

THE 31ST IEEE INTERNATIONAL CONFERENCE
ON MICRO ELECTRO MECHANICAL SYSTEMS



★ MEMS 2018 ★

BELFAST ★
NORTHERN IRELAND

21-25 JANUARY 2018

FINAL PROGRAM

CONFERENCE CHAIRS:

Michel Despont CSEM, SWITZERLAND

Jens Duerée Dublin City University, IRELAND

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SUNDAY 21 JANUARY

17:00 - 19:00	Registration (Belfast Waterfront)
17:00 - 19:00	Wine & Cheese Welcome Reception (Belfast City Hall)

MONDAY 22 JANUARY

08:00 - 08:30	Welcome Address Conference Chairs: Michel Despont & Jens Duerée
08:30 - 08:50	<ul style="list-style-type: none"> • IEEE Fellows Recognition in the Field of MEMS/NEMS • IEEE Electron Devices Society Robert Bosch Micro and Nano Electro Mechanical Systems Award Recipient Pasqualina M. Sarro <i>Delft University of Technology, THE NETHERLANDS</i>
08:50 - 09:35	Plenary Speaker I <i>Jonathan M. Cooper, University of Glasgow, UK</i>
09:35 - 10:20	Session I - Biosensors
10:20 - 10:50	Break and Exhibit Inspection
10:50 - 12:05	Session II - Optical MEMS
12:05 - 13:30	Grab & Go Lunch and Exhibit Inspection
13:30 - 14:30	Session III - Fabrication
14:30 - 16:30	Poster/Oral Session I (Refreshments will be served at 16:00)
16:30 - 16:35	Announcements
16:35 - 17:50	Session IV - Implantable & Wearable Medical Devices
17:50	Adjourn for the Day

TUESDAY 23 JANUARY

08:30 - 09:15	Plenary Speaker II <i>Matthias Steffen, IBM Research Center, USA</i>
09:15 - 10:15	Session V - Resonators
10:15 - 10:45	Break and Exhibit Inspection
10:45 - 12:00	Session VI - Biofabrication
12:00 - 12:15	MEMS 2019 Announcement
12:15 - 13:15	Grab & Go Lunch and Exhibit Inspection
13:15 - 14:30	Session VII - Inertial
14:30 - 16:30	Poster/Oral Session II (Refreshments will be served at 16:00)
16:30 - 17:45	Session VIII - Cells
17:45	Adjourn for the Day

WEDNESDAY 24 JANUARY

08:30 - 09:15	Plenary Speaker III <i>Hiroyuki Fujita, University of Tokyo, JAPAN</i>	
09:15 - 10:00	Session IX - Materials & Fabrication for Microfluidics	
10:00 - 10:30	Break and Exhibit Inspection	
10:30 - 11:45	Session X - Vibrating RF MEMS	
11:45 - 13:00	Grab & Go Lunch and Exhibit Inspection	
13:00 - 14:00	Session XIa - Electrical & Optical Biointerfaces	Session XIb - Actuators & Power MEMS
14:00 - 16:00	Poster/Oral Session III (Refreshments will be served at 15:30)	
16:00 - 17:00	Session XIIa - Environmental Sensing	Session XIIb - Energy Harvesting
17:00	Adjourn for the Day	
18:00 - 22:30	Conference Banquet - Titanic Belfast	

THURSDAY 25 JANUARY

08:30 - 09:15	Plenary Speaker IV <i>Franz Laermer, Robert Bosch GmbH, GERMANY</i>	
09:15 - 10:15	Session XIII - Acoustic MEMS	
10:15 - 10:45	Break and Exhibit Inspection	
10:45 - 11:45	Session XIV - Droplets	
11:45 - 12:00	Award Ceremony and Final Remarks	
12:00	Conference Adjourns	



LEVEL 1



GROUND FLOOR



Meeting Room Locations

Floor Plan Legend

- Plenary Sessions Auditorium
- Concurrent Sessions a Auditorium
- Concurrent Sessions b Studio
- Poster Sessions Hall 1 and Hall 2
- Exhibits Hall 1 and Hall 2
- Award Presentations Auditorium
- Breaks Hall 1 and Hall 2
- Grab & Go Lunch Distribution Hall 1 and Hall 2
- Lunch Seating Bar 1
- Cloak Room Foyer

- 1
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Plenary Speakers

Monday 22 January

08:50 - 09:35 | Jonathan M. Cooper, *University of Glasgow, UK*

Tuesday 23 January

08:30 - 09:15 | Matthias Steffen, *IBM Research Center, USA*

Wednesday 24 January

08:30 - 09:15 | Hiroyuki Fujita, *University of Tokyo, JAPAN*

Thursday 25 January

08:30 - 09:15 | Franz Laermer, *Robert Bosch GmbH, GERMANY*

Oral Sessions

Oral sessions will be held in the Auditorium, with the Wednesday parallel concurrent sessions in the Studio. See floor plan on page 3.

