detected DNA translocations continuously for 75 minutes using 5 nanopores.

09:50 **MULTIPLEXED MICROFLUIDIC PLATFORM COUPLED WITH PHOTODETECTOR ARRAY FOR POINT-OF-NEED AND SUB-MINUTE DETECTION OF FOOD CONTAMINANTS** **6**

R.R.G. Soares[1,2], D.R. Santos[1,2], I.F. Pinto[1,2], A.M. Azevedo[2], M.R. Aires-Barros[2], V. Chu[1], and J.P. Conde[1,2]
[1]Instituto de Engenharia de Sistemas e Computadores - Microsistemas e Nanotecnologias (INESC MN), *PORTUGAL and* [2]*Universidade de Lisboa, PORTUGAL*

This paper presents an integrated microfluidic platform, allowing an ultrarapid and multiplexed detection of mycotoxins. The detection of aflatoxin B1, deoxynivalenol and ochratoxin A at the relevant limits is achieved in a single step within 1 min. This platform can potentially be the basis of portable tools allowing routine and cost-effective on-site screening of mycotoxin contamination by non-specialized personnel and be extended to other applications such as biomedical and environmental.

10:05 **ZEBRAFISH SPERM ACTIVATION THROUGH AN ARTIFICIAL CILIA EMBEDDED SERPENTINE MICROFLUIDIC PLATFORM** **10**

B. Panigrahi, C.-H. Lu, N. Ghayal, and C.-Y. Chen
National Cheng Kung University, TAIWAN

This work reports an artificial cilia embedded serpentine microfluidic channel for high throughput zebrafish sperm cell activation. With this proposed device, an average of 74.44 ± 6.07 % of the used zebrafish sperm cells was activated within the first 15 second of the experiment, which is at least 20 % superior to the currently available other manual techniques.

10:20 **Break & Exhibit Inspection**

Session II - Optical MEMS

Session Chairs:
D. Uttamchandani, University of Strathclyde, UK
J.-B. Yoon, Korea Advanced Institute of Science and Technology (KAIST), KOREA

Auditorium, Ground & Level 1

10:50 **SWITCHABLE LIQUID SHUTTER FOR SECURITY AND DESIGN OF MOBILE ELECTRONIC DEVICES** **14**

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

This paper presents a new type of switchable liquid shutter operated by electrowetting-on-dielectric (EWOD) actuation for security and design of mobile devices. The proposed liquid shutter not only allows a simple design to be easily miniaturized and integrated with electronic devices but also provides fast and robust switching operation.

11:05 **MEMS-BASED NEAR-ZERO POWER INFRARED WIRELESS SENSOR NODE** **17**

V. Rajaram, Z. Qian, S. Kang, N.E. McGruer, and M. Rinaldi
Northeastern University, USA

We demonstrate a system-level implementation of a near-zero standby power infrared wireless sensor node (WSN) based on vacuum-packaged micromechanical photoswitches. We show that by using plasmonically-enhanced micromechanical photoswitches, we can reduce the standby power of wireless infrared sensor nodes to just <2.6 nW, which translates into near-unlimited battery life for realizing large scale battery-replacement-free remote sensor networks.

11:20 **LARGE-SCALE MEMS-ACTUATED 2-D OPTICAL PHASED ARRAYS** **21**

Y. Wang[1], G. Zhou[2], K. Yu[3], and M.C. Wu[1]
[1]University of California, Berkeley, USA,
[2]National University of Singapore, SINGAPORE and
[3]Korea Advanced Institute of Science and Technology (KAIST), KOREA

We report on a novel two-dimensional (2-D) optical phased arrays with 25,600 addressable phase shifters made of diffraction gratings with in-plane movement. The phase shift is independent of wavelength, and only depends on the displacement of the grating. The large optical aperture 3.2x3.1mm2 produces a narrow beam (0.028°_0.029°) steerable over a field-of-view of 4.4°_4.6° at 1550nm wavelength, with a response time of 6μs.

11:35 **A HIGHLY MINIATURIZED SINGLE-CHIP MOEMS SCANNER FOR ALL-IN-ONE IMAGING SOLUTION** **25**

A. Jovic[1], T. Uto[2], K. Hei[1], J. Sancho[3], N. Sanchez[3], K. Zinoviev[4], J.L. Rubio[3], E. Margallo[3], G. Pandraud[1], and P.M. Sarro[1]
[1]Delft University of Technology, NETHERLANDS, [2]Kaneka, JAPAN,
[3]Medlumics S.L., SPAIN, and [4]Imec, BELGIUM

A highly miniaturized, single-chip, large scanning range MOEMS scanner is demonstrated. These self-aligned, monolithically integrated devices use small angular displacement to provide a large linear scanning range. Within a small footprint, the presented system fully integrates a photonic interferometer with mirror, a Si microlens and the MEMS actuator system into a single chip, thus offering an unprecedented miniaturized scanning solution.

11:50 **RESPONSIVISITY ENHANCEMENT OF CMOS-MEMS THEROELECTRIC INFRARED SENSOR BY HEAT TRANSDUCTION ABSORBER DESIGN** **29**

T.-W. Shen[1], Y.-C. Lee[1], K.-C. Chang[2], and W. Fang[1]
[1]National Tsing Hua University, TAIWAN and
[2]Asia Pacific Microsystems, Inc., TAIWAN

This study presents a heat transduction absorber design to improve the responsivity of thermoelectric infrared sensor using TSMC standard CMOS process. Features of the proposed design are: 1. umbrella-like heat transduction structure providing a better heat-flow path, 2. absorber membrane with designed etching release holes to enhance absorption area/efficiency of infrared, and 3. serpentine thermocouple for large thermal resistance.

12:05 **Grab & Go Lunch & Exhibit Inspection**

Session III – Fabrication

Session Chairs:
K. Kurabayashi, University of Michigan, USA
X. Li, Chinese Academy of Sciences, CHINA

Auditorium, Ground & Level 1

We report a novel mechanical-interlocking nano-transfer method, fabricating ultralong, fully-aligned nanowires made of diverse materials on a plastic-sheet. Using the developed method, we firstly fabricated fully-aligned, dense and diverse-material nanowires on a plastic-sheet. We also fabricated a unique nanowire-heater embedded gas-sensor using the transferred metal and metal-oxide nanowires. The developed device exhibited 33-folds enhanced sensitivity to 10 ppm NO_2 using 0.6 V heater-bias.

This paper reports a novel 3D micro-printing method for the fabrication of polytetrafluoroethylene (PTFE) microstructures by using optical maskless exposure technology and thermal decomposition process. 3D PTFE microstructures with nanopores ranging from tens to hundreds of nanometers were fabricated for the first time. The printed PTFE microstructures have great potential in medical implants, chemically inert micro-reactors/filters, and microfluidics control applications.

This paper reports a reusable, flexible and low cost parylene-C/Cr shadow mask for fabricating diverse microscale patterns on arbitrary surfaces. The smallest feature size of the fabricated patterns can reache 3 μm and the mask can be reused for more than 6 times with good integrity and high accuracy. Compared to state of the art, this shadow mask has smaller feature size and thickness, longer usage time and better feature transfer fidelity.

We propose a batch fabrication of a perforated separator for formation of a planar lipid bilayer, aiming for commercial production. A bilayer system attracts attention as a biosensor platform, and a perforated separator is essential for reconstitution of a bilayer on such devices. We designed a fabrication process of the separator composed of a microaperture and its frame. Approx. 300 pieces were obtained by a batch, and electrical properties of a bilayer were certified with the separator.

14:30 **Poster/Oral Session I** (Refreshments will be served at 16:00)
Poster presentations are listed by topic category with their assigned number starting on page 23.

Session IV - Implantable & Wearable Medical Devices

Session Chairs:
W. Li, Michigan State University, USA
S. Takeuchi, University of Tokyo, JAPAN

Auditorium, Ground & Level 1

16:35 **PARYLENE-OIL-ENCAPSULATED LOW-DRIFT IMPLANTABLE PRESSURE SENSORS** **47**
A. Shapero and Y.-C. Tai
California Institute of Technology, USA

We present a packaging method of pressure sensors targeted for long-term implantation with low-drift. Commercial digital-output barometers are submerged in biocompatible silicone oil and encapsulated in situ with parylene-C, -D, or –HT, without an increase in size. Intrinsic stress of parylene as deposited on oil under varying conditions is investigated to optimize the recipe. Low-drifts of <0.5% sensitivity and <1mmHg offset are achieved in accelerated lifetime tests in high-temperature saline.

16:50 **A MANDIBULAR ADVANCEMENT DEVICE EMBEDDED WITH POLYMER-BASED TUNNELING PIEZORESISTIVE PRESSURE SENSING ARRAY** **51**
Y.-T. Chen[1], C.-C. Yeh[1], M.-X. Xu[1], F. Tan[1], Y.-J. Chen[2], and Y.-J. Yang[1]
[1]*National Taiwan University, TAIWAN and*
[2]*National Taiwan University Hospital, TAIWAN*

In this work, a mandibular advancement device (MAD) embedded with a polymer-based tunneling piezoresistive pressure sensing array was developed for the obstructive sleep apnea evaluation. The pressure sensing element consists of a conductive polymer film assembled with interdigital electrodes. The patterned microstructures on the film enhance the device sensitivity. The sensor array exhibits excellent sensitivity and rapid response, and its flexibility enables seamless assembly of the MAD.

17:05 **WEARABLE MUSCLE TRAINING AND MONITORING DEVICE** **55**
Y. Takei, M. Yoshida, T. Takeshita, and T. Kobayashi
National Institute of Advanced Industrial Science and Technology (AIST), JAPAN

We developed a wearable device that can electrically stimulate muscle and measure the muscle activities simultaneously. This device is composed only of flexible material such as textile electrode printed on cloth and 5μm-thick piezoresistive silicon, polyimide substrate and PDMS. By deploying this device on sportswear, muscle training and motion assist by electric muscle stimulation become possible, monitoring muscle activity simultaneously.

17:20 **TARGETED DRUG DELIVERY TECHNOLOGY (CARRYING, RELEASING, PENETRATING) USING ACOUSTIC BUBBLES EMBEDDED IN AN ELECTROMAGNETICALLY DRIVEN MICROROBOT** **59**
J. Jeong, D. Jang, and S.K. Chung
Myongji University, KOREA

This paper presents a new type of targeted drug delivery technology where an electromagnetically driven untethered microrobot swimming inside blood vessels performs drug delivery operations – carrying, releasing, and penetrating drugs to a target tissue by the selective acoustic excitation of microbubbles. This technology uses only compressible bubbles to wirelessly manipulate drugs without any complicated mechanical components, allowing the design of a microrobot simple.

17:35 **PHOTOTHERAPEUTIC CONTACT LENS FOR DIABETIC RETINOPATHY** **62**

C.A. Cook[1], J.C. Martinez-Camarillo[2], Q. Yang[2],
N.E. Scianmarello[1], M.S. Humayun[2], and Y.-C. Tai[1]
[1]*California Institute of Technology, USA and*
[2]*University of Southern California, USA*

A phototherapeutic contact lens to manage diabetic retinopathy by reducing retinal metabolism via suppression of rod cell dark current. Composed of PDMS embedded with radioluminescent sources, it provides near continuous illumination over the lens' lifetime. Rabbit ERG demonstrate bioactivity of the lens along with 1D retinal O_2 simulations. Tests in human eyes validate comfort, fit, and Troxler effect. An oxygen transmissibility of 130 Fatt meets FDA guidelines for overnight wear.

17:50 **Adjourn for the Day**

Tuesday, 23 January 2018

Plenary II
Session Chair:
M. Despont, CSEM, SWITZERLAND
Auditorium, Ground & Level 1

08:30 **EARLY APPLICATIONS OF QUANTUM COMPUTERS** **66**
Matthias Steffen
IBM Research Center, USA

Session V – Resonators
Session Chairs:
S.-S. Li, National Tsing Hua University, TAIWAN
M. Rinaldi, Northeastern University, USA
Auditorium, Ground & Level 1

09:15 **A MICRO RESONANT ELECTROMETER WITH 9-ELECTRON CHARGE RESOLUTION IN ROOM TEMPERATURE** **67**
J. Yang, H. Kang, and H. Chang
Northwestern Polytechnical University, CHINA

This paper reports a mode-localized resonant electrometer with 9-electron resolution in room temperature. To the best knowledge of the authors, it is the highest resolution level for MEMS resonant electrometers. It uses a 3-DoF weakly coupled resonators, then input charge causes stiffness perturbation to one resonator and leads to a drastic change of the mode shape owing to the mode localization phenomenon. Under the closed-loop test, the resolution is 9.21e/√Hz.

09:30 **TOP ELECTRODE SHAPING FOR HARNESSING HIGH COUPLING IN THICKNESS SHEAR MODE RESONATORS IN Y-CUT LITHIUM NIOBATE THIN FILMS** **71**
A. Kochhar, G. Vidal-Álvarez, L. Colombo, and G. Piazza
Carnegie Mellon University, USA

We report novel electrode shape for harnessing the high electromechanical coupling of the thickness shear mode in Y-cut lithium niobate (LN) thin film resonators. To maximize the coupling, we use two-dimensional equations of motion with transverse shear deformations to determine the most appropriate electrode shape. We experimentally demonstrate a kt2 of ~37%, which is matching with 3D COMSOL FEA simulations. Such high coupling resonators could find application in reconfigurable RF systems.

09:45 **GATED CMOS-MEMS THERMAL-PIEZORESISTIVE OSCILLATOR-BASED PM2.5 SENSOR WITH ENHANCED PARTICLE COLLECTION EFFICIENCY** **75**
T.-Y. Liu[1], C.A. Sung[1], C.-H. Weng[2], C.-C. Chu[3], A.-A. Zope[1], G. Pillai[1], and S.-S. Li[1]
[1]Nation Tsing Hua University, TAIWAN, [2]TXC Corporation, TAIWAN, and [3]Taiwan Semiconductor Manufacturing Company (TSMC), TAIWAN

A gated operation PM2.5 (aerosol) sensor using CMOS-MEMS thermal-piezoresistive oscillator has been demonstrated in this work. The thermophoresis effect often seen in the thermal-drive devices is resolved by the gated operation to ensure the functionality of the proposed sensor. Impactor was designed meticulously to enhance the landing probability of the small (~0.6um) size aerosol on the proof-mass. The proposed sensor can detect aerosol concentration within a range of 50 ug/m^3 to 200 ug/m^3.

10:00 **TRANSPARENT GRAPHENE-AZO/ZNO/GLASS SURFACE ACOUSTIC WAVE DEVICE APPLICATIONS FOR ELECTRONICS AND LAB-ON-A-CHIP** **79**

J. Zhou, D.B. Xiao, Z.X. Song, M. Zhuo, and X.Z. Wu
National University of Defense Technology, CHINA

This paper reports the fabrication of transparent surface acoustic wave (SAW) resonators using graphene-AZO composite structure as the transparent electrodes with the transparency above 80%. Temperature, Humidity sensing and strong acoustic streaming using the transparent SAW devices have been achieved, demonstrating the great potential for applications in transparent electronics.

10:15 **Break and Exhibit Inspection**

Session VI – Biofabrication

Session Chairs:
N. Roxhed, KTH Royal Institute of Technology, SWEDEN
M. Ziaei, iSono Health, USA

Auditorium, Ground & Level 1

10:45 **FORMATION OF A THIN-WALLED SPIDER SILK TUBE ON A MICROMACHINED SCAFFOLD** **83**

W. Guo, L. Gustafsson, R. Jansson, M. Hedhammar, and W. van der Wijngaart
KTH Royal Institute of Technology, SWEDEN

This paper reports on the first formation of a thin bio-functionalized spider silk tube, supported by an internal micromachined scaffold, in which both the inside and outside of the tube wall are freely accessible. The silk tube could potentially be used as an artificial blood vessel in an in vitro tissue scaffold, where endothelial cells and tissue cells can grow on both sides of the silk tube.

11:00 **WAFER-SCALE FABRICATION OF BIODEGRADABLE SILK-FIBROIN-BASED MEMRISTORS** **86**

G. Kook[1], S. Jeong[2], M. Kim[1], S. Lee[1], H. Kim[1], N. Choi[2], and H.J. Lee[1]
[1]*Korea Advanced Institute of Science and Technology (KAIST), KOREA and*
[2]*Korea Institute of Science and Technology (KIST), KOREA*

We develop a set of wafer-scale fabrication methods to pattern a silk fibroin film and its adjacent metal layers using conventional UV photolithography for the first time. Using this newly developed process, we fabricate a flexible, biodegradable, and highly dense silk-fibroin-based memristor in cross-bar architecture showing reliable switching characteristics over individual memory cell interfaces.

11:15 **PROTEIN LEGO: 3D BIONANOARCHITECTURES WITH SHAPES AND FUNCTIONS ON DEMAND** **90**

J. Jiang[1], S. Zhang[1,2], L. Sun[1,3], N. Qin[1], Z. Zhou[1,3], and H. Tao[1,2,3]
[1]*Chinese Academy of Sciences, CHINA,* [2]*University of Texas, Austin, USA, and*
[3]*University of Chinese Academy of Sciences, CHINA*

We report precise nanostructuring on genetically engineered spider silk using ion beam lithography (IBL) to create well-defined 2D bionanopatterns and further assemble 3D bionanoarchitectures, named "Protein Lego", with shapes and functions on demand, serving as functional biointerfaces for structure enhanced fluorescence and guided cell seeding as proof-of-concepts.

11:30 **SELF-ROLLING UP MICRO ASSEMBLY USING TEMPERATURE - RESPONSIVE HYDROGEL SHEET WITH RIGID PLATE ARRAY 93**

Y. Iwata[1], S. Miyashita[2], and E. Iwase[1]
[1]Waseda University, JAPAN and [2]University of York, UK

We propose a micro self-rolling up method using temperature-responsive hydrogel sheet with rigid plate array. Our self-rolling up is a method for a micro three-dimensional (3D) structure performed by rolling up a two-dimensional (2D) flat sheet, like making a croissant, through continuous self-folding. Using our method, we assembled rotational symmetry 3D structures, such as cylindrical and croissant-like ellipsoidal structures, and demonstrated repetitive deformation for micro soft devices.

11:45 **SIMPLE MANUFACTURING APPROACH FOR 3D OVERHANGING STRUCTURE OF HYDROGEL WITH IN-SITU LIGHT-GUIDING MECHANISM 97**

J. Lim[1], S. Lee[2], D.-J. Won[1], I.H. Choi[3], and J. Kim[1]
[1]Pohang University of Science and Technology (POSTECH), KOREA,
[2]Dong-Eui University, KOREA, and [3]Samsung Electronics, KOREA

This study proposes a method for fabricating a three-dimensional (3D) overhanging structure of a photo-polymerized hydrogel without supporting material as a sacrificial layer. The manufacturing method utilizes a precise micro-droplet printing technique and a light-guiding hydrogel. The method is expected to be applied to a wide range of components, such as sensors and actuators using functional hydrogels.

MEMS 2019 Announcement
Auditorium, Ground & Level 1

12:00 **MEMS 2019 Announcement**

Shoji Takeuchi, *University of Tokyo, JAPAN*
Jun-Bo Yoon, *Korea Advanced Institute of Science & Technology (KAIST), KOREA*

12:15 **Grab & Go Lunch & Exhibit Inspection**

Session VII – Inertial
Session Chairs:
G. Langfelder, Politecnico di Milano, ITALY
C.-C. Lo, Richtek Technology Inc., TAIWAN
Auditorium, Ground & Level 1

13:15 **100 nT/√HZ, 0.5 mm^2 MONOLITHIC, MULTI-LOOP LOW-POWER 3-AXIS MEMS MAGNETOMETER 101**

C.R. Marra[1], G. Laghi[1], M. Gadola[1], G. Gattere[2],
D. Paci[2], A. Tocchio[2], and G. Langfelder[1]
[1]Politecnico di Milano, ITALY and [2]STMicroelectronics, ITALY

The work proposes the first monolithic, 3-axis, multi-loop MEMS Lorentz-force magnetometer, compatible for 6-DOF, all-MEMS combos, and more convenient in terms of cost/area than hybrid solutions. The structure exploits an innovative geometry, which enables to combine in a single device the sensitivity along three axes. This generates an 8-fold active area reduction while halving noise density down to 100 nT/√Hz, with respect to previous multi-loop solutions.

13:30 **A HIGH-PERFORMANCE SINGLE-CHIP TIMING AND INERTIAL MEASUREMENT UNIT WITH ROBUST MODE-MATCHED GYROSCOPES** **105**

H. Wen[1], A. Daruwalla[1], Y. Jeong[2], P. Gupta[1], J. Choi[1], C.-S. Liu[1], and F. Ayazi[1]
[1]Georgia Institute of Technology, USA and
[2]Panasonic Device Solutions Laboratory of MA, USA

We present a single-chip timing and inertial measurement unit (TIMU) with novel high-frequency mode-matched gyroscopes, high-bandwidth accelerometers, and high-fQ BAW timing resonator. It's the first single-chip IMU featuring 3-axis quadrature-cancelled mode-matched gyros. The 3-axis gyros show sub-1°/√h ARW and ~10°/h BI. The 3-axis accels give sub-300µg/√Hz VRW and sub-100µg BI. The TIMU provides self-contained position tracking and is a good candidate for high-end applications.

13:45 **SMALL FOOTPRINT, HIGH-PERFORMANCE SILICON CAPACITIVE ACCELEROMETER WITH A 3-D PROCESS** **109**

F. Maspero[1,2], S. Delachanal[1,2], A. Berthelot[1,2], L. Joet[1,2], G. Langfelder[3], and S. Hentz[1,2]
[1]CEA-LETI, FRANCE, [2]Université Grenoble Alpes, FRANCE, and
[3]Politecnico di Milano, ITALY

A new process for multi-layer MEMS is presented and demonstrated with an in-plane accelerometer. With this solution, sensing elements and seismic mass can be fabricated in different layers and located on top of each other for significantly reduced size and enhanced performance: both can be independently optimized. For this first demonstration, we show intrinsic noise floor of 7 µg/rtHz, mechanical stiffness of 20 N/m, large bandwidth and sensitivity of 5.3 fF/g with total size of 400µm x 600µm.

14:00 **A BROAD-BAND SILICON MICROSEISMOMETER WITH 0.25 NG/RTHZ PERFORMANCE** **113**

W.T. Pike[1], I.M. Standley[2], S.B. Calcutt[3], and A.G. Mukherjee[1]
[1]Imperial College London, UK, [2]Kinemetrics, USA, and [3]University of Oxford, UK

We report a micromachined silicon seismometer with a sensitivity of 0.25 ng/rtHz from 0.1 to 2 Hz. This represents the highest performance of a MEMS inertial sensor to date, and is below the noise floor of the Earth's lowest ambient seismic levels over this bandwidth with a performance comparable to conventional seismometers. The microseismometer is robust to high shock (> 1000 g) and vibration (> 30 g rms), and can operate from +60C to -80C allowing deployment under harsh conditions.

14:15 **SINGLE-RESONATOR, TIME-SWITCHED FM MEMS ACCELEROMETER WITH THEORETICAL OFFSET DRIFT COMPLETE CANCELLATION** **117**

C.R. Marra[1], F.M. Ferrari[1], S. Karman[1], A. Tocchio[2], F. Rizzini[2], and G. Langfelder[1]
[1]Politecnico di Milano, ITALY and [2]STMicroelectronics, ITALY

The work presents the first time-switched FM accelerometer: readout is based on a double sampling of the oscillation frequency of a single resonator, consecutively biased in two different configurations in time. This technique theoretically enables zeroing of offset drift related to the temperature coefficient of frequency or its tuning to compensate the thermal-stress component, delivering ultra-low-drift (sub-50 µg/K) accelerometers without post-acquisition corrections.

14:30 **Poster/Oral Session II** (Refreshments will be served at 16:00)

Poster presentations are listed by topic category with their assigned number starting on page 23.

Session VIII – Cells

Session Chairs:
C.-Y. Chen, National Cheng Kung University, TAIWAN
K.S. Drese, Coburg University of Applied Sciences & Arts, GERMANY

Auditorium, Ground & Level 1

16:30 **ON-CHIP PLATELET PRODUCTION USING THREE DIMENSIONAL MICROCHANNEL** **121**

H. Kumon[1], S. Sakuma[1], S. Nakamura[2], K. Eto[2], and F. Arai[1]
[1]Nagoya University, JAPAN and [2]Kyoto University, JAPAN

We proposed a 3D-microchannel whose height decreases gradually along the flow pass. Since megakaryocytes (MKs) have large variety in size, MKs are trapped at the gap of the proposed 3D-microchannel corresponding to their size. By using the chip, we successfully trapped the MKs induced from hiPSCs and applied the fluid force. Eventually, MKs exposed to the fluid force were split into platelets. From these results, we succeeded in on-chip platelets production using proposed 3D-microchannel.

16:45 **RAPID FABRICATION OF MULTIFUNCTIONAL MICROCAPILLARY FOR FOUR-DIMENSIONAL SINGLE CELL MANIPULATION** **125**

Y.T. Chow, T. Man, G.F. Acosta-Vélez, X. Zhu, X. Wen,
P.-S. Chung, T. Liu, B.M. Wu, and P.-Y. Chiou
University of California, Los Angeles, USA

A novel manufacturing approach to fabricate liquid metal–based, multifunctional microcapillary pipettes able to provide electrodes with high electrical conductivity for high frequency electrical stimulation and measurement is demonstrated. Four-dimensional single cell manipulation has been realized by applying multi-frequency, multi-amplitude, and multi-phase electrical signals to the microelectrodes near the pipette tip to create 3D dielectrophoretic trap and 1D electrorotation simultaneously.

17:00 **LOAD DEPENDENCY MEASUREMENT OF IPS CELL-DERIVED CARDIOMYOCYTES' CONTRACTION** **129**

K. Matsudaira, H. Takahashi, K.H. Shoji, T.-V. Nguyen,
T. Tsukagoshi, and I. Shimoyama
University of Tokyo, JAPAN

We propose a method to evaluate relationships between the twitch forces and the static stretch stimuli of iPS cell-derived cardiomyocytes (iPSC-CMs) (force-length relationships). The method realized the twitch force measurement of iPSC-CMs statically stretched under the culturing condition. As a result, twitch forces of a few tens of μN were measured, and the increase of twitch forces was observed as the static stretch was increased.

17:15 **A NOVEL HIGH THROUGHPUT MICROFLUIDIC CELL TRANSIT ANALYZER USING AIR LIQUID INTERFACE AS LOCALIZED PRESSURE SENSOR** **133**

R.S. Kotesa, K.R. Joshi, G.K. Ananthasuresh, and P. Sen
Indian Institute of Science, INDIA

We introduce a novel microfluidic platform that measures pressure drop during the passage of single cell for mechano-phenotyping of cell populations. It uses a precisely positioned Air-Liquid Interface as a Sensor near the outlet of a constriction. When cells pass through the constriction, hydrodynamic pressure at the outlet drops. This change in pressure leads to motion of the air-liquid interface which can be correlated to the entry and transit time of the cell passage.

17:30 **INTEGRATION OF FLUCTUATION SPECTROSCOPY INTO A MICROFLUIDIC PLATFORM FOR NOVEL CELLULAR VISCOELASTIC MEASUREMENT** **137**

H. Ito[1], C.-H.D. Tsai[2], and M. Kaneko[1]

[1]Osaka University, JAPAN and [2]National Chiao Tung University, TAIWAN

We demonstrate the integration of fluctuation spectroscopy into a microfluidic platform, which enables a novel viscoelasticity measurement for micrometer-sized soft objects such as red blood cells (RBCs). Using high-speed/precise manipulation inside a microchannel, we performed fluctuation spectroscopy sequentially combined with conventional constriction-passage method. The implicit correlations between the results provide indications to full information of viscosity and elasticity of a RBC.

17:45 **Adjourn for the Day**

Wednesday, 24 January 2018

Plenary III
Session Chair:
J. Ducrée, Dublin City University, IRELAND
Auditorium, Ground & Level 1

08:30 **FROM WOW TO WORK: CYCLES OF MEMS EVOLUTION** **141**
Hiroyuki Fujita
University of Tokyo, JAPAN

In the evolutionary cycle of MEMS, we have witnessed some brilliant new ideas were introduced first via proof-of-the-concept presentations and, after sophistication supported by intensive multi-disciplinary improvements, diversified into practical applications with excellent performance. For example, the comb-drive actuator made of 2-micrometer-thick-poly-Si was introduced in 1989. Optimized electromechanical design allowed longer strokes with low driving voltage. Thick and strong devices were possible with DRIE technology. Now many commercial devices use it. Looking back to the historical cycle will provide us with a vision for the future prospects of MEMS.

Session IX - Materials & Fabrication for Microfluidics
Session Chairs:
N. Barniol, Universitat Autonoma de Barcelona, SPAIN
J. Lötters, Bronkhorst High-Tech B.V., NETHERLANDS
Auditorium, Ground & Level 1

09:15 **MAGNETICALLY-INDUCED VARIOUS RECOVERABLE DEFORMATION OF MAGNETIC LIQUID METAL MARBLE** **145**
J. Seo[1], J.-B. Lee[2], S.K. Chung[1], and D. Kim[3]
[1]Myongji University, KOREA, [2]University of Texas, Dallas, USA, and [3]Korea Army Academy, Yeong-cheon, KOREA

We report various recoverable deformation of a magnetic liquid metal marble, a liquid metal droplet coated with iron (Fe) particles, by changing mass of the coated iron particles and applying different shapes of magnetic field.

09:30 **STICKER MICROFLUIDICS: A TOOLBOX OF COMBINABLE SACRIFICIAL TEMPLATES FOR INSTRUMENT-FREE CUSTOMIZATION OF COMPLEX MICROFLUIDIC SYSTEMS IN ONE-PIECE** **148**
X. Lai, B. Lu, H. Yu, and D. Li
Tianjin University, CHINA

We report an all-in-one toolbox which allows easy and instrument-free customization of integrated microfluidic systems. To create flexible and high performance microfluidic systems, a 'template sticker' method of assembling factory-packaged sacrificial templates is proposed. A wettability guided emulsion linking method is employed to thoroughly connect the sticker templates.

09:45 **NANO-SIZED ASYMMETRIC LIPID VESICLES FOR DRUG CARRIER APPLICATIONS 152**

K. Kamiya[1], T. Osaki[1,2], S. Fujii[1], N. Misawa[1], and S. Takeuchi[1,2]
[1]*Kanagawa Institute of Industrial Science and Technology, JAPAN and*
[2]*University of Tokyo, JAPAN*

We reported a formation of asymmetric lipid vesicles with a size range of 100-400 nm in diameter, using an improved jetting method based on a microfluidic technology. When jet flow was applied to a planar asymmetric lipid bilayer formed by a droplet contact method, nano-sized asymmetric vesicles were found by a transmission electron microscopy. Therefore, we believe that the nano-sized asymmetric lipid vesicle formation method is applicable in the generation of drug carriers.

10:00 **Break and Exhibit Inspection**

Session X - Vibrating RF MEMS

Session Chairs:
C. Nguyen, University of California, Berkeley, USA
S. Tanaka, Tohoku University, JAPAN

Auditorium, Ground & Level 1

10:30 **MAGNETIC-FREE RADIO FREQUENCY CIRCULATOR BASED ON SPATIOTEMPORAL COMMUTATION OF MEMS RESONATORS 154**

Y. Yu[1], G. Michetti[1], A. Kord[2], D. Sounas[2], F.V. Pop[1],
P. Kulik[1], M. Pirro[1], Z. Qian[1], A. Alu[2], and M. Rinaldi[1]
[1]*Northeastern University, USA and* [2]*University of Texas, Austin, USA*

We demonstrate the first magnetic-free radio frequency Microelectromechanical Resonant Circulator. For the first time, magnetic-free non-reciprocity is achieved by imparting an effective angular momentum bias to a MEMS resonant circuit. The angular momentum is efficiently realized through spatiotemporal modulation of three strongly coupled high-Q (>1000) Aluminum Nitride Contour Mode MEMS Resonators with signals of the same magnitude and phase difference of 120.

10:45 **HIGH K_t^2 .*Q* SILICON FIN BULK ACOUSTIC RESONATORS (FinBAR) FOR CHIP-SCALE MULTI-BAND SPECTRUM ANALYSIS 158**

M. Ramezani, M. Ghatge, and R. Tabrizian
University of Florida, USA

We report the Fin Bulk Acoustic Resonator (FinBAR) technology that enables extreme frequency scaling and integration of multi-band signal processors over the UHF and SHF regimes. High-aspect-ratio Si fins are covered by aluminum nitride films to enable efficient electromechanical transduction with large coupling coefficient (k_t^2). The low phononic dissipation of single crystal Si, along with suppression of piezoelectric charge redistribution loss result in unprecedentedly high quality-factors.

11:00 **DELAY LINE WITH DIFFERENT RECEIVER-RESONATOR CHANNELS AS AN ALL MECHANICAL FRONT-END OF A DISCRETE MATCHED FILTER FOR WAKE-UP RADIOS 162**

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

We present the conceptual approach, theoretical simulations, and experimental results of a new radio frequency mechanical signal processor composed of a delay line with one transmitter and several receivers integrated with different-frequency resonators. The system allows to set different delays and voltage gains for every receiver-resonator subsystem. This all-mechanical signal processor is ideal for improving signal to noise ratio in low-power wake-up receivers.

11:15 **A NOVEL TRANSDUCER DESIGN TO ENABLE HIGH-PERFORMANCE PIEZOELECTRIC MEMS RESONATORS AND OSCILLATORS** **166**

G. Pillai, A.A. Zope, and S.-S. Li
National Tsing Hua University, TAIWAN

A novel mechanism to drive SCS MEMS structure into resonance using piezoelectric transducer uniquely positioned in its support/anchor location is being reported for the first time with exceptional performance. A wine-glass mode resonator operated in differential drive/sense mode working at 21MHz is successfully demonstrated with a Qu of 8054. Using Lock-in amplifier with PLL, PN of -106dBc/Hz at 100Hz offset and -125dBc/Hz at 1kHz offset for a carrier frequency of 20.936MHz is recorded.

11:30 **HIGHLY FLEXIBLE PIEZOELECTRIC MEMS RESONATORS ENCAPSULATED IN POLYMER THIN FILMS** **170**

L. Zhang, Y. Jiang, B. Liu, M. Zhang, and W. Pang
Tianjin University, CHINA

This paper presents a flexible film bulk acoustic resonator(FBAR) with superior mechanical flexibility and electrical performance. The quality factor and effective coupling coefficient of the flexible FBAR reach 1108 and 5.0%, respectively. The resonator can be bent to a minimal radius of 0.5 mm without electrical performance degradation and function well after 100 times bending cycles. Our solution provides a viable approach to fabricate other flexible MEMS devices.

11:45 **Grab & Go Lunch and Exhibit Inspection**

Session XIa - Electrical & Optical Biointerfaces

Session Chairs:
E. Meng, University of Southern California, USA
P. Ruther, University of Freiburg, GERMANY

Auditorium, Ground & Level 1

13:00 **A MINIATURIZED, WIRELESSLY-POWERED, REFLECTOR-COUPLED SINGLE CHANNEL OPTO NEUROSTIMULATOR** **174**

W. Khan[1], Y. Jia[2], F. Madi[1], A. Weber[1], M. Ghovanloo[2], and W. Li[1]
[1]Michigan State University, USA and [2]Georgia Institute of Technology, USA

We report a free-floating, wirelessly-powered, single channel opto neurostimulator consisting of a reflector-coupled µLED and a mm-sized receiver (Rx) coil for untethered optogenetics neuromodulation. An optimized 2 coil inductive link delivers instantaneous power at a low frequency to continuously drive the µLED. In vivo experiment and histological analysis verify the efficacy of wireless optical stimulation, by c-Fos as a report of light-evoked neuronal activity.

13:15 **SINGLE NEEDLE ELECTRODE–TOPPED AMPLIFIER PACKAGE (STACK) FOR *IN VIVO* APPLICATIONS** **178**

Y. Kita, H. Kubo, H. Sawahata, S. Yamagiwa, X.L.A. Leong,
R. Numano, K. Koida, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

We propose the STACK device for use in a low invasive and a high signal-to-noise ratio neuronal recording from brain in vivo. A microscale-diameter needle-electrode with a high impedance characteristic induces the signal amplitude attenuation, which is improved by stacking the amplifier module. Other advantages of the STACK device include the device minimization (1 mm^2) and the high device yield. We also demonstrated the neuronal recording capability of the device using a mouse's brain in vivo.

13:30 **DECODING PERIPHERAL NERVE SENSORY INFORMATION WITH A SPIKED FLEXIBLE NEURAL INTERFACE 182**

J. Wang, X.Y. Thow, H. Wang, S. Lee, K. Voges,
N.V. Thakor, S.-C. Yen, and C. Lee
National University of Singapore, SINGAPORE

This paper reports a flexible neural interface integrated with spiked structures, which allow access to nerve fascicles, to record sensory signal of higher SNR than traditional extraneural interface. The high-quality recording using our intrafascicular interface enables classification of different sensory modalities.

13:45 **STRETCHABLE MICRO-DOUGHNUTS KIRIGAMI BIOPROBE 186**

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

We developed a 'doughnuts'-shaped stretchable microelectrode array device using a Kirigami structure. The stretchable film is suitable for sphere or columnar shaped wet biological tissues, enabling to fix microelectrodes to the tissue without slip. In addition, due to the device's small strain-stress, physical stress to the tissue can be minimised. We also demonstrated the in vivo electrocardiogram (ECG) recording capability of the fabricated device using a mouse's beating heart.