Poster/Oral Sessions

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

All poster papers are listed in this program by topic category with their assigned number starting on page 30.

Session I	Session II
Monday 22 January 14:30 – 16:30	Tuesday 23 January 14:30 – 16:30
Poster/Oral Presentation 1 – 15:00	Poster/Oral Presentation 1 – 15:00
Poster/Oral Presentation 2 – 15:30	Poster/Oral Presentation 2 – 15:30
Poster/Oral Presentation 3 – 16:00	Poster/Oral Presentation 3 – 16:00
Session III	
Wednesday 24 January 14:00 – 16:00	
Poster/Oral Presentation 1 – 14:30	
Poster/Oral Presentation 2 – 15:00	
Poster/Oral Presentation 3 – 15:30	

Guide to Understanding Poster Numbering

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

Poster number: **M-130**

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

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

The second character (i.e. **130**) is the poster board position on the floor plan.

Outstanding Student Paper Award Finalists

Award Nominees are indicated with an * above the paper title in the program and on the poster board number.

★ MEMS 2018 ★

**ROBERT BOSCH
AWARD RECIPIENT**



THE 2018
IEEE
Robert Bosch

MICRO and NANO ELECTRO MECHANICAL SYSTEMS
AWARD

The Robert Bosch Micro and Nano Electro Mechanical Systems Award was established by the IEEE Electron Devices Society in 2014 to recognize and honor advances in the invention, design, and/or fabrication of micro- or nano- electromechanical systems and/or devices. The 2018 Bosch Award will be presented on Monday 22 January at 08:30.

Pasqualina M. Sarro

For pioneering contributions in novel materials, material integration and innovations in MEMS and strong commitment to education and technology transfer.

Lina (P.M.) Sarro received the Laurea degree (cum laude) in solid-states physics from the University of Naples, Italy, in 1980. From 1981 to 1983, she was a post-doctoral fellow in the Photovoltaic Research Group of the Division of Engineering at Brown University, Rhode Island, U.S.A. In 1987 she received a PhD in Electrical Engineering from the Delft University of Technology, the Netherlands, and then joined the EE Faculty to establish and lead research on silicon micromachining, integrated sensor, MEMS and material processing. In 2001 she was appointed Antoni van Leeuwenhoek Full Professor for research merits. Her main research interests are in novel materials and

structures for MEMS and NEMS to be applied in health, automotive, environmental applications and scientific instrumentation. She has (co)-authored more than 500 publications. She is member of the International Steering Committee of Eurosensors, Transducers and IEEE MEMS and acted as General Chair and Technical Program Committee Chair several times for all major international conferences in the field of sensors, MEMS and microsystems. She is associate editor for the IEEE Journal of Microelectromechanical Systems and has been associate editor (2006 2009) for IEEE Sensors Journal. She serves on various international advisory boards and panels for research. She is an IEEE Fellow, an (elected) member of the KNAW (Royal Netherlands Academy of Sciences), Knight in the Order of the Dutch Lion and Knight in the Order of the Italian Star.



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

SUNDAY 21 JANUARY

17:00 -
19:00

Registration and Wine & Cheese Welcome Reception

MONDAY 22 JANUARY

Welcome Address

Auditorium, Ground & Level 1

08:00 Visit Belfast

08:05 MEMS 2018 Conference Chairs

Michel Despont, *CSEM, SWITZERLAND*

Jens Ducreé, *Dublin City University, IRELAND*

08:30

- IEEE Fellows Recognition in the Field of MEMS/NEMS
- IEEE Electron Devices Society Robert Bosch Micro and Nano Electro Mechanical Systems Award Recipient

Pasqualina M. Sarro

Delft University of Technology, THE NETHERLANDS

Plenary Speaker I

Session Chair:

J. Ducreé, *Dublin City, IRELAND*

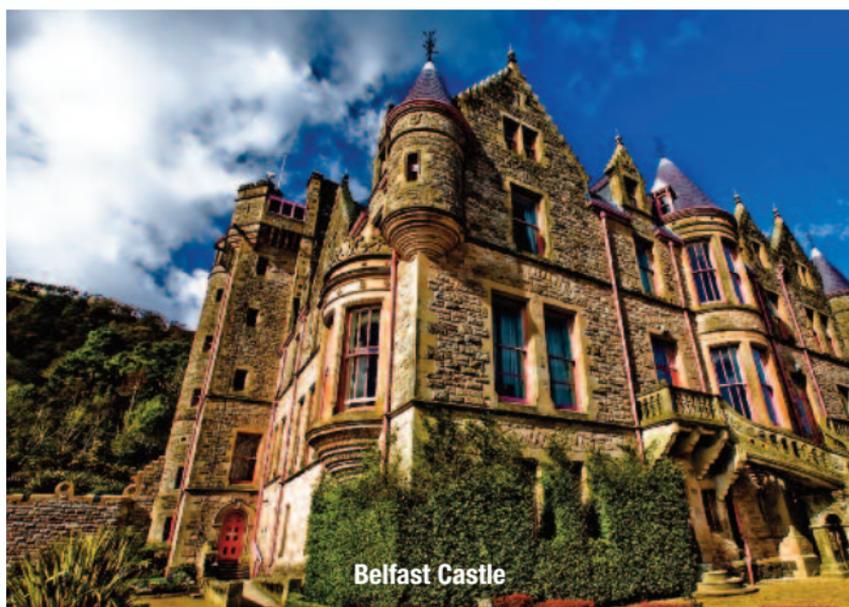
Auditorium, Ground & Level 1

08:50 MICROSTRUCTURES TO SHAPE ACOUSTIC FIELDS AND CREATE COMPLEX MICROFLUIDIC FLOWS

Jonathan M. Cooper

University of Glasgow, UK

Microfluidics and Lab-Chip technologies are synonymous with the movement of fluids on or around microstructured surfaces, including channels. To better control the nature of the acoustic field when using surface acoustic waves (SAWs), we have introduced the concept of using frequency dependent periodic arrays known as phononic crystals within microfluidics. In doing so, we have enabled waveguides, reflectors, bandgaps and lenses, that shape the ultrasonic field and create new fluid flows.



Belfast Castle

Session I – Biosensors**Session Chairs:**K. Cheung, *University of British Columbia, CANADA*T. Cui, *University of Minnesota, USA***Auditorium, Ground & Level 1****09:35 AWARD NOMINEE*****HANDHELD NANOPORE-BASED BIOSENSING DEVICE**Y. Izawa^{1,2}, T. Osaki², K. Kamiya², S. Fujii², N. Misawa²,
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 CONTAMINANTSR.R.G. Soares^{1,2}, D.R. Santos^{1,2}, I.F. Pinto^{1,2}, A.M. Azevedo²,
M.R. Aires-Barros², V. Chu¹, 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 PLATFORMB. 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**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 NODEV. 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 ARRAYSY. Wang¹, G. Zhou², K. Yu³, and M.C. Wu¹¹*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 3.2×3.1 mm² 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 6 μ s.

11:35 A HIGHLY MINIATURIZED SINGLE-CHIP MOEMS SCANNER FOR ALL-IN-ONE IMAGING SOLUTIONA. Jovic¹, T. Uto², K. Hei¹, J. Sancho³, N. Sanchez³, K. Zinoviev⁴, J.L. Rubio³, E. Margallo³, G. Pandraud¹, and P.M. Sarro¹¹*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.

Session II - Optical MEMS (continued)**Auditorium, Ground & Level 1****11:50 RESPONSIVITY ENHANCEMENT OF CMOS-MEMS THERMOELECTRIC INFRARED SENSOR BY HEAT TRANSDUCTION ABSORBER DESIGN**T.-W. Shen¹, Y.-C. Lee¹, K.-C. Chang², and W. Fang¹¹*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 and Exhibit Inspection**Session III – Fabrication****Session Chairs:**K. Kurabayashi, *University of Michigan, USA*X. Li, *Chinese Academy of Sciences, CHINA***Auditorium, Ground & Level 1****13:30 MATERIAL-INDEPENDENT NANOWIRE-TRANSFER METHOD BASED ON MECHANICAL INTERLOCKING FOR HIGH PERFORMANCE FLEXIBLE DEVICES**M.-H. Seo¹, S.H. Park², J.-Y. Yoo¹, S.K. Lim², M.-S. Jo¹, K.-W. Choi¹, J.-S. Lee¹, S.-B. Kim¹, and J.-B. Yoon¹¹*Korea Advanced Institute of Science and Technology (KAIST), KOREA and* ²*National Nanofab Center (NNFC), KOREA*

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 NO₂ using 0.6 V heater-bias.

13:45 OPTICAL 3D μ -PRINTING OF POLYTETRAFLUOROETHYLENE (PTFE) MICROSTRUCTURES

Y. Zhang, M. Yin, O. Xia, A.P. Zhang, and H.-Y. Tam

Hong Kong Polytechnic University, HONG KONG

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.