Session XIb - Actuators & Power MEMS

Session Chairs:
D. Horsley, University of California, Davis, USA
G. Le Rhun, CEA-Leti, FRANCE

Studio, Ground & Level 1

13:00 **INDEPENDENT ACTUATION AND MASTER-SLAVE CONTROL OF MULTIPLE MICRO MAGNETIC ACTUATORS 190**

T. Kawaguchi, Y. Inoue, M. Ikeuchi, and K. Ikuta
University of Tokyo, JAPAN

We proposed new method to realize both an independent actuation and real-time positon control of "multiple" micro magnetic actuators in 3D space. We developed unique actuation/control scheme and utilized the helical shape magnetic micro actuators and specially designed rotating magnetic fields. We succeed to obtain good experimental results to verify both theory and device. This is the world's first result for independent control of the multiple micro magnetic actuators in 3D liquid chamber.

13:15 **A HIGH SPECIFIC CAPACITY ANODE WITH SILICON ENCLOSED IN RGO SPHERE BY USING LYOPHILIZATION FOR LITHIUM-ION BATTERY 194**

X. Kuang, X. Jia, B. Hu, and X. Wang
Tsinghua University, CHINA

We report a novel rGO/Si anode for Li-ion batteries with high capacity and superior recyclability. Here, the Si nanoparticles (SiNPs) are enclosed in cross-linked spherical rGO sheets by lyophilization method, and the stable rGO conductive framework provides enough space for volume expansion of SiNPs. Meanwhile, rGO spheres prevent electrolysis consume silicon and retain the capacity. It shows a high initial specific capacity (1444.45 mAh/g) and recyclability (993.06 mAh/g after 500 cycles).

13:30 **MEMS BASED FLEXIBLE MICRO-SUPERCAPACITOR AS MINIATURE HIGH-POWER COMPONENT** **198**
S.J. Patil, J.S. Park, and D.-W. Lee
Chonnam National University, KOREA

We fabricate a lightweight, portable, and superior flexible micro-supercapacitor as a power component by microelectromechanical systems (MEMS) processes. In order to improve the power performance of the microdevice, the operating voltage range of the device has tuned through the implementing nanomaterial by electrodeposition method.

13:45 **REDUCING THE CONTACT TIME OF DROPLET IMPACT BY ACTIVE CONTROL OF SUBSTRATE MOTION** **202**
T.-V. Nguyen and I. Shimoyama
University of Tokyo, JAPAN

We report a method to reduce the contact time of a droplet impacting on a solid substrate by controlling the substrate motion. This motion is sinusoidal and triggered by a detection of the moment of impact using a MEMS-based force sensor fabricated on the substrate. We show that substrate motion can reduce the contact time by approximately 50% for a flat superhydrophobic surface.

14:00 **Poster/Oral Session III** (Refreshments will be served at 15:30)
Poster presentations are listed by topic category with their assigned number starting on page 23.

Session XIIa - Environmental Sensing
Session Chairs:
A. Ionescu, École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND
D.-W. Lee, Chonnam National University, KOREA
Auditorium, Ground & Level 1

16:00 **SELF-ACTUATING AND SELF-SENSING ZNO NANORODS/CHITOSAN COATED PIEZORESISTIVE SILICON MICROCANTILEVER FOR HUMIDITY SENSING** **206**
J. Xu[1], M. Bertke[1], X. Li[1], H. Mu[2], F. Yu[1], A. Schmidt[1], A. Bakin[1], and E. Peiner[1]
[1]*Technische Universität Braunschweig, GERMANY and*
[2]*Northwest A&F University, CHINA*

This paper reports a piezoresistive silicon microcantilever based self-actuating and self-sensing gravimetric humidity sensor. ZnO nanorods modified with chitosan self-assembled films are grown as the sensing material. The microantilever is self-actuated by a p-diffused heating resistor. And the resonant frequency shift induced by the adsorbed water on the hybrid sensing nanostructure can be read out directly by the p-diffused full Wheatstone bridge at the clamped end of the microcantilever.

16:15 **SELECTIVE SENSING OF CHEMICAL VAPORS USING PHASE SPECTRA DETECTION ON CVD GRAPHENE FET** **210**
H. Liu[1,2], Y. Chu[1,2], Y. Liu[2], T. Hayasaka[2], N. Joshi[2], Y. Cui[2], X. Wang[1], Z. You[1], and L. Lin[1,2]
[1]*Tsinghua-Berkeley Shenzhen Institute, CHINA and*
[2]*University of California, Berkeley, USA*

We develop phase spectra detection method to realize selective sensing of chemical vapors on a graphene FET. Three distinctive advances have achieved: (1) first demonstration of selective gas sensing on a single CVD graphene FET without surface functionalization; (2) first demonstration of quantitative phase spectra detection results for four gas vapors; and (3) illustrations of the sensing selectivity by the extraction of phase spectra features with experimental validations by using PCA scheme.

16:30 **WATERPROOF PITOT TUBE WITH HIGH SENSITIVE DIFFERENTIAL PRESSURE SENSOR AND NANO-HOLE ARRAY** **214**

H. Takahashi and I. Shimoyama
University of Tokyo, JAPAN

This paper reports a waterproof pitot tube. The pitot tube is composed of piezoresistive cantilevers as a differential pressure sensing element and nano-hole array as waterproof element. The nano-hole array is attached to the air inlets. When airflow is applied to the pitot tube, air passes through the nano-hole arrays, and differential pressure between two inlets acts on the cantilevers. On the other hand, when locating in water, the nano-hole arrays protect the water penetration into the tube.

16:45 **FULLY INTEGRATED MASS FLOW, PRESSURE, DENSITY AND VISCOSITY SENSOR FOR BOTH LIQUIDS AND GASES** **218**

T.V.P. Schut[1], D. Alveringh[1], W. Sparreboom[2],
J. Groenesteijn[2], R.J. Wiegerink[1], and J.C. Lötters[2]
[1]*University of Twente, NETHERLANDS and*
[2]*Bronkhorst High-Tech BV, NETHERLANDS*

We report a novel fluid viscosity sensor consisting of a pressure sensor fully integrated with a Coriolis mass flow sensor on a single chip. The sensor is capable of measuring viscosities of both liquids and gases through a newly derived mathematical model. The mathematical model for liquids is simply the Hagen-Poiseuille equation. For gases, a more complicated model is derived taking into account compressibility.

Session XIIb - Energy Harvesting

Session Chairs:
T. Seki, OMRON Corporation, JAPAN
L.F. Velásquez-García, Massachusetts Institute of Technology, USA

Studio, Ground & Level 1

16:00 **DEVELOPMENT OF HIGHLY EFFICIENT MICRO ENERGY HARVESTERS WITH MgHf-CODOPED AlN PIEZOELECTRIC FILMS** **222**

H.H. Nguyen, L.V. Minh, H. Oguchi, and H. Kuwano
Tohoku University, JAPAN

We present the novel vibration micro energy harvesters (VEHs) exploiting MgHf-codoped AlN piezoelectric films. The device provides a normalized power density of 34.9 $mW \bullet g^{-2} \bullet cm^{-3}$ increases 18-fold that of the best published AlN-based device and 4-fold that of the recent publication. Our piezoelectric films with MgHf dopants offered high power figure of merit of 22 GPa. The results confirm the high possibility of utilizing $(MgHf)_xAl_{1-x}N$-based VEHs as a power source in wireless sensor networks.

16:15 **AUTOPARAMETRIC RESONANCE IN A PIEZOELECTRIC MEMS VIBRATION ENERGY HARVESTER** **226**

Y. Jia[1,2], S. Du[1], E. Arroyo[1], and A.A. Seshia[1]
[1]*University of Cambridge, UK and* [2]*University of Chester, UK*

This paper reports for the first time the achievement of autoparametric resonance by a piezoelectric MEMS energy harvester without compromising transducer strain energy optimisation, for enhancing the mechanical efficiency of vibration energy harvesting. The autoparametric resonator records over two folds increase in power output than the same device driven into direct resonance at the same input level, and about an order of magnitude higher in power density than the state-of-the-art.

16:30 **LOW-PROFILE ROTATIONAL ELECTRET GENERATOR USING PRINT CIRCUIT BOARD FOR ENERGY HARVESTING FROM ARM SWING 230**

T. Miyoshi, M. Adachi, K. Suzuki, Y. Liu, and Y. Suzuki
University of Tokyo, JAPAN

A novel low-profile rotational electret energy harvester (EH) is prototyped for capturing power from low-frequency vibration. Thanks to cost-effective flexible print circuit board (PCB), the maximum thickness for the rotational part including the eccentric mass is as thin as 3.3 mm. Experimental data are in good accordance with the prediction of our improved model of rotational electret EH. Output power up to 35 uW has been obtained from arm swing during walking in our initial test.

16:45 **A FREE MOTION DRIVEN ELECTROMAGNETIC AND TRIBOELECTRIC HYBRIDIZED NANOGENERATOR FOR SCAVENGING LOW FREQUENCY VIBRATIONS 233**

M. Salauddin, R.M. Toyabur, and J.Y. Park
Kwangwoon University, KOREA

We have proposed and experimentally validated a free motion driven hybridized electromagnetic and triboelectric nanogenerator for scavenging low-frequency ambient vibrations using dual Halbach array, Nanostructure PTFE, and Al nano-grass. The fabricated hybrid energy harvester delivered an output power of 3.1mW, corresponding to a volume power density of 193W/m^3 under a loading resistance of 700Ω at 5Hz frequency and 0.5g acceleration.

17:00 **Adjourn for the Day**

18:00 - 22:30 **Conference Banquet at Titanic Belfast**

Thursday, 25 January

Plenary IV
Session Chair:
M. Despont, CSEM, SWITZERLAND
Auditorium, Ground & Level 1

08:30 **MEMS AT BOSCH - INVENTED FOR LIFE** **237**
Franz Laermer
Robert Bosch GmbH, GERMANY

MEMS is an enabling technology for many new sensors which made their way into automotive, consumer, Internet-of-things and Industry4.0 applications. Their success story is based on miniaturization, high accuracy, reliability, low manufacturing costs and scalability to high production volumes yielding significant economy of scales effects. Today chip- and device-level technology has matured. MEMS innovation happens mainly on the system and product level which represents a move up in the value chain. Technology innovation can be found in new domains away from classical silicon MEMS sensors, like microfluidic solutions for diagnostics at the point of care.

Session XIII - Acoustic MEMS
Session Chairs:
H. Takao, Kagawa University, JAPAN
H. Yu, Arizona State University, USA
Auditorium, Ground & Level 1

09:15 **ACOUSTO-OPTIC GYROSCOPE** **241**
A. Mahmoud, M. Mahmoud, L. Cai, M. Khan,
J.A. Bain, T. Mukherjee, and G. Piazza
Carnegie Mellon University, USA

An acousto-optic gyroscope (AOG) consisting of a Mach-Zehnder interferometer (MZI) embedded into two inherently matched SAW piezoelectric cavities is introduced. This constitutes the first demonstration of a MEMS strain-based optomechanical gyroscope based on refractive index change due to the acousto-optic effect rather than conventional displacement sensing. Integrating acoustic and photonic components on same LNOI platform demonstartes how optical detection can provide greater stability.

09:30 **FOCUSED ULTRASOUND TRANSDUCER WITH ELECTRICALLY CONTROLLABLE FOCAL LENGTH** **245**
L. Zhao and E.S. Kim
University of Southern California, USA

We report and demonstrate a novel acoustic transducer capable of delivering focused acoustic beam with electrically tunable focal length over 7mm (from 5 to 12mm). Constructed on a PZT substrate, the transducer uses a collection of equal-width-equal-spacing concentric ring electrodes. With each electrode individually addressable, a desired focal length is mapped to a set of the electrodes generating the acoustic waves that arrive at the focal point in-phase for constructive interference.

09:45 **FIRST MICROPHONES BASED ON AN IN-PLANE DEFLECTING MICRO-DIAPHRAGM AND PIEZORESISTIVE NANO-GAUGES** **249**

H. Lhermet[1,2], T. Verdot[1,2], A. Berthelot[1,2], B. Desloges[1,2], and F. Souchon[1,2]
[1]*Université Grenoble Alpes, FRANCE and* [2]*CEA-LETI, FRANCE*

First functional in-plane deflection microphones have been fabricated, validating a new concept based on a diaphragm moving in the plane of the substrate and inducing strain on piezoresistive Si nano-gauges. Such architecture, integrating furthermore a back cavity, leads to microphones with a smaller footprint that preserve at the same time high performance, and is therefore adapted for the achievement of miniature sensors and their integration for medical applications or consumer electronics.

10:00 **A MEMS MICROPHONE INSPIRED BY *ORMIA* FOR SPATIAL SOUND DETECTION** **253**

Y. Zhang[1], R. Bauer[1], W.M. Whitmer[2], J.C. Jackson[1], J.F.C. Windmill[1], and D. Uttamchandani[1]
[1]*University of Strathclyde, UK and* [2]*University of Nottingham, UK*

This work introduces a MEMS microphone having two pairs of orthogonally orientated and joined sensor membranes, with the directional patterns of these two pairs of membranes independent of each other. It can thus be regarded as two individual 2D bi-directional microphones. Combining this architecture with fly Ormia ochracea's tympana mechanism, this microphone is also the first biomimetic MEMS microphone combining both piezoelectric and capacitive sensing, designed for 3D sound localization.

10:15 **Break and Exhibit Inspection**

Session XIV – Droplets

Session Chairs:
K.S. Drese, Coburg University of Applied Sciences & Arts, GERMANY
N. Jackson, University of New Mexico, USA

Auditorium, Ground & Level 1

10:45 **SIGNIFICANT REDUCTION IN DROPLET EJECTION FOR TERMINAL VELOCITY IMPACT USING A COMBINATION OF SUPERHYDROPHILIC & SUPERHYDROPHOBIC SIEVE** **257**

A. Kumar, A. Tripathy, S. Raj, and P. Sen
Indian Institute of Science, INDIA

In our study we demonstrate that a combination of superhydrophilic-superhydrophobic copper mesh leads to less than $6\times10^{(-4)}$% liquid ejection for impact of 20 water droplets at terminal velocity.

11:00 **ANTI-BIOFOULING DROPLET MANIPULATION BY SLIPPERY LIQUID INFUSED POROUS SURFACE (SLIPS) INTEGRATED WITH ELECTROWETTING AND LIQUID-DIELECTROPHORESIS** **261**

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

We present a simple, versatile, and anti-biofouling droplet manipulation on a single substrate integrated with a slippery liquid infused porous surface (SLIPS). This platform was confirmed effective for both electrowetting-on-dielectric (EWOD) driving of conductive liquids and dielectrophoretic (DEP) driving of dielectric liquids.

11:15 **SORT 'N MERGE: A DETERMINISTIC MICROFLUIDIC PLATFORM FOR CO-ENCAPSULATING DISTINCT PARTICLES IN MICRODROPLETS** **265**

M.T. Chung, D. Nunez, D. Cai, and K. Kurabayashi
University of Michigan, USA

We developed a microfluidic platform that enables us to co-encapsulate distinct particles with a predetermined number in a droplet. Our method first produces microdroplets, each containing a single particle, subsequently merges these droplets, and deterministically forms the combination of the desired particle in the final droplets. Therefore, such performance is no longer limited by Poisson statistics. This system can be immediately applied to various cell-bead or cell-cell based assays.

11:30 **DROPLET MICROFLUIDICS INSIDE PAPER** **269**

H. Yasuga[1], W. Guo[2], J. Hansson[2], T. Haraldsson[2],
N. Miki[1], and W. van der Wijngaart[2]
[1]Keio University, JAPAN and [2]KTH Royal Institute of Technology, SWEDEN

We achieved, for the first time: 1) the self-digitization, i.e. spontaneous formation, of droplets during the imbibition of paper; 2) the self-digitization of 3D droplet lattices; and 3) the on-demand transport and merging of individual droplets. Two technical novelties underlie these functions: the formation of free standing synthetic microfluidic paper, i.e. a porous matrix of slanted and interlocked micropillars without bottom layer; and the hydrophobic surface modification of the paper.

Award Ceremony & Final Remarks
Auditorium, Ground & Level 1

11:45 **Award Ceremony**

12:00 **Conference Adjourns**

POSTER/ORAL PRESENTATIONS

Hall 1 and 2, Level 1

M – Monday (14:30 - 16:30) ..... **T** – Tuesday (14:30 - 16:30)
W – Wednesday (14:00 - 16:00)

Poster Classification Chart

Bio and Medical MEMS
Materials, Fabrication, and Packaging for Generic MEMS and NEMS
MEMS Actuators and PowerMEMS
MEMS for Electromagnetics
MEMS Physical Sensors
Micro- and Nanofluidics

Bio and Medical MEMS

Biosensors and Bioreactors

M-001 **STIMULATION/CONTROL SYSTEM FOR TFT ARRAY BIOSENSOR - APPLICATION TO DIELECTROPHORESIS** **272**

D. Blanchard[1], P.-M. Faure[1,2], S. Ihida[1], T. Kohno[1],
H. Toshiyoshi[1], T. Levi[1,2], and A. Tixier-Mita[2]
[1]University of Bordeaux, FRANCE and [2]University of Tokyo, JAPAN

A system with waveform generator with 28x2 modular outputs for the control of Thin-Film-Transistors (TFT) array devices is presented. It has a large range of amplitudes: -5V to +27V. It allows application of arbitrary shapes of electrical signals: DC, AC, pulses etc. It is used to individually control the integrated microelectrodes array of TFT array devices, which are promising transparent substrates for biological applications. Demonstration of dielectrophoresis on micro-beads is presented.

T-002 **BREATHABLE FABRIC MEETS A LIPID BILAYER SYSTEM FOR RAPID VAPOR DETECTION** **276**

S. Fujii[1], N. Misawa[1], K. Kamiya[1], T. Osaki[1,2], and S. Takeuchi[1,2]
[1]Kanagawa Institute of Industrial Science and Technology, JAPAN and
[2]University of Tokyo, JAPAN

We propose a rapid vapor biosensor by using a breathable fabric, layered on lipid bilayer system to guard the liquid from evaporation and permeate the vapor from air. Time-dependent vapor absorption and inhibition of the liquid evaporation compared to the open chamber were experimentally confirmed. Vaporized pesticide was detected by absorption into device, forming a complex with DNA aptamer, and transition through a nanopore in the lipid bilayer, in a short-term.

W-003 **QUANTITATIVE ANALYSIS OF OPTICAL TRANSDUCTION IN MICROFLUIDIC BIOSENSING PLATFORMS: NANOPOROUS MICROBEADS COUPLED WITH THIN-FILM PHOTODIODES** **278**

I.F. Pinto[1,2], D.R. Santos[1,2], C.R.F. Caneira[1], R.R.G. Soares[1,2],
V. Chu[1], and J.P. Conde[1,2]
[1]Institute of Nanoscience and Nanotechnology, PORTUGAL and
[2]Universidade de Lisboa, PORTUGAL

This work presents a simple and innovative approach to quantitatively analyze and compare different optical transduction signals coupled to a model affinity interaction inside a microfluidic device. By combining microbeads packed inside a microfluidic device with an integrated photodetector, it was possible to provide an understanding of a biosensing mechanism in general, establishing a generic methodology to design a microfluidic point-of-need device to achieve a certain performance.

M-004 **A HIGH-DENSITY INTEGRATED ODORANT SENSOR ARRAY SYSTEM BASED ON INSECT CELLS EXPRESSING INSECT ODORANT RECEPTORS** **282**

S. Nagata[1], N. Kameshiro[1], D. Terutsuki[2], H. Mitsuno[2], T. Sakurai[2], K. Niitsu[3,4], K. Nakazato[3], R. Kanzaki[2], and M. Ando[1]
[1]Hitachi, Ltd., JAPAN, [2]University of Tokyo, JAPAN, [3]Nagoya University, JAPAN, and [4]Japan Science and Technology Agency (JST), JAPAN

In order to realize a high-sensitive bio-hybrid olfactory sensor, we demonstrated parallel detection of electrical signals caused by odorant responses of insect cells expressing insect odorant receptors by using a 64×64 complementary metal-oxide semiconductor monolithically integrated sensor array for the first time. The individual sensor element transduces odorant responses of cells, which is confirmed by the simultaneous fluorescence imaging of calcium indicator GCaMP6s in the cells.

T-005 **INTEGRATED MICROFLUIDIC SYSTEM WITH FIELD EFFECT TRANSISTOR FOR AUTOMATIC DETECTION OF MULTIPLE CARDIOVASCULAR BIOMARKERS** **286**

A. Sinha, T.-Y. Tai, Y.-L. Wang, and G.-B. Lee
National Tsing Hua University, TAIWAN

We have developed FET integrated microfluidic device which could detect the concentration of multiple Cardio Vascular Disease biomarkers from the blood in an automatic manner.

W-006 **SELECTIVE PAIRING AND FUSION OF VESICLES USING DIELECTROPHORETIC TWEEZERS** **290**

S. Yoshida and S. Takeuchi
University of Tokyo, JAPAN

We develop a method for selective pairing and fusion of biological vesicles using MEMS dielectrophoretic (DEP) tweezers. We demonstrate that cell-sized liposomes can be selectively paired and fused using the tweezers and a hand-made electrofusion chamber. Giant bacteria are also electrially fused. We believe the method will be useful in artificial cell studies.

M-007 **DIFFERENTIAL METHOD FOR UNDISTURBED DETECTION OF 17β-ESTRADIOL USING AN INTEGRATED APTAMERIC GRAPHENE NANOSENSOR** **293**

Y. Li[1,2], Y. Zhu[1], Z. Hao[1], C. Wang[3], Z. Zhang[1], M. He[2], and Q. Lin[1]
[1]Columbia University, USA, [2]Tsinghua University, CHINA, and [3]Tianjin Normal University, CHINA

We develop a novel differential method for the label-free and undisturbed detection of 17β-estradiol, using an integrated aptameric graphene nanosensor. Compared with other differential methods, our method introduces a sensitivity factor, for the first time, to indicate the sensitivity difference between sensor channels. Fake responses, generated from the background, are calibrated by the sensitivity factor. Finally, the undisturbed detection of 17β-estradiol is realized.

We propose an integrated device to perform the simultaneous electrical and mechanical characterization of single cells in flow. The device contains a built-in channel with two tips (for compressing and sensing single cells captured in between) accessing laterally from each side. Having electrical readout provides a practical detection method while characterizing fixed breast cancer cells (SUM159PT) both mechanically and electrically with high sensitivity and high information content.

We demonstrate the dipstick-based digitisation and detection of bacterial sample of concentration down to 1e3 CFU/mL. The significance of this work is that we are able to detect concentrations of bacteria relevant for urinary tract infection (UTI) with a minimal handling time and without the need for complicated external equipment.

We propose a gaseous odorant detection system by using collagen pillars containing cells expressing olfactory receptor. As a result, gaseous odorants detection was achieved. Moreover, 3D structure enhanced reaction efficiency because of large surface. Therefore, we believe that our system will be useful gaseous odorant sensors.

Bio and Medical MEMS

Manufacturing for Bio- and Medical MEMS

We show a fabrication of shallow chamber for formation of bilayer lipid membranes (BLMs). The chamber is composed of perforated film, and two magnetic rings that work as both electrodes and the chamber walls. Comparing to conventional devices for BLM formation using open chambers, our approach can reduce the water depth, and it becomes that much easier to access the BLM via liquid ab extra. This shallow-water is useful for odorant sensing based on olfactory receptors reconstructed in BLM.

Bio and Medical MEMS

Materials for Bio- and Medical MEMS

This paper reports a microneedle device, which is slid and inserted into a narrow gap in the brain. The polyethylene glycol (PEG)-coated device was slid and inserted into a <1-mm-gap between the dura mater and the tissue surface of a mouse's cortex, while the neural signals via the electrode were recorded after the PEG dissolved. These results indicate that our device can be implanted without unnecessary craniotomy, offering low invasive neuronal recordings compared to conventional devices.

We develop a cell culture platform by utilizing a robust and ultra-thin silicon carbide (SiC) membrane with an ultra-high aspect ratio (length/thickness) of up to 20,000. The membranes possess high fracture strength up to 2.75 GPa and withstand pressure up to 1500 mbar. Taking advantage of SiC material for biological applications, the as-developed membranes were experimentally demonstrated as an excellent substrate platform for bio cell culturing with the cell viability of more than 92%.

We develop a potential modulated amino acid sensing chip by modifying $Ti_3C_2T_x$, a typical 2D transition metal carbides (MXene), on the substrate of total internal reflection imaging ellipsometry (TIRIE) biosensor. Thanks to the capacity of MXene, the positive charged arginine can adsorb on the biosensor substrate abundantly when a potential is applied to the sensing surface. This work has demonstrated the extraordinary capacity of MXene can be used for the detection of charged biomolecules.

This paper demonstrates the straightforward fabrication process of PDMS circular microchannel by using gas pressure to define the deformation of partially cured PDMS. Based on this technique, circular cross-section microchannel can be easily produced in a wide range of dimensions from 100 µm to 500 µm. This technique can eliminate air plasma bonding and tedious alignment processes. We successfully fabricate the circular microchannels to mimic the artery thrombosis phenomenon on a chip.

We develop the glucose responsive fluorescence microparticles for monitoring the glucose concentration inside the spheroid. When the glucose concentration increases, the fluorescence intensity also increases depending on the glucose concentration. The fluorescence intensity decreases over time, it is indicated the consumption of the glucose. We believe that the microparticles will be applicable to continuous monitoring inside spheroid briefly.

Bio and Medical MEMS
Medical Microsystems (Probes, Implantables, Imaging, etc.)

We describe novel MEMS structures for untethered tissue biopsy. The work derives from earlier work on untethered residual stress responsive grippers and these structures are inspired by pollen. We show that depending on the shape and spacing, different extent of tissue can be retrieved.

We developed, fabricated, and tested a novel calorimetric flow sensor which uses high-frequency electrochemical impedance to measure temperature changes. Ultra-low flow velocities ±200 µm/s are measurable with a 2σ LOD of 19.1 µm/s, a 4x improvement over the state of the art. The sensor's bidirectionality, biocompatibility, and flexibility make it ideal for microfluidic, lab-on-chip, and in vivo applications.

We develop a long, biocompatible and highly flexible micron sized cold atmospheric pressure plasma jet device which has no thermal damage and electric shock to human body. The generated microplasma jet has strong sterilization effect and the dose applied can be controlled by adjusting the plasma treatment time and the gas composition. All these advantages make this device capable of in-vivo precise endoscopic therapies.

This paper reports the development of a connector system using magnetic forces and spring-suspended contact pads. It is designed for neural implants requesting reduced forces during connector mating. The interface applies magnets of different polarity which inherently guarantee a correct connector positioning without alignment pins. MEMS-based test structures were fabricated which provided 100% connection yield, disconnection forces down to 100 mN and a lateral alignment accuracy better 50 µm.

T-029 **LIQUID METAL ELECTRODES MICRO-ARRAY FOR ELECTRICAL STIMULATION VIA DIRECT CONTACT** **373**

R. David and N. Miki
Keio University, JAPAN

We develop a liquid metal based electrodes micro-array for electrical stimulation of biological tissues via a direct contact interface, down to an electrode width of 50um. The intrinsic Gallium oxide skin alloys direct stabilization of the liquid metal electrodes in a flexible polymer chip. The electrical performances and stability of the liquid metal electrodes are characterized in-vitro. The integrity of the electrodes under mechanical and electro-chemical constraints are assessed.

W-030 **ULTRA-COMPLIANT PERIPHERAL NERVE CUFF ELECTRODE WITH HYDROGEL ADHESION** **376**

X.C. Ong[1], W.-C. Huang[2], I.S. Kwon[1], C. Gopinath[3], H. Wu[1], L.E. Fisher[3], R.A. Gaunt[3], C.J. Bettinger[1], and G.K. Fedder[1]
[1]Carnegie Mellon University, USA, [2]Taipei Medical University, TAIWAN, and [3]University of Pittsburgh, USA

We report a method of fabricating peripheral nerve cuff electrodes attached to a sticky hydrogel that is more compliant compared to typical electrodes and contains adhesion-promoting functional groups that allow for good electrical contact with the nerve without the need for continuous application of pressure. A transfer process is developed using PAA as the sacrificial material which has tunable solubility, avoiding the need for release chemicals which may affect the properties of the hydrogel.

M-031 **ENDOSCOPE CAMERA USING TUNABLE LIQUID-FILLED LENS WITH ANTIREFLECTIVE STRUCTURES** **380**

S.-I. Bae, Y. Lee, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We report tunable liquid-filled lens with antireflective structures (ARS) on a flexible membrane of PDMS for endoscope camera. ARS on a flexible membrane significantly enhance light transmission by suppressing Fresnel reflection on air-PDMS interfaces on both planar and curved surfaces. ARS are fabricated by using template-confined repeated dewetting on a wafer scale. Tunable liquid-filled lens with ARS is completely packaged with silicon chamber diameter of 4.0 mm and lens diameter of 1.3 mm.

T-032 **LED-BASED INTRACEREBRAL OPTRODE FOR SIMULTANEOUS OPTICAL STIMULATION AND ELECTROPHYSIOLOGICAL RECORDING** **384**

E. Otte, S. Ayub, O. Paul, and P. Ruther
University of Freiburg, GERMANY

We present a new optrode based on light-emitting diodes integrated in a 70-µm-thin multifunctional silicon stiffening structure realized using a novel dual-side wafer-level micromachining process. The stiffener comprises apertures confining the area of light exposure and low-impedance electrodes for electrophysiological recordings. The co-integration of optical and electrical functionality on a single shaft is expected to minimize tissue damage in long-term optogenetic in vivo experiments.

W-033 **MEASUREMENT OF BOTH VISCOUS AND ELASTIC CONSTANTS OF A RED BLOOD CELL IN A MICROCHANNEL** **388**

A. Kirimoto[1], H. Ito[1], C.-H.D. Tsai[2], and M. Kaneko[1]
[1]Osaka University, JAPAN and [2]National Chiao Tung University, TAIWAN

We report a novel measurement of both viscous and elastic constants of a red blood cell in a microfluidic channel using only high-speed and precise feedback cell manipulation. Through the theoretically estimated shear force and the deformed cell shape, we obtained Young's modulus of the cell in the channel. The combination with the conventional "Loading examination" in the constriction channel provides the absolute values of viscous and elastic constants of the cell.

M-034 **MICROWELL-ARRAY ON A FLEXIBLE NEEDLE: A TRANSCUTANEOUS INSERTABLE IMPEDANCE SENSOR FOR LABEL-FREE CYTOKINE DETECTION** **392**

N. Song[1], P. Xie[2], W. Shen[1], M. Javanmard[2], and M.G. Allen[1]
[1]*University of Pennsylvania, USA and* [2]*Rutgers University, USA*

We present a flexible micromachined needle-shaped impedance sensor for label-free in-situ detection of cytokines and other biomarkers. The sensor utilizes a micro-well array configuration at the needle tip to enable label-free detection while capable of high-sensitivity detection despite high salt concentration of biological matrix. To mimic in-vivo detections, the sensor is inserted into a skin phantom using a stiff backing that is subsequently removed to minimize mechanical damage to tissues.

T-035 **ULTRASONIC IMAGING OF MUSCLE-LIKE PHANTOMS USING BIMORPH PMUTS TOWARD WEARABLE MUSCLE DISORDER DIAGNOSTICS** **396**

H. Ding[1,2], S. Akhbari[2], B.E. Eovino[2], Y. Wu[2,3], J. Xie[1], and L. Lin[2,3]
[1]*Zhejiang University, CHINA,* [2]*University of California, Berkeley, USA, and* [3]*Tsinghua-Berkeley Shenzhen Institute, CHINA*

A piezoelectric micromachined ultrasonic transducer (pMUT) system based on aluminum nitride is developed for the ultrasonic imaging of muscle-like phantoms. In the experiments, polymer materials are fabricated to emulate different human muscles. Experiment results show clear images from both A- and B-mode scans of three phantoms by the pulse-echo measurements. As such, this medical imaging system could find potential applications in wearable devices toward real-time muscle disorder diagnostics.

W-036 **MICRONEEDLE ROLLER ELECTRODE ARRAY (M-REA): A NEW TOOL FOR *IN VIVO* LOW-VOLTAGE ELECTRIC GENE DELIVERY** **400**

D. Huang[1], D. Zhao[1], Y. Huang[2], Z. Liang[1], and Z. Li[1]
[1]*Peking University, CHINA and* [2]*Beijing Institute of Technology, CHINA*

We develop a novel device, so-called microneedle roller electrode array (M-REA), for minimally invasive in vivo electric gene delivery. Owing to reduced resistance by penetrating stratum corneum and small space between electrodes, electric gene delivery can be achieved under low voltage. Ability of large area electroporation, less damage, low cost fabrication and convenient operation offer vast potential for practical clinical applications.

M-037 **SELF-POWERED PULSE SENSORS WITH HIGH SENSITIVITY TO REVEAL SINUS ARRHYTHMIA** **404**

Y. Chu[1,2], J. Zhong[2], H. Liu[1,2], N. Liu[2], Y. Song[2], X. Zang[2], Y. Dong[1], X. Wang[1], and L. Lin[1,2]
[1]*Tsinghua-Berkeley Shenzhen Institute, CHINA and*
[2]*University of California, Berkeley, USA*

We have successfully demonstrated a self-powered pulse sensor with high sensitivity to reveal sinus arrhythmia as a practical medical microsystem. We have achieved: (1) a self-powered and flexible pulse sensor based on cellular piezoelectret; (2) high sensitivity to record pulse waveforms for the diagnose of sinus arrhythmia; and (3) maintaining high sensitivity within a large range of applied pressure (10-120 mmHg) when optical pulse sensor fails to perform.

W-042 **PATTERN PROJECTOR USING SUPERPOSITION OF DOUBLE MICROLENS ARRAYS FOR HYBRID 3D ENDOSCOPE 422**

S.-P. Yang, J.-B. Kim, and K.-H. Jeong
Korea Advanced Institute of Science and Technology (KAIST), KOREA

This work reports microfabrication and superposition of double microlens arrays (MLAs) for pattern projector. MLAs were fabricated on a large scale with thermoplasitic photoresist with Teflon coating and additional parylene coating to have high fill-factor and curvature. Fabricated MLAs were aligned with dynamic rotation between them to generate high-density diffraction pattern with uniformity using monochromatic laser light source.

M-043 **A COMPACT MAGNETIC RESONANCE IMAGING SYSTEM INTEGRATED MICRO RF AND GRADIENT COILS FOR SMALL SAMPLE MEASUREMENT 426**

D. Tsuchiya and T. Dohi
Chuo University, JAPAN

We fabricated a compact MRI system for small sample measurement. Since the micro coils was fabricated by assembling flexible substrate to 3D printed jigs, the coil wiring of our micro RF coil and micro gradient coils have spatially high positional accuracy. Therefore, our micro RF coil has high sensitive area with high uniformity, and our micro gradient coil has high gradient magnetic field efficiency with high linearity. Thus, we took clear and high-resolution MRI images of small samples.

T-044 **RECONSTRUCTION OF VASCULAR NICHE OF NEURAL STEM CELLS USING PERFUSABLE MICROFLUIDIC DEVICE 430**

S. Nagata, Y. Morimoto, and S. Takeuchi
University of Tokyo, JAPAN

We develop in vitro model of vascular niche maintaining neural stem cells (NSCs) in brain. To reconstruct the niche, NSCs and vascular endothelial cells (VECs) are co-cultured in perfusable microfluidic device. In the culture system, the NSCs and VECs are maintained with sustaining their characteristics in both static and perfusion culture condition. We also find that stem cell identity of the NSCs co-cultured with the activated VECs is enhanced through activation of NOTCH signaling.

Bio and Medical MEMS
Nanobiotechnology

W-045 **FLUORESCENT OBSERVATION OF ATP BINDING IN KINESIN DRIVEN MICROTUBULE GLIDING USING NANO-SLITS 432**

K. Fujimoto[1], R. Iino[2], M. Tomishige[3], H. Shintaku[1],
H. Kotera[1], and R. Yokokawa[1]
[1]Kyoto University, JAPAN, [2]Institute for Molecular Science, JAPAN, and [3]Aoyama Gakuin University, JAPAN

We report a linear-shaped zero mode waveguides (LZMWs) device for single molecule fluorescent observation of ATP consumed in the motility of kinesin and microtubules. LZMWs device was fabricated by electron beam lithography to reduce background noise by confining excitation light in ~100 nm width slits. Microtubule motility driven by kinesin and attachment/detachment of ATP were simultaneously observed in LZMWs, with ten times higher concentration of labelled ATP in conventional methods.

M-046 **LONG NANOWIRE ARRAYS FOR *IN VITRO* AND *IN VIVO* DNA INJECTIONS INTO CELLS IN BRAIN TISSUES** **436**

Y. Kubota[1], R. Numano[1], A. Goryu[2], H. Sawahata[1], S. Yamagiwa[1], M. Matsuo[1], M. Ishida[1], and T. Kawano[1]
[1]Toyohashi University of Technology, JAPAN and [2]Toshiba Corporation, JAPAN

DNA injection into a cell has potential to genetically alter the function of living brain cells. However, conventional intracellular nanowire devices have been limited to cultured cells, due to the short wire length of < 10 µm. To overcome this issue, here we developed three-dimensional (3D) nanoscale-tipped wire (NTW) array device with the length of ~ 200 µm. We also demonstrated the DNA injection using mouse brain tissues both in vitro and in vivo.

T-047 **TIP-ENHANCED NEARFIELD GRAYSCALE THERMAL NANOLITHOGRAPHY** **440**

W. Lee[1], S. Zhang[1], Z. Zhou[2], and T.H. Tao[1]
[1]University of Texas, Austin, USA and
[2]Shanghai Institute of Microsystem and Information Technology, CHINA

We develop a novel scanning probe lithography technique for fabricating nanoscale hierarchical biostructures. Using the tip-enhanced nearfield optics, we demonstrate dual-tone 3D nanostructuring of arbitrary shapes with FWHM spatial resolution down to 30 nm. A thin film of silk protein used as the resist is biocompatible and can be developed with water. Finally, we show via an in-situ nearfield IR nanocharacterization that silk protein is crosslinked by tip-enhanced thermal effect.

W-048 **MULTIPLEXED MOLECULAR BIOMARKER ANALYSIS USING AN EXPANDED LIBRARY OF NANOELECTRONICALLY BARCODED PARTICLES ENABLED THROUGH MACHINE LEARNING ANALYSIS** **444**

J. Sui, P. Xie, Z. Lin, and M. Javanmard
Rutgers, State University of New Jersey, USA

We developed a novel method for nanoelectronically barcoding particles previously. Barcodes using atomic layer deposited oxides formed onto microspheres can be differentiated from each other. In this work, we have significantly expanded our library of barcodes using varying oxide thicknesses and dielectric permittivities, coupled with machine learning analysis. We provide systematic guidelines for selecting barcoded particles for a multiplexed biomarker assay with minimal crosstalk.

M-049 **A HIGHLY SENSITIVE MERCURY (II) ION DETECTION BASED ON NANOFLUIDIC CRYSTAL SENSING** **448**

Y. Wu[1], J. Gong[2], Y. Jin[1], and W. Wang[1]
[1]Peking University, CHINA and
[2]National Institute for Communicable Disease Control and Prevention, CHINA

Water pollution caused by Hg^{2+} is a challenging environmental issue and the Hg^{2+} detection attracts the extensive attention. Here, based on the high-consistent nanofluidic crystal sensing chip, an electrical read-out Hg^{2+} detection with an ultra-high sensitive (around 1 pM) was developed. Differs from traditional methods, most of which rely on complicated optical systems, the Hg^{2+} detection we proposed has more possibility on realizing portability under the premise of sensitivity and consistency.

Bio and Medical MEMS
Other Bio and Medical MEMS

T-050 **AN ULTRAMINIATURE AND FLEXIBLE PRESSURE SENSOR BASED ON ELECTRICAL-DOUBLE-LAYER CAPACITANCE FOR CATHETER-TIP APPLICATIONS** **451**

W. Hong[1], L. Tang[1,2], W. Sun[1], B. Yang[1], X. Chen[1], X. Wang[1], and J. Liu[1]
[1]*Shanghai Jiao Tong University, CHINA and*
[2]*MicroPort NeuroTech Co., Ltd., CHINA*

This paper proposes an ultraminiature and flexible pressure sensor (PS) based on electrical-double-layer (EDL) capacitance. The EDL capacitive PS can directly work in biofluids without packaging, and utilize the liquid and gas in the working environment to sense the fluidic pressure. The sensor is compact in architecture, only including two Parylene layers and gold electrodes, which contributes to the ultraminiature footprint and mechanical flexibility.

W-051 **A MICRO-FABRICATED FLEXIBLE AND FLAT POLYIMIDE MODULE WITH HIGHLY C-AXIS ORIENTED ALN PIEZOELECTRIC ELEMENT FOR ACCURATE VITAL SIGNS MONITORING** **455**

T. Sun[1], B.B. Han[1], C.L. Sun[1,2], L.Y.L. Wong[1], and A.Y.D. Gu[1]
[1]*Agency for Science, Technology and Research (A*STAR), SINGAPORE and*
[2]*Wuhan University, CHINA*

We report for the firsttime, a micro-fabricated flexible and flat AlN/polyimide module enables to accurately monitor radial pulse and respiratory rate. Unlike previous studies, the 8-inch wafer micro-fabrication process does not significantly undermine the piezo-electrical effect of AlN, but maintains the module flexible and flat. As a consequence, the flat AlN/polyimide module with low stress is as flexible as PVDF, but has better piezo-electrical properties.

Materials, Fabrication, and Packaging for Generic MEMS and NEMS
Digital Micromanufacturing (Laser Micromachining, Additive Manufacturing)

M-052 **PLASMA ION-BEAM 3D PRINTING: A NOVEL METHOD FOR RAPID FABRICATION OF CUSTOMIZED MEMS SENSORS** **459**

K. Watanabe[1], M. Kinoshita[1], T. Mine[1], M. Morishita[1], K. Fujisaki[1],
R. Matsui[1], M. Sagawa[1], S. Machida[1], H. Oba[2], Y. Sugiyama[2],
N. Sugii[1], D. Ryuzaki[1], H. Kurata[1], and S. Nishimura[1]
[1]*Hitachi, Ltd., JAPAN and* [2]*Hitachi High-Technologies Corp., JAPAN*

We report a novel method that reduces fabrication period of customized MEMS sensors. A 3D printing method by high-current plasma focused ion beam system was developed and applied to MEMS sensor fabrication. Capacitive MEMS vibration sensors fabricated by the conventional lithography process and the 3D printing process were compared. The difference in the resonance frequency was as small as 4%. Compared to the conventional process, the 3D printing process reduced the fabrication period by 82%.

Materials, Fabrication, and Packaging for Generic MEMS and NEMS
Generic MEMS and NEMS Manufacturing

W-057 **SELECTIVE METALLIZATION AND PASSIVATION OF DRY-TRANSFERRED CARBON NANOTUBES IN FIELD-EFFECT TRANSISTORS** **479**

L.V. Jenni, M. Haluska, and C. Hierold
ETH Zürich, SWITZERLAND

The use of selective atomic layer deposition was investigated for top-clamping and passivation of contacts of suspended single-walled carbon nanotubes in field-effect transistor configuration. The annealing and clamping effect can be used to obtain higher currents, signal to noise ratio (SNR), and to induce band gap opening in metallic nanotubes. A current increase of more than one order of magnitude and SNRs as high as 200 could be observed for metallic and small-gap semiconducting devices.

M-058 **EPITAXIAL ENCAPSULATION OF FULLY DIFFERENTIAL ELECTRODES AND LARGE TRANSDUCTION GAPS FOR MEMS RESONANT STRUCTURES** **483**

I.B. Flader[1], Y. Chen[2], C.H. Ahn[2], D.D. Shin[1],
A.L. Alter[1], J. Rodriguez[1], and T.W. Kenny[1]
[1]Stanford University, USA and [2]Apple Inc., USA

This work demonstrates, for the first time, a wafer encapsulation process for hermetic sealing of MEMS resonant structures incorporating fully differential electrodes, in and out of the device plane, and large lateral transduction gaps. Transduction gaps up to 50µm were fabricated and devices were driven into a strongly nonlinear regime using the bottom, top, and in-plane capacitive electrodes.

T-059 **AN EXPERIMENT-BASED MODEL FOR FOCUSED ION BEAM SIMULATION AND THE PROCESS DESIGN OPTIMIZATION** **487**

Y. Li, Y. Xing, H. Zhang, and X. Qiu
Southeast University, CHINA

An experiment-based model is presented for simulating the Focused Ion Beam process and guiding the scan strategy and parameter design. This approach applies Gaussian function fitting on both etching and deposition, and builds an expectation difference function to solve the redeposition attenuation. We optimize the model parameters with basic experiments. This model and its parameters are further applied to the scan strategy and parameter optimization for the complex structure realizations.

W-060 **FABRICATION OF POLYMER MICRONEEDLE ARRAY BASED ON TUNGSTEN MOLD AND OPTIMIZED REPLICATION METHOD** **491**

L. Song[1], Y. Xia[2], X. Li[1], J. Chen[1], and S. Ma[2]
[1]Peking University, CHINA and [2]Xiamen University, CHINA

Fabrication of high performance tungsten microneedle array (MNA) which has tunable height and diameter is reported for the first time. Further, stable replica molding of cycloolefine copolymer (COC) MNA is achieved using novel vacuum isostatic hot embossing followed by PDMS casting with tungsten MNA mold. Radius of needlepoint is less than 1µm while microneedle height reaches as high as 100µm. High hardness of tungsten ensures reliability of mold which offers commercial potential.

M-061 **LOCATION-SPECIFIC FABRICATION OF SUSPENDED METAL NANOWIRE BASED ON ELECTROSPUN NANOFIBERS ON MEMS PLATFORM** **494**

Y. Oh, D.-S. Kwon, W. Kim, and J. Kim
Yonsei University, KOREA

We propose a location-specific fabrication process to form suspended metal nanowire. This fabrication method consists of 3 steps; electrospinning polymer nanofibers on MEMS platform, metal evaporation, and dissolving polymer nanofibers in liquid and drying. The surface tension force during the drying enables the formation of single wire from multiple wires. This method allows diverse choice of nanowire material and thus can find various applications of two-terminal suspended nanowire devices

T-062 **RAPID THERMAL NANOIMPRINTING ON SILK PROTEIN SUBSTRATES FOR CONTROLLED DEGRADATION OF TRANSIENT DEVICES** **498**

Z. Gao[1,2], Z. Zhou[1,3], H. Tao[1,3,4], and N. Qin[1]
[1]Chinese Academy of Sciences, CHINA, [2]Shanghai University, CHINA,
[3]University of Chinese Academy of Sciences, CHINA, and
[4]University of Texas, Austin, USA

This paper reports a facile patterning technique for silk protein based transient electronic materials by rapid thermal nanoimprinting. The solubility of silk films strongly depends on the crystalline conformation of the silk proteins, which can be well tuned by thermal treatment. Compared with the previous methods, this approach mainly focuses on the combination of nonuniform thermal distribution and high precision nanopatterns formation.

W-063 **FLEXIBLE PRESSURE SENSOR MADE USING PDMS CONTAINING CARBON NANOTUBES** **501**

Y. Jung, M.G. Shin, H.J. Tak, K.K. Jung, and J.S. Ko
Pusan National University, KOREA

Three-axis high sensitivity flexible pressure sensor was proposed that can measure applied pressure using changes in the contact resistance. This sensor was fabricated with PDMS embeded CNTs. CNTs were made to protrude on the surfaces of pyramidal microstructures to maximize the sensitivity of the sensor. It was identified that the fabricated flexible pressure sensor has high-sensitivity in pressure ranges when objects are pressed by a finger.

M-064 **DIRECT PATTERNING USING PROTEIN-BASED WATER LITHOGRAPHY** **504**

Z. Liu[1,2], Z. Zhou[2,3], H. Tao[2,3,4], and K. Liu[2]
[1]Shanghai Normal University, CHINA, [2]Chinese Academy of Sciences, CHINA,
[3]University of Chinese Academy of Sciences, CHINA, and
[4]University of Texas, Austin, USA

We report a new facile functional patterning method using high precision inkjet printing technologies. Water - eitherpure or functionally doped - is used as the "exposure" source and water-dissolvable silk fibroin proteins are used asthe resist. Micropatterns of ~ 16 μm (including both planar and greyscale ones) are successfully demonstrated andthe resolution can be further improved by using a smaller nozzle size (therefore smaller droplets) and optimizationof printing conditions.

T-065 **AN INTEGRATED, DIRECT-WRITE TEMPERATURE SHOCK RECORDING CHIP** **507**

Z. Shao[1], H. Liu[1,2], Y. Liu[1], H.-S. Jang[1], B. Liu[1],
B. Zhao[1], A.M. Niknejad[1], and L. Lin[1,2]
[1]University of California, Berkeley, USA and
[2]Tsinghua-Berkeley Shenzhen Institute, CHINA

We demonstrate an on-chip, passive temperature shock recording chip to memorize temperature events in its electrical resistance with ultrahigh sensitivity. Three distinctive advancements have been achieved: Size of 400*450μm^2 with integrated passive temperature sensor and circuitry; Passive temperature sensing based on the heating-induced reduction of silver-ions in a polymer film; Direct-write integration of the sensor strip onto IC by electrohydrodynamic printing.

W-066 **IMPROVED SENSITIVITY OF IONIC LIQUID-BASED PRESSURE SENSOR FOR BODY-ON-A-CHIP USING SIMULATION-BASED 3D LITHOGRAPHY** **511**

Y. Hirai, Y. Tsuji, K. Kamei, T. Tsuchiya, and O. Tabata
Kyoto University, JAPAN

We report the advanced ionic liquid-based pressure sensor with an increased sensitivity for monitoring the inside of PDMS microfluidic device. Since sensitivity of the sensor depends on the cross-sectional geometry of ionic liquid-filled channel, the mold for PDMS casting is fabricated by 3D lithography utilizing numerical process optimization. The measured sensitivity showed reasonable agreement with the simulated one, confirming the efficiency of triangular shape to improve the sensitivity.

M-067 **CHARACTERISTIC RESONANCE FEATURES OF SOI-CMOS-COMPATIBLE SILICON NANOELECTROMECHANICAL DOUBLY-CLAMPED BEAMS UP TO 330 MHZ** **515**

Y. Tsuchiya[1], Y. Feng[1], C. Giotis[1], N. Harada[1,2], M. Shikida[2], C. Dupre[3], E. Ollier[3], F. Arab Hassani[1,4], and H. Mizuta[1,5]
[1]University of Southampton, UK, [2]Hiroshima City University, JAPAN, [3]CEA-Leti, FRANCE, [4]National University of Singapore, SINGAPORE, and [5]Japan Advanced Institute Science Technology (JAIST), JAPAN

We have systematically characterised Si NEM resonators fabricated via SOI-CMOS compatible processes. The highest resonance frequency of 332.57 MHz has been achieved as the fundamental resonance mode of lithographically-defined 800-nm-long Si NEM beams. Considerable difference of the resonance frequencies between measurements and simulations, and clear change of their temperature dependence suggest significant contribution of the undercut support area to the resonance characteristics.

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

T-068 **A NOVEL APPROACH TO BLACK TITANIA FABRICATION VIA ATOMIC LAYER DEPOSITION FOR ENERGY STORAGE** **519**

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

We accomplish: (1) development of a direct deposition method of black titania (b-TiOx); (2) deposition of b-TiOx onto highly porous materials with Ångstrom-level precision; (3) increased solar response over TiO_2, as demonstrated by >10x photocurrent; (4) >7x improvement in capacitance over a TiO_2-based supercapacitor. As such, this work allows for robust and precise black titania deposition, opening up new possibilities of devices based on b-TiOx.

W-069 **SULFONATION OF POLY(PHTHALAZINON ETHER KETONE) FOR MEMS HUMIDITY SENSOR** **523**

X. Leng[1], Y. Wang[1], and F. Wang[1,2]
[1]Southern University of Science and Technology (SUSTech), CHINA and [2]Chinese Academy of Sciences, CHINA

A simple sulfonation process for Poly(phthalazinone ether ketone) (PPEK) was proposed with concentrated sulfonic acid. Different degrees of sulfonation (DS) were realized through the control of reaction time and temperature. For the first time, sulfonated PPEK (SPPEK) was applied in humidity sensors with MEMS electrodes. Both spray-coating and drop-casting methods were used to optimize the sensing performance.

M-070 **MOLYBDENUM DISULFIDE (MoS_2) NANOELECTROMECHANICAL RESONATORS WITH ON-CHIP ALUMINUM NITRIDE (AlN) PIEZOELECTRIC EXCITATION** **527**

H. Jia[1], X.-Q. Zheng[1], M. Faizan[2], T. Larsen[2], L.G. Villanueva[2], and P.X.-L. Feng[1]
[1]Case Western Reserve University, USA and [2]École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We demonstrate the first vibrating two-dimensional nanoelectromechanical systems (2D NEMS) with on-chip piezoelectric excitation. Combining a wafer-scale AlN thin film technology with an all-dry transfer technique for 2D semiconductors, we fabricate and piezoelectrically actuate few-atomic-layer molybdenum disulfide (MoS_2) NEMS resonators in the high-frequency band. The piezoelectrically excited 2D NEMS resonators may enable remotely driven, ultrasensitive transducers.

This paper reports an improved photoresponse of molybdenum disulfide (MoS_2) functionalized with tin oxide (SnO_2). SnO_2-functionalized MoS_2 induces the transfer of photo-generated electrons from MoS_2 to SnO_2 preventing the recombination of photo-excited electron-hole pairs. This photo-induced carrier separation process leads to p-type doping of MoS_2, resulting in an increase of current. Accordingly, the functionalized MoS_2 exhibited improved photoresponse compared to pristine MoS_2.

This paper reports wide-range tuning of LSPR wavelength using Ag and Au alloyed nanoislands for wafer-level fabrication of subtractive plasmonic color filter. The fabrication method includes concurrent thermal evaporation of Ag and Au sources to deposit thin alloy metal film onto wafer, followed by dewetting process. The subtractive color filters are fabricated by sequential lift-off processes of different Ag-Au alloy fractions, allowing facile wafer-level fabrication.

This paper introduces a highly flexible, stretchable, and self-sustainable lubricating electrode. We developed, for the first time, deformable conductive materials with long-term liquid repellency (roll-off-angle (ROA) < 5°) through a simple process. Our multifunctional material spontaneously releases the lubricant from inner gel matrices to the outer surfaces. The prepared materials have high electrical conductivity (≥65 Ω), stretchability, and high flexibility.

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

In our previous work, Quality Factor (Q) measurements at low temperature enabled direct determination of anchor damping. Here, we use this new method to perform the first direct examination of the relationship between the design of the anchors and mounting structures and the strength of anchor damping. We clearly see a number of very surprising results that in many ways indicate that the common understanding of anchor damping is wrong.

MEMS Actuators and PowerMEMS
Actuator Components and Systems

We report a novel electrostatic comb actuator for linear motion output by electrostatically induced self-vibration under a direct-current (DC) power supply. This comb actuator with a mass of 60 mg contains 4 pairs of electrodes. It can achieve output displacement with amplitude range of 0.9-1.4 mm by a frequency of about 220 Hz. The power density can reach 32.04 W/kg, which is 4 times of the previous actuators with single-pair electrodes.

We demonstrate high-force-density rapid actuation of electrostatic gap-closing actuator (GCA) array devices operating in an aqueous environment. Actuators operate in deionized water as well as ionic solution, and preliminary tests achieve partial operation of submerged inchworm motors. These results indicate that operation of a MEMS inchworm motor in liquid is feasible, which is expected to allow microrobots to perform tasks ranging from micro-manipulation to locomotion in aqueous environments.

MEMS Actuators and PowerMEMS
Manufacturing for Actuators and PowerMEMS

This paper reports a fabrication scheme that utilizes MEMS techniques to manufacture high performance lithium ion battery electrodes. The technology enables precise control over all electrode dimensions while maintaining a high surface area geometry that leads to excellent capacity retention and power/energy density performance. The scalable scaffold approach also allows the same fabrication process to generate electrodes in a wide range of volumes, which gives rise to high total energy output.

The fabrication of a flexible thermoelectric generator, with a lens array that converts near-infrared (NIR) solar light, was investigated in this study. The device comprised a number of serially connected thin-film thermocouples and a polydimethylsiloxane (PDMS) lens array. It possessed the flexibility to be placed on glass windows. When solar light (A.M. 1.5) was irradiated onto the fabricated device, the open-circuit voltage and maximum power were 7.4 V/m^2 and 11 uW/m^2, respectively.

M-091 **WEARABLE STRETCHABLE DOUBLE-SIDED MICRO-SUPERCAPACITORS WITH POROUS CONDUCTIVE ELASTOMERS** **608**

Y. Song, Z. Song, H. Chen, X. Chen, H. Guo, H. Wu, X. Cheng, and H. Zhang
Peking University, CHINA

We present a scalable fabrication for wearable stretchable double-sided micro-supercapacitors, which combines laser cutting with electrolyte transferring process. With in-planar and parallel layout, the device exhibits enhanced electrochemical performance. Taking advantage of porous structure and high conductive elastomers, this device could be integrated with Ecoflex substrate as a stretchable energy storage bracelet and show promising potentials in the wearable electronics and smart systems.

T-092 **PERFORATED ELECTRODE FOR PERFORMANCE OPTIMIZATION OF ELECTROSTATIC ENERGY HARVESTER** **612**

Y. Zhang[1], X. Guo[1], and F. Wang[1,2]
[1]*Southern University of Science and Technology (SUSTech), CHINA and*
[2]*Chinese Academy of Sciences, CHINA*

We have proposed a novel design of perforated electrode structure for electrostatic energy harvester. Holes with different diameters have been manufactured to optimize the air damping condition for the resonant device during vibration. Compared with the regular electrode, higher power output can be achieved at lower amplitude of external vibration source, which gives a large normalized power density.

W-093 **INKJET-PRINTED MEM RELAYS FOR ACTIVE SOLAR CELL ROUTING** **616**

S. Patel, W.J. Scheideler, M.A.U. Karim, and V. Subramanian
University of California, Berkeley, USA

We have created a low resistance, high power printed relay for active solar switching applications. These relays exhibit the lowest on-state resistance for a printed MEMS device and high current carrying capabilities which are important for the solar cell active routing schemes. We have demonstrated a proof of concept to show the increase in performance with silicon solar cells and have performed simulations to show the increase in solar array performance when coupled with varied solar arrays.

M-094 **A SUB-MW ELECTROMAGNETIC MICROSPEAKER WITH BASS ENHANCEMENT USING A PARYLENE/GRAPHENE/PARYLENE COMPOSITE MEMBRANE** **620**

P.R. Jadhav[1], Y.T. Cheng[1], S.K. Fan[2], and C.Y. Liang[2]
[1]*National Chiao Tung University, TAIWAN and*
[2]*National Taiwan University, TAIWAN*

We demonstrate the first ultra-low-power electromagnetic microspeaker employing parylene/graphene/parylene composite layer as the speaker membrane for bass sound enhancement and power consumption improvement for CIC (Completely-in-the-Canal) hearing aids applications with better battery life. The speaker with the ~500nm thin composite membrane in a size of 3.5mm in diameter can exhibit an output of 104dB sound pressure level (SPL)@670Hz in a 2c.c. coupler only with an input power of 380μW.

T-095 **3D IMPACT-BASED ALN/SUS MICROENERGY HARVESTERS FOR MULTI-DIRECTIONAL AND LOW-FREQUENCY VIBRATIONS** **624**

M.V. Le[1], S. Igarashi[1], and H. Kuwano[1,2]
[1]*Tohoku University, JAPAN and* [2]*Sendai Smart Machines Co. Ltd., JAPAN*

We developed a novel three-dimensional (3D) impact-based micro-energy harvester for harvesting random vibrations from multiple directions. The device consisted of a 3D box built up from flexible AlN/SUS-based microcantilevers and a freely-moving SUS ball. The concept enabled to generate electricity from multi-directional and frequency-independent vibrations. The device demonstrated the peak output power of 70 nW on average for the triaxial vibrations at the extremely low frequency of 4.5 Hz.

MEMS Actuators and PowerMEMS
Materials for Actuators and PowerMEMS

It is demonstrated that electrostatically actuated, suspended graphene membranes can be used as gas pumps. Gas is pumped by graphene through a narrow channel between 2 cylindrical cavities, each having a volume of only 3 femtoliter. Flow is detected by upward deflection of the second graphene membrane. The system is thus, as far as we know, not only the smallest graphene microfabricated gas pump, but also the smallest pneumatically actuated NEMS device.

We report a transient triboelectric nanogenerator (TENG) with optical feedback that integrates the features of enhanced harvesting of biomechanical energy, biodegradability, and real-time monitoring of degradation behaviors. By patterning the reflective grating nanostructures onto silk frictional layers, the energy conversion efficiency is improved due to the increased effective frictional area.

MEMS Actuators and PowerMEMS
Nanoscale for Actuators and PowerMEMS

In this study, the $NiCo_2O_4$ nano-needle structure was used as the primary electrode layer and the empty space of $NiCo_2O_4$ was filled with the CNT bundle as the secondary electrode layer. Through the above process, the output was increased compared to the device made of only $NiCo_2O_4$ electrode. In addition, AgNWs are used to coat between CNT bundles to maximize capacitance by increasing electrical contact between CNT bundles.

We report on electrostatic switching of the Pulse-Activated Piezo-NEMS Shuttle Relay, a new highly scalable geometry where only layer thickness affects device performance to first order. Testing demonstrates non-volatile states, proving the device can be used in memories. Switching occurred at electrostatic voltages ranging 5V-19V. Although relatively high, this voltage will be used as a body bias in the envisioned use of the relay. An on resistance of 700±200ω was measured for the relay.

MEMS Actuators and PowerMEMS
PowerMEMS Components and Systems

MEMS Actuators and PowerMEMS
Other Actuators and PowerMEMS

We report, for the first time, experimental demonstration of bistabilty in simple, straight and non-axially-forced clampled-clamped microbeam resonators in the MHz range. The device was fabricated and monolithically integrated with readout circuitry using a commercial 0.35-µm CMOS technology resulting in a low-cost platform to investigate potential bistability applications like switches, mechanical memories, micro-relays, band-pass filters, chaotic generators or energy harvesters.

This paper presents a new type of underwater energy harvesting technology where a pulsating microbubble (20 ~ 800 nl) actuated by the optothermal effect induces the periodic vibration of piezocantilevers contacted with the microbubble to generate an electric power. The proposed energy harvesting technology can extract a mechanical power from a light energy by optothermally pulsating microbubbles in an aqueous medium and convert the mechanical power to an electric power for wireless devices.

MEMS for Electromagnetics
Free Space Optical Components and Systems (Displays. Lenses, Detectors)

This paper reported the miniaturization method of NIR spectrometer using a plasmonic near infrared photodetector. The spectrometer changes the incident angle of light by resonating the MEMS cantilever. Since the incident angle corresponds to SPR resonant wavelength, time responses of photocurrent from SPR provides the spectrum of the incident light. We measured the time responses of photocurrent and confirmed they were dependent on the incident wavelength, and coherent to the SPR theory.

We demonstrate the utilization of high-fill factor absorber structures integrated onto SOI diode type low-cost uncooled microbolometers for broadband absorption performance. Different types of absorber structures are employed on the same focal plane array (FPA) in order to evaluate the improvement provided by absorbers differentially on the same sensor FPA.

W-114 **DIFFRACTION GRATING INTEGRATED ON MICROMACHINED STEPPER MOTOR FOR DIVERSITY IMPLEMENTATION IN IMAGING SPECTROSCOPY** **696**

S.S. Muttikulangara[1], M. Baranski[1], S. Rehman[2], L. Hu[1], and J. Miao[1]
[1]*Nanyang Technological University, SINGAPORE and*
[2]*Singapore-MIT Alliance for Research and Technology, SINGAPORE*

We report monolithic fabrication of electrostatic MEMS rotary stepper motor integrated with a highly efficient diffraction grating for spectroscopic applications. The rotational motion is achieved by a three-phase electrostatic actuation mechanism which allows highly precise stepping motion that is difficult to achieve using classical actuation, like comb-drive that depend on the structural resonance frequency.

M-115 **CUSTOM ADAPTER FOR EXTENDED FIELD-OF-VIEW MICROSPHERE-BASED SCANNING SUPER-RESOLUTION MICROSCOPY** **700**

G. Huszka and M.A.M. Gijs
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We present a dielectric microsphere-based super-resolution optical microscope that can image diffraction-limited features of a sample. Normally, such a system has a limited field-of-view, but we fixed the microsphere to a microscope objective via our custom adapter and performed scanning, imaging and reconstruction of a single wide-field super-resolution image. Furthermore, we propose the parallel use of microspheres, thereby enabling faster scanning or bigger sample areas to be imaged.

T-116 **ZERNIKE GENERATION WITH MEMS DEFORMABLE MIRROR ACTUATED BY ELECTROSTATIC PISTON ARRAY** **704**

A. Uno, Y. Hirai, O. Tabata, and T. Tsuchiya
Kyoto University, JAPAN

We report a low-voltage and large-displacement electrostatic deformable mirror for retinal imaging by adaptive-optics optical coherence tomography. The mirror utilizes an electrostatic piston actuator which allows bottom electrodes to move vertically to keep the gap small to maintain large actuation force at low actuation voltage. An 8-mm-diameter mirror device was fabricated from the mirror part and the actuator part. Successful demonstration of the mirror operation in various Zernike modes.

W-117 **MULTI-COLOR DIFFRACTIVE PROTEIN OPTICS AS A SENSING PLATFORM** **708**

X. Cai[1,2], S. Zhang[1,2], Z.T. Zhou[1,2], and T. Hu[1,2,3]
[1]*Chinese Academy of Sciences, CHINA,*
[2]*University of Chinese Academy of Sciences, CHINA, and*
[3]*University of Texas, Austin, USA*

We report silk protein-based multi-color diffractive optical elements (DOEs) for sensing applications. The silk protein, known for its excellent biocompatibility, robust mechanical properties, high transmittance and controllable degradation, providing a powerful pathway to integrate sensing and drug delivery into a single platform. The multi-color protein DOEs can generate a true color diffractive pattern when simultaneously illuminated by three laser pointers with the proper wavelengths.

MEMS for Electromagnetics
MEMS for Timing and Frequency Control

A statistical campaign on the frequency and Q temperature coefficients (TC) of resonators fabricated in a standard MEMS process is presented. The frequency drift is dominated by the elastic modulus TC, not compensated at process level. Four real-time clock resonators are examined and a characterization on 40 samples shows the possibility to obtain a frequency stability within 50ppm/20ppm with electronic compensation to 1st/2nd-order, without part-to-part characterization.

A 3.5-GHz-band FBAR was employed instead of the quartz resonator in the atomic frequency standard. Applying the FBAR to the VCO, a clock frequency of 87Rb (fclock/2=3.42 GHz) can be directly generated, realizing the reduction of the cost, size, and power consumption by eliminating the PLL. We also developed Rb MEMS gas cells and demonstrated a CPT clock. Incorporating the FBAR-VCO into the CPT clock, a sustained operation was achieved with a frequency stability of 2.1_10-11 at 1s.

This paper reports results for an analog feedback controller that can induce parametric resonance (PR) in microresonators that do not intrinsically demonstrate this phenomenon (i.e., linear microresonators with time-independent parameters.) The bifurcation results resemble those for intrinsic parametric resonators, showing that the controller is highly effective in attaining the desired dynamics. This work enables the use of linear high-Q resonators for clocks and frequency sources based on PR.

This work reports a 40 MHz lithium niobate-on-oxide micromechanical resonator which features a compensated TCF of -13 ppm/°C and a record high Q > 3,900 in vacuum for low phase noise oscillators with a minimal bias instability of only 6.2 ppb. A 0.7 µm X-cut LN thin film atop a 2 µm SiO_2 compensation layer was used to form the body of the proposed resonator based on a quasi-fundamental shear horizontal (Q-SH0) plate wave.

T-122 **AlN-ON-Si MEMS RESONATOR BOUNDED BY WIDE ACOUSTIC BANDGAP TWO-DIMENSIONAL PHONONIC CRYSTAL ANCHORS** **727**

M.W.U. Siddiqi and J.E.-Y. Lee
City University of Hong Kong, HONG KONG

We report an AlN-on-Si Lamb wave resonator with a unique wide acoustic bandgap (ABG) phononic crystal (PnC) structure at its anchors that provides an almost 4-fold increase in Q. We show that the wider ABG provides for greater suppression of anchor loss and thus higher Q relative to a narrower ABG. Compared to common circular void PnC structures, the unique PnC structures presented herein based on solid disks offer a 9-fold increase in the ABG size at a similar center frequency around 142MHz.

W-123 **MICRO-OVEN-CONTROLLED MEMS OSCILLATOR WITH ELECTROSTATIC TUNING FOR FREQUENCY TRIMMING** **731**

B. Pei[1,2], P. Zhong[1,2], K. Sun[1], H. Yang[1], and X. Li[1]
[1]*Chinese Academy of Sciences, CHINA and*
[2]*University of Chinese Academy of Sciences, CHINA*

This paper reports a micro-oven-controlled MEMS oscillator with electrostatic tuning for frequency trimming for the first time. The resonator is degenerately doped with P and micro-oven controlled to achieve ppm level temperature stability, while the frequency is tuned by electrostatic force to compensate for fabrication tolerance. This study demonstrates that the resonant frequency can be tuned of 38 ppm while achieving a temperature drift of less than 3.6 ppm from -40 °C to 85 °C.

MEMS for Electromagnetics
Phototonic Components and Systems

M-124 **MONOLITHIC INTEGRATION OF PHOTONIC STACK ONTO CMOS IMAGER FOR ABSORPTION SPECTROSCOPY** **735**

M. Malak[1], T. Claes[1], V. Garcia-Munoz[1], H. Kumar Tyagi[3], R. Van Hoof[1], G. Winderickx[1], S. Severi[1], W. Lee[2], D. Kim[2], S. Ahn[2], P. Van Dorpe[1], X. Rottenberg[1], P. Peumans[1], and H.A.C. Tilmans[1]
[1]*Interuniversity Microelectronic Center, BELGIUM, and*
[2]*Samsung Advanced Institute of Technology, KOREA*

We report about the monolithic integration of a unique photonic stack on top of a CMOS imager using a dedicated fabrication process. The system key components consists of silicon nitride optical waveguides, sloped input mirror, grating in/out-couplers, and copper-based vertical mirrors defining the resonator boundaries. The stack is optimized for operation in the NIR range (800 - 900nm). Up to the authors' knowledge, this is the first demonstration of a fully integrated photonic stack including a sloped metal mirror combined with SiN_y waveguide technology. The photonic build-up can be used for various applications among them is absorption spectroscopy as demonstrated hereafter.

T-125 **PORT: A PIEZOELECTRIC OPTICAL RESONANCE TUNER** **739**

B. Dong[1], H. Tian[1], M. Zervas[2], T.J. Kippenberg[2], and S.A. Bhave[1]
[1]*Purdue University, USA and*
[2]*École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND*

This abstract presents a piezoelectric actuator for tuning optical resonance modes of silicon nitride photonic resonators. The actuator is fabricated on top of a thick silicon dioxide cladding that encapsulates the nitride resonator and waveguide. The PORT tunes the optical wavelength by 20pm on applying 60V to the top electrode with a 0.3nA current draw.

This paper presents the first demonstration of a fully integrated electro-optically controlled acousto-optic racetrack modulator on the Lithium Niobate Over Insulator (LNOI) platform. This design takes advantage of the unique acousto-optic(AO) and electro-optic(EO) properties of LN to build a very efficient modulator that can be tuned to operate at the desired wavelength. Taking advantages of multiple functionalities on the LNOI patform demonstrates imprtant block for RF-photonic applications.

MEMS for Electromagnetics
RF MEMS Components and Systems

This work reports the largest $LiNbO_3$ resonator array for the highest passive voltage gain thus far in low-power wake-up radio front ends. We exploit parallelism with 56 identical SH0 mode resonators to simultaneously attain the highest static capacitance (1.05 pF), the highest array figure of merit of 120 without de-embedding, and a spurious mode free response, resulting in the high gain (>30) for a wide range of reactive loading (0.34-0.87 pF) typically presented by RF CMOS rectifiers.

This work reports the first $LiNbO_3$ LOBAR. The fabricated device shows the highest reported Qs (1966, 1215, and 1513) for $LiNbO_3$ resonators at the equally-spaced resonances (446.4, 599.8, and 757.3 MHz). Furthermore, high FOMs (83.6, 102.6 and 63.1) have been obtained simultaneously, which are much higher than those of the state-of-the-art overtone devices. A frequency-hopping oscillator based on $LiNbO_3$ LOBARs can be enabled for low-power and phase-continuous synthesis of OFC signals.

This work demonstrates a novel magnetic-free RF circulator that facilitates the development of in-band full duplexers (IBFD). It uses CMOS-integrable components such as AlN MEMS filters and CMOS RF switches, hence showing a compact approach that can be used in handheld devices. The AlN MEMS filter network is parametrically modulated via a switching matrix to break its reciprocity. The modulation frequency and duty cycle were optimized to provide >15dB isolation over the filter bandwidth.

A micromechanical CC-beam resonant switch, a.k.a. resoswitch, based on a 0.35-μm 2-poly-4-metal CMOS-MEMS process platform has been demonstrated. In particular, a CMOS-MEMS-based 2.12-MHz resoswitch that employs the difference of the mode-shape derived displacement along its CC-beam structure and generic via layers available in the CMOS process to achieving displacement gain and metal W-to-W contact, yielding an average power gain of 18.15 dB when embedded in a simple switched-mode amplifier.

MEMS for Electromagnetics
THz MEMS Components and Systems

We report real-time, multi-spectrally selective T-ray imaging as a proof-of-principle study using hyperspectral metamaterial focal plane arrays (MM-FPAs) that are fully compatible with existing microfabrication technologies. A set of frequency switchable quantum cascade lasers (QCLs) is used as THz sources for multi-color illumination. Both MM-FPAs and QCLs can be readily tuned to operate at multiple discrete THz frequencies to match the "fingerprints" of the analytes.

This paper will present the first silicon-based parabolic Sub-THz reflector antenna with corresponding fabrication processes. The antenna with a size of 18x18x4mm3 and an aperture of ~10mm is side fed with a 40nm CMOS triple-push oscillating source and exhibits not only ~12.4dB directive gain enhancement and 4.34° HPBW for far-field radiation but also an excellent near field focus characteristic with a 28.5mm DOF potential for high-speed data transmission and THz imaging system applications.

We report a dielectric gradient metasurface (DGM) of high transmission with a complete 2π phase control, which allows more efficient terahertz (THz) wave focusing compared to the state-of-the-art plasmonic metasurfaces. The DGM was theoretically and experimentally demonstrated to focus a THz plane wave to a beam spot of several wavelengths, which may have potential for applications in THz imaging and communication systems.

MEMS for Electromagnetics
Other Electromagnetic MEMS

A tunable surface plasmonic resonance (SPR) driven by microelectromechanical system (MEMS) and deformable elastomer with nanostructure was proposed in a hybrid system. The MEMS isotropically stretched and expanded the elastomer film, which in turn moved the integrated SPR nanostructure into controllable positions on the xy-plane, resulting in different SPRs. Under various MEMS operating conditions, arbitrary electromagnetic (EM) responses could be modulated from a single SPR design.

We report the first-ever through-wafer silicon-based Electrostatic Quadrupole Array (ESQA) to focus high energy ion beams. This device is a key enabler for a wafer-based accelerator architecture that lends itself to orders-of-magnitude reductions in cost, volume and weight of accelerators. ESQA are a key building block in developing compact Multiple Electrostatic Quadrupole Array Linear Accelerator (MEQALAC).

MEMS Physical Sensors
Fluidic Sensors (Flow, Pressure, Density, Viscosity, etc.)

For the first time, we report a wireless Dual-Mode Micro Thermal Flow (DMTF) sensor system with the extended flow range by using InvenSense 0.18μm CMOS MEMS technology. The DMTF sensor achieves an excellent flow range of 0~73m/s, which is 2.4 times larger than that of calorimetric sensor (0~31m/s) and an accuracy of less than 2% with the wireless monitoring capacity. Therefore, this low-cost wireless DMTF sensor system will be a useful IoT device for smart energy-efficient buildings.

Capacitively sensed squeeze-film pressure sensors are implemented, for the first time, in an inertia-sensor fabrication platform to facilitate multi-sensor integration. The complete fabrication is simplified as the sensors do not require a mechanical membrane with a sealed reference cavity. Sensitivity grows as the plate size increases. Results also show the important trade-off between quality factor and sensitivity for resonant plates of the same size.

M-148 **GROUND EFFECT MEASUREMENT OF BUTTERFLY TAKE-OFF 832**
T. Hagiwara, H. Takahashi, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

We measured the ground effect during butterfly taking-off. We used a differential pressure sensor array and a force plate to measure the pressure distribution on the ground and the jumping force, respectively. The force of ground effect is obtained as an integration of the pressure distribution. The aerodynamic force of wings is obtained from the jumping force and acceleration of the taking-off motion. The results showed the force of ground effect was ~40% of the aerodynamic force.

T-149 **EIGHT-TRIGRAM-INSPIRED MEMS THERMAL WIND SENSOR WITH IMPROVED ACCURACY 836**
Y. Ye, Z. Yi, M. Qin, and Q.-A. Huang
Southeast University, CHINA

A high accurate MEMS thermal wind sensor inspired by eight trigrams is demonstrated. The sensor, shaped like eight trigrams, consists of eight central heaters and eight thermistors. This configuration is divided into two sensing groups. The two groups monitor wind independently, and the final wind information are compensation values extracted by the two-group measurement results. Based on this design, the sensor achieves significantly improved accuracy for both speed and direction measurement.

W-150 **INLINE RELATIVE PERMITTIVITY SENSING USING SILICON ELECTRODES REALIZED IN SURFACE CHANNEL TECHNOLOGY 840**
D. Alveringh[1], R.J. Wiegerink[1], and J.C. Lötters[1,2]
[1]*University of Twente, NETHERLANDS and*
[2]*Bronkhorst High-Tech BV, NETHERLANDS*

The relative permittivity varies significantly between fluids that are chemically related and has therefore great potential for fluid characterization. We report on a novel inline relative permittivity sensor realized in surface channel technology. The sensor enables non-contact composition measurements of chemicals. Integration with other fluid sensors, e.g. flow or pressure sensors, on a single chip could be achieved.

M-151 **ULTRA SENSITIVE OPTOMECHANICAL MICRODISK RESONATORS WITH VERY LARGE SCALE INTEGRATION PROCESS 844**
M. Hermouet[1,2], M. Sansa[1,2], L. Banniard[1,2], A. Fafin[1,2,3], M. Gely[1,2], P.E. Allain[3], E. Gil Santos[3], I. Favero[3], T. Alava[1,2], G. Jourdan[1,2], and S. Hentz[1,2]
[1]*Université Grenoble Alpes, FRANCE,* [2]*CEA-LETI, FRANCE, and*
[3]*Université Paris Diderot, FRANCE*

We report the first Very Large Scale Integration silicon optomechanical microdisk resonators operating in liquid with state-of-the-art performance: high optical-Q and optomechanical coupling allow the Brownian noise of these resonators to be easily resolved in a highly dissipative environment like water with many different devices, without the need of an optical amplifier.

T-152 **RESONANT PRESSURE SENSING USING A MICROMECHANICAL CANTILEVER ACTUATED BY FRINGING ELECTROSTATIC FIELDS 846**
N. Krakover[1], B.R. Ilic[2], and S. Krylov[1]
[1]*Tel Aviv Unversity, ISRAEL and*
[2]*National Institute of Standards and Technology (NIST), USA*

We demonstrate a pressure sensing approach based on a resonant operation of a cantilever positioned near a flexible, pressurized membrane. The membrane deflection perturbs the electrostatic force acting on the cantilever and alters the beam's resonant frequency. Sensitivity was enhanced by tailoring the actuating force nonlinearities through fringing electrostatic fields. We achieved frequency sensitivity to pressure and displacement of ≈30 Hz/kPa and ≈4 Hz/nm, respectively.

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

T-161 **UTILIZING LARGE HALL OFFSET VOLTAGE FOR CONVERSION FREE 4H-SIC STRAIN SENSOR** **882**

T.-K. Nguyen, H.-P. Phan, J. Han, T. Dinh, A.R.M. Foisal,
Y. Zhu, N.-T. Nguyen, and D.V. Dao
Griffith University, AUSTRALIA

We develop a highly sensitive 4H-SiC Van der Pauw strain sensor by utilizing a four-terminal configuration. The sensors aligned in different orientations in (0001) wafer were measured, then a high sensitivity of 26.3/ppm was found for the sensor aligned 45o to <1-100> direction. Coupling the good repeatability and linearity with the excellent mechanical strength, thermal stability, and chemical inertness of 4H-SiC, the sensor is promising for strain monitoring in harsh environments.

W-162 **TRI-MODAL THIN-FILM FLEXIBLE ELECTRONIC SKIN TO AUGMENT ROBOTIC GRASPING** **886**

C. Yu, M.R. Cavallari, and I. Kymissis
Columbia University, USA

We report a combination of three sensing modes (piezoelectric, strain, capacitive) for measuring relative movement, absolute movement, and object proximity, respectively. The piezoelectric and capacitive modes consist of silver on PVDF film. Strain is measured using silver traces on spin-coated PDMS. A compliant layer of open-cell foam is placed beneath the sensing layers to increase sensitivity. The resulting 820-micron thick stack is wrapped around robotic fingers to augment grasping feedback.

M-163 **OPTICAL TYPE STRAIN SENSOR BASED ON VARIABLE-TRANSMITTANCE OF CARBON NANOTUBE EMBEDDED ELASTOMER THIN FILM** **889**

J. Gu, D. Kwon, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), KOREA

We report a novel optical type flexible and stretchable strain sensor based on a carbon nanotube(CNT)-elastomer nanocomposite thin film which shows high sensitivity, quick dynamic response, and small hysteresis. Initially, the percolated CNTs embedded on the surface of the elastomer film block most of the light transmitted through the film. As an external tensile strain is applied to the CNT-elastomer film, cracks on the film cause an increase of optical transmittance of the CNT-elastomer film.

T-164 **FLEXIBLE OPTICAL PRESSURE SENSOR AND ITS APPLICATION TO WEARABLE HUMAN MOTION DETECTING DEVICE** **893**

D. Kwon, K. Na, K. Kang, J.-Y. Lee, and I. Park
Korea Advanced Institute of Science and Technology (KAIST), KOREA

This paper reports a flexible optical pressure sensor based on a microporous structured elastomer and its application to a wearable human motion detecting device, which is operated in a self-power-generating way by integrating with an organic photovoltaic cell. Complete investigation of material characteristics and sensing performances as well as optical simulation for understanding the sensing mechanism have been produced to realize self-power-generated wearable motion sensing devices.

W-165 **LARGE AREA CONTACT RESONANCE SPECTROSCOPY MAPPING SYSTEM FOR ON-THE-MACHINE MEASUREMENTS** **897**

M. Bertke, M. Fahrbach, G. Hamdana, H.S. Wasisto, and E. Peiner
Technische Universität Braunschweig, GERMANY

We develop a phase locked loop (PLL) controlled micro tactile measurement system for on-the-machine contact resonance spectroscopy (CRS) mapping of square centimeter sized surface areas. A robust, large dimension, piezo resistive silicon cantilever probe is used for the CRS based layer and material analysis of contaminated surfaces. We realized a compact, LabWIEW controlled, full automated scanning system using a homemade software PLL circuit for resonance frequency tracking and out-reading.

MEMS Physical Sensors
Gas and Chemical Sensors

This paper firstly reports a method to fabricate C-doped tungsten oxide (WO_3) nanomaterials using carbon nanotubes (CNTs) template and demonstrates its application to highly sensitive NO_2 gas sensing at room temperature. The fabricated sensor achieved a lower detectable limit at room temperature than the previously reported WO_3-based NO_2 sensors, which may be due to the very large surface area of the synthesized materials as well as the carbon doping effect.

MEMS Physical Sensors
Inertial Sensors (Gyros, Accelerometers, Resonators, etc.)

A capacitive MEMS accelerometer utilizes a moving mass formed by a SOI wafer was designed and experimentally demonstrated. A proposed separated servo mass architecture reduces electrical coupling noise and power consumption related to servo operation. Two layers of perforation increase mechanical sensitivity and reduce squeeze film damping. A prototype sensor showed a low noise floor of 30 nG/√Hz with a low-cost getter-less vacuum ceramic package and low power consumption of 20 mW.

This paper presents a new self-clocked dual-resonator Lorentz force magnetometer, based on electromechanical sigma-delta modulation closed-loop operation. The frequency of the oscillation loop of resonator 1 is used to generate the injected Lorentz drive current of resonator 2, and also generates all internal circuit clocks based on a self-clocking scheme. The proposed design achieved 7X and 16X improvement in bias instability and the bandwidth, respectively.

We present the first MEMS Rate-Integrating-Gyroscope (RIG) based on the Catch-and-Release (CR) scheme for continuous angle measurement without feedback control. The CR-RIG has the mass electrostatically caught at a maximum displacement position, and then released to free precession during which angle measurement is performed. A tunable damper to compensate the damping asymmetry is also proposed. Using a fabricated CR-RIG, the CR operation and the direct angle measurement are confirmed.

MEMS Physical Sensors
Manufacturing for Physical Sensors

MEMS Physical Sensors
Materials for Physical Sensors

T-202 **EVALUATION OF PIEZORESISTIVE PROPERTY OF VANADIUM OXIDE THIN FILM** **1044**

N. Inomata, N.V. Toan, M. Toda, and T. Ono
Tohoku University, JAPAN

This paper shows the evaluation of piezpresistive property of vanadium oxide (VOx) film. The VOx films is deposited and patterned as a piezoresistor on an edge of suspended silicon membrane. The resistance of the VOx resistor changes as the membrane is deflected. The deflection of the membrane is caused by evacuating to each differential pressure. The resistance decreased as the strain increased. The gauge factor of the deposited VOx is 259.

MEMS Physical Sensors
Nanoscale Physical Sensors

W-203 **MULTI-FREQUENCY SILICON NANOFRACTAL RESONATOR** **1048**

V. Tzanov[1], J. Llobet[2,3], F. Torres[1], F. Pérez-Murano[3], and N. Barniol[1]
[1]*Universitat Autonoma de Barcelona, SPAIN,*
[2]*International Iberian Nanotechnology Laboratory, PORTUGAL, and*
[3]*Institut de Microelectronica de Barcelona, SPAIN*

Novel top down Si-based electrostatically driven clamped-clamped resonator was manufactured. The resonating body (12 [um] in length) is a fractal with a hexagonal shape based on a cell-triangle with a side of 3.354 [um]. The experimental measurements and simulations proved that the device can resonate at many different frequencies allowing multiple operational frequencies. The size, and the power needed for actuation are comparable with the ones of single beam resonator.

M-204 **ALL-ELECTRICAL TRANSDUCTION OF BLACK PHOSPHORUS TUNABLE 2D NANOELECTROMECHANICAL RESONATORS** **1052**

A. Islam, J. Lee, and P.X.-L. Feng
Case Western Reserve University, USA

We report on the first all-electrically transduced and frequency tunable two-dimensional (2D) vibrating nanoelectromechanical resonators enabled by atomic layer black phosphorus (P) crystal. The resonance frequency is detected using a down-mixing technique with frequency modulation (FM). The black P resonator suspended on a circular microtrench exhibits resonance in high frequency (fres~24MHz).

T-205 **INCREASED PIEZORESISTIVE EFFECTS OF SILICON NANOWIRES FOR EFFECTIVE BIOMIMETIC SENSING** **1056**

S. Jang[1], B. Chang[1], J. Sung[1], T. Kim[1], H. Ko[2], K.-I. Koo[3], and D.-I. Cho[1]
[1]*Seoul National University, KOREA,*
[2]*Chungnam National University, KOREA, and*
[3]*University of Ulsan, KOREA*

This paper presents the piezoresistive (PZR) effects of silicon nanowires (SiNWs) and evaluates the possibility of using them in biomimetic sensors. The structure of SiNWs can be fabricated to be similar to receptor cells to mimic their functions. SiNWs are fabricated by a new MEMS process. The developed process can independently control the width and the thickness of SiNWs. The PZR effects of the fabricated SiNWs change as a nonlinear function of SiNW cross-section dimensions.

MEMS Physical Sensors
Sonic and Ultrasonic Transducers (Microphones, PMUTs, etc.)

We report on a wide-bandwidth Spin-MEMS microphone, in which spintronic strain-gauge sensors are integrated on a diaphragm, with a mechanical resonance frequency of over 70 kHz and a SNR of 49 dBA. SNR enhancement is realized by adopting an optimum bias magnetic field. We compare operation sounds of defective and normal bearings using the packaged microphone. The Spin-MEMS microphone detects differences in the operation sounds between two bearings at the high-frequency range of 10 to 50 kHz.

This study employs the MOSBE process to design and implement the MEMS microphone to improve the SNR and the sensing range. It has three merits: (1) rigid diaphragm without release holes together with ring-type oxide/polySi mesa could reduce the low frequency acoustic loss; (2) rigid diaphragm supported by flexible V-shaped springs enables the parallel plate gap-closing capacitance sensing to improve sensitivity; (3) silicon nitride electrical isolation improve initial capacitance and noise floor.

This paper reports a new in-ear MEMS loudspeaker. The piezoelectric device operates without a closed membrane, which improves the acoustic performance, efficiency and manufacturability. Measurements using an ear simulator have revealed high SPL of more than 110 dB. Unlike conventional in-ear speakers the SPL can be maintained up to 20 kHz leading to a very flat frequency response. Additionally, the total harmonic distortion has proven to be less than 1 % over a large range of frequencies.

We develop a capacitive MEMS microphone using a slit membrane. This microphone is composed of an oscillating membrane with slit structures, a fixed back-plate, a back-chamber, and an air gap between two parallel poly silicon layers of the membrane and back-plate. The microphone detects a sound level by a capacitance variance between the back-plate and the membrane. Slit structures in the membrane give low stiffness which results in large displacement.

MEMS Physical Sensors
Other Physical Sensors

W-215 **FLEXIBLE ELECTRONIC-WALLPAPER INTEGRATED WITH FGRAM-BASED TACTILE MEMORY AND TEMPERATURE SENSORS** **1096**

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

We developed an electronic wallpaper (e-wallpaper) integrated with tactile memorable sensor and temperature sensor arrays to use it as electrical message board and to monitor an environmental temperature for a smart house concept. To realize this, a flexible nonvolatile floating gate random access memory (FGRAM) array integrated with tactile and temperature sensors are incorporated. In addition to the demonstrations, the flexible FGRAM is systematically studied as the fundamental properties.

M-216 **A SILICON RESONANT THERMOMETER FOR HIGH PRESSURE AND HIGH TEMPERATURE ENVIRONMENT** **1100**

K. Kanno, M. Noro, T. Mitsuhashi, S. Yoshita, T. Mishima, and T. Yoshida
Yokogawa Electric Corporation, JAPAN

We developed a novel silicon resonant thermometer for the usage under a high pressure and a high temperature environment. The characteristic of this thermometer design is that it is not one fixed end structure such as a cantilever type, and does not change in resonant frequency even when high pressure (300 MPa) is applied. Moreover, it has high accuracy of temperature measurement because balancing hard spring effect and soft spring effect can improve the frequency stability.

T-217 **FABRICATION OF A NOVEL NANOPOROUS FILM BY CHEMICAL DEALLOYING OF CU-CR AND ITS APPLICATION FOR A SENSOR** **1104**

Y. Yoshii, J. Sakurai, M. Mizoshiri, and S. Hata
Nagoya University, JAPAN

In this paper, a novel nanoporous film having a transparency and an insulation state was fabricated by new chemical dealloying of Cu-Cr needing no annealing with high temperature. Moreover, the fabricated nanoporous film was successfully applied to a nanoporous electrode film filter of a moisture-in-oil sensor for the first time. The fabricated moisture-in-oil sensor showed outstanding sensitivity and low hysteresis in air. Furthermore, this sensor showed the favorable 90% response time in oil.

W-218 **A CMOS COMPATIBLE GHZ ULTRASONIC PULSE PHASE SHIFT BASED TEMPERATURE SENSOR** **1108**

M. Abdelmejeed, J.C. Kuo, and A. Lal
Cornell University, USA

We present an ultrafast and high-resolution novel temperature sensor based on measurement of the phase shift between the transmitted and received ultrasonic pulses through silicon substrate generated using CMOS-compatible AlN thin film transducers. The phase shift between the transmitted signal and the received echo increases as temperature of the substrate increases. By detecting the phase shift of multiple echoes, both wide dynamic range and high resolution can be achieved simultaneously.

Micro- and Nanofluidics
Biological and Medical Microfluidics and Nanofluidics

W-224 **LOW DNA DAMAGE SPERM SORTING WITH VARIED VISCOSITIES IN MICROFLUIDIC CHIP** **1130**

Y.-H. Lu, C.-Y. Lu, and D.-J. Yao
National Tsing Hua University, TAIWAN

We develop a sperm sorting method about semen stock sample with different viscosities applying on microfluidic chip with corresponding velocity ratio, and detect the DNA damage rate by Sperm Chromatin Structure Assay (SCSA). Most viscosities of semen are range from 1 to 5 mPa*s, the difference of viscosity will make the separation in the biochip failed. To overcome this problem, we modified the infused flow rate ratio and achieve good viability enhancements as our previous work.

M-225 **AUTOMATED DNA PURIFICATION AND MULTIPLEXED LAMP ASSAY PREPARATION ON A CENTRIFUGAL MICROFLUIDIC ''LAB-ON-A-DISC'' PLATFORM** **1134**

D.J. Kinahan[1], L.A.N. Julius[1], C. Schoen[2], T. Dreo[3], and J. Ducrée[1]
[1]Dublin City University, IRELAND, [2]Wageningen University & Research, NETHERLANDS, and [3]National Institute of Biology, SLOVENIA

This work presents a rotational-pulse actuated microfluidic cartridge enabling automated detection of plant pathogens towards point-of-use monitoring of food safety. This highly integrated "Lab-on-a-Disc" (LoaD) system purifies a sample using a stationary phase of silica beads. Eluted DNA is then accurately metered and then mixed with reagents for loop-mediated isothermal amplification (LAMP). We successfully purify plant DNA and demonstrate on-disc quantitative LAMP amplification.

W-226 **USING EWOD CHIP FOR THE CULTURE MEDIUM MOVEMENT AND DYNAMIC CULTURE OF MOUSE EMBRYOS** **1138**

H.-T. Li, Y.-H. Huang, and D.-J. Yao
National Tsing Hua University, TAIWAN

EWOD system is used in reproductive medicine and has been expected to be a dynamic cell culture platform for assisted reproductive technology (ART). The EWOD device is anticipated to provide a stable culture environment and improve the growth environment of mouse embryos based on its advantages of uniform hormone mixing in the culture medium. As we predicted, the development rate of embryos cultured by dynamic process is better than embryos of static group.

M-227 **A PDMS-BASED DIGITAL PCR CHIP WITH VACUUM ASPIRATION AND WATER-FILLING CAVITY INTEGRATED FOR SAMPLE LOADING AND EVAPORATION REDUCTION** **1142**

T. Xu[1], X. Wang[1], X. Zhu[2], Y. Bao[1], S. Cai[1], G. Li[3], and X. Li[1]
[1]Chinese Academy of Sciences, CHINA,
[2]Fujian Agriculture and Forestry University, CHINA, and
[3]Chongqing University, CHINA

We report a novel PDMS-based digital PCR (dPCR) chip with vacuum aspiration cavity and water-proof layer integrated, where neither external pumping nor degassing setup is needed for sample loading. A normal syringe is enough for sample suction and partition. In this way the sample loading time is shortened to 4min and the water loss in the chamber is reduced to a negligible level. Therefore the novel chip is suitable for on-site detection.

T-228 **3D ELECTRODES INTEGRATED IN A DYNAMIC MICRO ARRAY FOR LIPOSOME ELECTROFUSION** **1146**

K. Sugahara, S. Yoshida, and S. Takeuchi
University of Tokyo, JAPAN

We develop a microfluidic device that enables pairing and fusion of liposomes. Our device has dynamic micro array system for pairing liposomes and three-dimensional electrode for applying voltage to fuse liposomes. We successfully paired two liposomes in the dynamic micro array device and fused liposomes by the integrated 3D- electrodes. We believe that this dynamic micro array device will be useful in vesicle fusion and artificial cell studies.

M-229 **A URINE TESTING CHIP BASED ON THE COMPLEMENTARY SPLIT-RING RESONATOR AND MICROFLUIDIC CHANNEL 1150**

C.-H. Li[1], K.-W. Chen[2], C.-L. Yang[2], C.-H. Lin[1], and K.-C. Hsieh[1]
[1]*National Sun Yat-sen University, TAIWAN and*
[2]*National Cheng Kung University, TAIWAN*

A urine testing of microwave chip based on the complementary split-ring resonator (CSRR) coupling with a microstrip and the microfluidic channel was developed and demonstrated for determining the water content of the urine. Results show that the chip is sensitivity to the change of resonant frequency and insertion loss which increased as the urine color became darker due to the decreased water content. Therefore, this technique is proper to test the urine for monitoring the hydration state.

Micro- and Nanofluidics
Generic Microfluidics and Nanofluidics

T-230 **MICROFLUIDIC STEPWISE-WAVEFORM REGULATOR DRIVEN BY CONSTANT PRESSURE 1154**

G. Kim and S.-J. Kim
Konkuk University, KOREA

We report a stepwise-waveform (SW) regulator that stepwise increases or decreases pressure without any dynamic controllers but only with constant water-head pressure. The regulator consists of a microfluidic oscillator and a diode pump, and converts constant pressure to pulsatile and then to stepwise pressure. The pressure increment and duration time can be independently tuned. With connection of an additional valve to the regulator, it generates SWs of shear stress and chemical concentration.

W-231 **DROPLET-ENHANCED MICROSPECTROMETRY FOR TRACE LEVEL HEXAVALENT CHROMIUM DETECTION 1157**

X. Li, C. Chen, and H. Chang
Northwestern Polytechnical University, CHINA

This paper presents a flow-focusing droplet (FFD) chip for quantitative detection of trace level hexavalent chromium (Cr[VI]) in water. With the two inherent advantages of droplets, i.e., dispersion reduction by droplet compartmentalization and effective optical path-length increase by water/oil interface reflection, a 15-fold enhancement in absorbance has been achieved. The limit of detection was down to 7 μg L-1 (0.14 ppb).

M-232 **GENERATION OF HANGING DROPS WITH DEFINED SOLUTION CONCENTRATIONS USING A SLIDING HANGING DROP CHIP 1161**

C.-Y. Tang[1], C.-C. Fu[1], and C.-H. Hsu[1,2]
[1]*National Tsing Hua University, TAIWAN and*
[2]*National Health Research Institutes, TAIWAN*

A microfluidic chip is developed to generate multiple hanging drops which contain a solution of defined concentrations. The concentration gradient is generated by manual pipetting and slipping the chip, which is easy to operate and does not require a complex equipment setup involving fluid pump and valves. This chip provides a simple platform for performing drug screening on 3D-cultured cells.

Micro- and Nanofluidics
Integrated/Embedded Microfluidic and Nanofluidic Systems & Platforms

T-242 **DROPLET HEIGHT CONTROL BY ELECTROWETTING-ON-DIELECTRIC FOR SELECTIVE CONTACT FUSION OF DROPLETS ON FACING SUBSTRATES** **1201**

C. Ohya and S. Konishi
Ritsumeikan University, JAPAN

We present control of droplet-height for selective contact-fusion of droplets. This study is based on the concept of contact-fusion of droplets between vertically opposing substrates which was proposed elsewhere. Droplet-height is, for the first time, controlled by using electro-wetting-on-dielectric in this study. The shape of droplet such as droplet-height can be changed by electric field. It is possible to select contact/non-contact between facing droplets by controlling droplet-height.

W-243 **DETECTION OF MICRO RIBONUCLEIC ACIDS FROM EXTRACTED EXTRACELLULAR VESICLES FOR CARDIOVASCULAR DISEASES BY USING AN INTEGRATED MICROFLUIDIC SYSTEM** **1205**

H.-L. Cheng, C.-Y. Fu, Y.-W. Cheng, Y.-L. Wang, C.-C. Cheng, and G.-B. Lee
National Tsing Hua University, TAIWAN

We developed an integrated microfluidic system equipped with highly sensitive field-effect transistors which is capable of performing EVs extraction, EVs lysis, target miRNAs extraction and miRNAs detection. The entire detection process could be automated within three hours and the detection limit of miRNAs was observed to be in a femtomolar range, which meets the physiological concentrations.

M-244 **AUTOMATIC RAPID ANTIMICROBIAL SUSCEPTIBILITY TEST ON AN INTEGRATED MICROFLUIDIC DEVICE** **1209**

W.-B. Lee[1], K.-M. Shen[1], H.-L. You[2], M.S. Lee[2], and G.-B. Lee[1]
[1]National Tsing Hua University, TAIWAN and [2]Chang Gung University, TAIWAN

We developed an integrated microfluidic device which can perform antimicrobial susceptibility tests of antibiotics combination against clinical bacteria. A new approach to measure either drug interactions of three antibiotics or minimum inhibitory concentration of antibiotics by performing bacteria dispensation and antibiotics dilution automatically was proposed and it substantially reduced detection time and bacteria consumption when compared to the gold standard methods.

T-245 **WIRELESS CLOSED-LOOP CONTROL OF CENTRIFUGO-PNEUMATIC VALVING TOWARDS LARGE-SCALE MICROFLUIDIC PROCESS INTEGRATION** **1213**

D.J. Kinahan[1], S.M. Delgado[2,3], L.A.N. Julius[1], A. Mallette[1,4], D. Saenz-Ardila[2,3], R. Mishra[1], C.M. Miyazaki[1,5], J. Korvink[4], D. Mager[4], and J. Ducrée[1]
[1]Dublin City University, IRELAND, [2]University of Freiburg, GERMANY, [3]Karlsruhe Institute of Technology, GERMANY, [4]University of Notre-Dame, USA, and [5]Universidade Federal de Sao Carlos, BRAZIL

We present a wirelessly powered, Bluetooth controlled platform that co-rotates with a Lab-on-a-Disc to allow large-scale process integration on a centrifugal microfluidic platform. This modular, electronically controlled system can, during rotation, independently actuate up to 128 valves by an array of microheaters for enhanced process integration. Additionally, we implement real-time optical measurement for closed-loop control of liquid handling, sample preparation and detection.

M-250 **NOVEL PAPER-BASED MICROFLUIDIC CASSETTE FOR 2D PAPER CHROMATOGRAPHY AND PAPER SPRAY MASS SPECTROMETRY (PS-MS) FOR DRUG METABOLISM ANALYSIS IN URINE** **1233**

M.-H. Cheng and C.-H. Lin
National Sun Yat-sen University, TAIWAN

This paper presents a novel paper-based microfluidic cassette for 2D paper chromatography and paper spray mass spectrometry (PS-MS) for drug metabolism analysis in urine. Results showed that the developed system can detect the secreted species including caffeine, vitamin B6 and pyridoxinal (metabolite of Vitamin B2) in urine in two-hours.

Micro- and Nanofluidics
Manufacturing for Micro- and Nanofluidics

T-251 **INTEGRATION AND CHARATERIZATION OF NANOPOROUS ALUMINUM OXIDE MEMBRANES IN MICROFLUIDIC CHIPS** **1237**

F. Bunge, C. Habben, S. van den Driesche, and M.J. Vellekoop
University of Bremen, GERMANY

Anodized aluminum oxide is an extraordinary material because of its high porosity with unidirectional, nano-scale pores that are formed during the low-cost anodization process. We present for the first time a closed microfluidic chip in which this membrane is monolithically integrated on a wafer-level and the closed channel are formed by wafer-bonding. We show a 3 µm thick membrane with a porosity of 22% and a pore diameter of 38±6 nm and investigate the mass-transport through the membrane.

W-252 **RAPID ASSEMBLY OF MULTILAYER MICROFLUIDIC STRUCTURES** **1241**

C. Glick, A. Schwartz, M. Srimongkol, J. Lin, W. Zhuang,
R. Warren, D. Tekell, P. Satamalee, and L. Lin
University of California, Berkeley, USA

We demonstrate rapid 3D-printed molding and assembly of two-sided and multi-layered PDMS devices. We demonstrate the molding of complex geometries in PDMS – including vias, built-in alignment marks, and membrane valves – that are difficult or impossible to achieve using standard soft lithography. A new stamp-bonding method is used to selectively apply liquid PDMS adhesive, demonstrating a reliable method of assembling multi-layered PDMS microfluidic devices.

M-253 **A NEW METHOD TO MANUFACTURE PARYLENE MICROCAPILLARIES** **1245**

T.-C. Chou[1], Y. Pi[1,2], H. Xu[2], and Y.-C. Tai[1]
[1]California Institute of Technology, USA and [2]Peking University, CHINA

We developed a new way to manufacture parylene microcapillaries with an inner diameter smaller than 10 µm and a length exceeding 10 cm using the sacrificial poly(ethylene carbonate) (PEC) material. We also identified a high-temperature self-expelling mechanism of the molten PEC inside the capillaries, which greatly reduced the sacrificial time to tens of minutes.

T-254 **DIRECT AND ALL-DRY FABRICATION OF PAPER-BASED MICROFLUIDIC DEVICE USING PARYLENE-C DEPOSITION AND MASKLESS MICROPLASMA WRITING** **1249**

T. Wang, M.S. Hu, B. Yang, X.L. Wang, X. Chen, and J.-Q. Liu
Shanghai Jiao Tong University, CHINA

We develop a novel and simple method for direct and all-dry fabrication of paper-based microfluidic devices using parylene-C deposition and maskless microplasma writing. To fabricate hydrophilic microfluidic channels on hydrophobic filter paper, parylene-C is first coated on the filter paper followed by maskless atmospheric pressure microplasma scanning.

W-255 **ELECTRICALLY DRIVEN ION TRANSPORT IN NANOPORES FABRICATED BY METAL ASSISTED CHEMICAL ETCHING METHOD 1253**

N.V. Toan, N. Inomata, M. Toda, and T. Ono
Tohoku University, JAPAN

Nanopores with approximate 15 nm-diameter and 200 µm-height were successfully fabricated by MACE as well as the electrically driven ion transportation was demonstrated. The proposed fabrication method and structure show a great potential for manipulations of ions and may be useful in chemical analysis, biological processes, electrochemical supercapacitor, and thermoelectric power generator.

M-256 **SIMULTENEOUS IMPROVEMENT OF SURFACE FINISH AND BONDING OF CENTRIFUGAL MICROFLUIDIC DEVICES IN CYCLO-OLEFIN POLYMERS 1257**

E. Vereshchagina, P. Carmona, E. Andreassen, J. Batalden, M. Plassen, and M.M. Mielnik
SINTEF Digital, NORWAY

Two key issues in the manufacturing of microfluidic devices is to obtain low surface roughness, i.e. in the range ofnanometers, and to achieve robust bonding. Here we report that a chemical polishing step, used for smoothening the surface of cyclo-olefin polymer(COP) Components manufactured by micromilling, reduces the surface roughness and facilitates a leak-tight COP-COP bond. The process is demonstrated on centrifugal microfluidic devices.

T-257 **FABRICATION AND EVALUATION OF ASSEMBLED MICRO-TUBE RESONATOR FOR MASS MEASUREMENT IN FLOWING LIQUID 1261**

M.A. Indianto, M. Toda, and T. Ono
Tohoku University, JAPAN

This research offers simple fabrication of the microchannel resonator by assemblying to measure mass change in flowing liquid. The fabrication process of assembled micro-tube resonator is simply combining three different fabrications of a groove part, a micro-tube part, and a glass part, which are fabricated by common micromachining. The evaluation by injecting flowing liquid to the device shows consistent change of mass. The minimum resolution calculated is in the value of 1.04 pg.

W-258 **A FACILE ALIGNMENT OF PDMS LAYERS FOR THE FABRICATION OF 3D MICROFLUIDIC DEVICES USING SYNERGISTIC ZIPPER STRUCTURES 1265**

L. Wu[1], T. Xu[1], G. Li[2], X. Zhu[3], and J. Zhao[1]
[1]Chinese Academy of Sciences, CHINA, [2]Chongqing University, CHINA, and [3]Fujian Agriculture and Forestry University, CHINA

We describe a simple method for the assembly of 3D PDMS microfluidic devices using zipper-based microchannel alignment. Benefited from the synergistic effect of zipper teeth, the alignment of patterned PDMS layers can be easily and rapidly realized with a microscope. This method tolerates small-degree of mismatch between PDMS layers due to the shrinkage of cured PDMS and thus can be used for making large area 3D microfluidic devices.

M-259 **TRIPLE-COAXIAL FLOW FOR CONTINUOUS PRODUCTION OF MICROTUBES CONTAINING MICROBES FOR BIOREMEDIATION 1269**

K. Fujimoto, K. Higashi, H. Onoe, and N. Miki
Keio University, JAPAN

We develop a microfluidic device to continuously produce a hydrogel microtube using triple-coaxial flow, and demonstrate bioremediation using the microtubes that encapsulate microbial suspension. The microenvironment created by the microtubes enabled efficient purification of sample aqueous solution and in addition, the microbes are maintained inside the microtube and are easily collected without contaminating the solution. The proposed technology can be applied to any types of microbes.

Micro- and Nanofluidics
Materials for Micro- and Nanofluidics

We theoretically and experimentally show the significance of phase shift across multiple dielectric layers in electrowetting-on-dielectric (EWOD) microfluidic devices upon the use of AC voltage. Multiple dielectric layers were used to improve the reliability of EWOD devices, which results in phase mismatch among dielectrics. We demonstrate strong dependence of dielectric breakdown and actuation force on the frequency so that optimum operation condition can be found.

Micro- and Nanofluidics
Other Micro- and Nanofluidics

This paper reports the systematic batch fabrication of atomic force microscope (AFM) cantilevers with various photocurable polymers by using an aligned polydimethylsiloxane (PDMS) mold assembly consisting of two PDMS molds; one exhibiting tips and beams and the other exhibiting bases and injection channels. After the mold assembly is filled with photocurable polymers and UV is exposed, the mold assembly is simply separated and 40 cured polymeric AFM cantilevers are harvested simultaneously.

The effect of the droplet contact width on SAW attenuation was investigated for microfluidic applications. It has been firstly demonstrated that if there is one droplet on the wave path, the SAW energy radiated into the liquid is mostly depended on the droplet contact diameter but less correlated with contact angle and liquid viscosity. Whereas for multiple droplets, the SAW attenuation is determined by the droplet contact width more than the contact area.

This paper presents three-dimensional (3D) magnetic droplet manipulation through the combination of horizontal and vertical magnetic actuation between open parallel plates for biochemical analysis. The proposed method provides not only a simple, robust, and practical platform for manipulating biochemical droplets but also 3D actuation for improving the chip density and analysis sped for molecular diagnostic applications.

W-264 **MEMS-BASED PARTICLE SIZE MAGNIFIER FOR MEASURING ULTRA LOW NANOPARTICLE CONCENTRATION** **1286**

H.B. Kwon, S.J. Yoo, J.S. Han, S.M. Lee, U.S. Hong,
J.H. Hwang, and Y.J. Kim
Yonsei University, KOREA

We develop a MEMS-based particle size magnifier. By growingnanoparticles to a diameter greater than 1μm, the proposed device enables optical methods to detect the individualnanoparticles which cannot be seen optically due to their small size. The proposed device shows the potential ofrealizing a compact and low-cost nanoparticle sensor which can measure ultralow nanoparticle concentration.

M-265 **IN-SITU TEM STUDY OF HIGHLY STABLE OXYGEN NANOBUBBLES IN QUASI-2D LIQUID SYSTEM** **1289**

P. Kundu, S. Bhattacharya, S.-Y. Liu, F.-R. Chen, and F.-G. Tseng
National Tsing Hua University, TAIWAN

For the first time, using an in-house fabricated quasi-2D system in a LETEM, we have successfully generated highly stable oxygen nanobubbles (NBs) with diameter 10~50 nm via decomposition of 0.025% H2O2 on Platinum/CNT nanocomposite. The characterization of growth and long- term stability of NBs has been successfully carried out. In our system, the long-term stability of oxygen NBs comes from supersaturation of oxygen molecules.

T-266 **DETECTING THE SUB-STATES OF GRATING SUPERHYDROPHOBIC SURFACES WITH NAKED EYES** **1293**

N. Yu and C.-J. Kim
University of California, Los Angeles, USA

We develop an observation strategy that reveals the sub-states of plastron on grating superhydrophobic surface to naked eyes. The results are confirmed by visualizing the meniscus with a microscope.

W-267 **THERMAL RESISTANCE CHANGE OF LIQUID CARBON DIOXIDE BASED ON NARROW SPACE EFFECT IN MICRO CHAMBER** **1296**

M. Toda[1], T. Yamagami[1], N. Inomata[1], T. Fujii[2], and T. Ono[1]
[1]*Tohoku University, JAPAN and*
[2]*National Institute of Advanced Industrial Science and Technology (AIST), JAPAN*

The micro fluidic chamber with narrow gap for high pressurized fluid has been designed and fabricated. The liquid CO_2 is injected into the gaps of 0.5 μm and 1.6 μm. Their thermal resistance changes have been evaluated changing the pressure and temperature. Hence, relating the effect of narrow gap the critical pressure of supercritical CO_2 is shifted to lower. This result indicates that the filled fluid in MEMS chamber can use a different physical property of the packaged fluid in narrow spaces.