Session III – Fabrication (continued)

Auditorium, Ground & Level 1

14:00 REUSABLE, FLEXIBLE, AND LOW COST PARYLENE-C/CR SHADOW MASK FOR MICROPATTERNING ON ARBITRARY SURFACES

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

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 reach 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.

14:15 MONOLITHICALLY FABRICATED PERFORATED POLYIMIDE SEPARATOR FOR A PLANAR LIPID BILAYER DEVICE

T. Osaki¹, M. Kaneko², K. Araki², H. Uehara², T. Ura³, H. Hirata³, K. Kamiya¹, S. Fujii¹, N. Misawa¹, and S. Takeuchi^{1,4}

¹*Kanagawa Institute of Industrial Science and Technology, JAPAN,*

²*RAYTECH, INC., JAPAN,* ³*Toray Engineering Co., Ltd., JAPAN,* and

⁴*University of Tokyo, JAPAN*

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.

Poster/Oral Session I (Refreshments will be served at 16:00)

14:30 Poster presentations are listed by topic category with their assigned number starting on page 30.

Announcements

Auditorium, Ground & Level 1

16:30 Announcements



First arch of the stone built Queen Victoria bridge over the river Lagan in Belfast.

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

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

Y.-T. Chen¹, C.-C. Yeh¹, M.-X. Xu¹, F. Tan¹, Y.-J. Chen², and Y.-J. Yang¹
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

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 5 μ m-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

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.

Session IV - Implantable & Wearable Medical Devices (continued)

Auditorium, Ground & Level 1

17:35 PHOTOTHERAPEUTIC CONTACT LENS FOR DIABETIC RETINOPATHYC.A. Cook¹, J.C. Martinez-Camarillo², Q. Yang², N.E. Scianmarello¹,
M.S. Humayun², and Y.-C. Tai¹¹California Institute of Technology, USA and²University 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 O₂ 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

View of Belfast with the river Lagan

TUESDAY 23 JANUARY

Plenary Speaker II

Session Chair:

M. Despont, *CSEM, SWITZERLAND*

Auditorium, Ground & Level 1

08:30 EARLY APPLICATIONS OF QUANTUM COMPUTERS

Matthias Steffen*IBM Research Center, USA*

Quantum computing is a potentially revolutionary technology because it could be used to fundamentally speed up certain calculations by leveraging delicate quantum mechanical effects. Building a practical quantum computer is a tremendous technical challenge, but much progress has been made, in particular using superconducting qubits. Today it is possible to solve some small problems related to quantum chemistry using tens of qubits.

Session V – Resonators

Session Chairs:

S.-S. Li, *National Tsing Hua University, TAIWAN*M. Rinaldi, *Northeastern University, USA*

Auditorium, Ground & Level 1

09:15 **AWARD NOMINEE*****A MICRO RESONANT ELECTROMETER WITH 9-ELECTRON CHARGE RESOLUTION IN ROOM TEMPERATURE**

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 $9.21e/\sqrt{\text{Hz}}$.

09:30 **TOP ELECTRODE SHAPING FOR HARNESSING HIGH COUPLING IN THICKNESS SHEAR MODE RESONATORS IN Y-CUT LITHIUM NIOBATE THIN FILMS**

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 kt_2 of $\sim 37\%$, which is matching with 3D COMSOL FEA simulations. Such high coupling resonators could find application in reconfigurable RF systems.

Session V – Resonators (continued)

Auditorium, Ground & Level 1

09:45 GATED CMOS-MEMS THERMAL-PIEZORESISTIVE OSCILLATOR-BASED PM2.5 SENSOR WITH ENHANCED PARTICLE COLLECTION EFFICIENCYT.-Y. Liu¹, C.A. Sung¹, C.-H. Weng², C.-C. Chu³,
A.-A. Zope¹, G. Pillai¹, and S.-S. Li¹¹Nation Tsing Hua University, TAIWAN, ²TXC Corporation, TAIWAN, and
³Taiwan 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 (~0.6µm) size aerosol on the proof-mass. The proposed sensor can detect aerosol concentration within a range of 50 ug/m³ to 200 ug/m³.

10:00 TRANSPARENT GRAPHENE-AZO/ZNO/GLASS SURFACE ACOUSTIC WAVE DEVICE APPLICATIONS FOR ELECTRONICS AND LAB-ON-A-CHIPJ. 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 SCAFFOLDW. 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 MEMRISTORSG. Kook¹, S. Jeong², M. Kim¹, S. Lee¹, H. Kim¹, N. Choi², and H.J. Lee¹¹Korea Advanced Institute of Science and Technology (KAIST), KOREA and
²Korea 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.

Session VI – Biofabrication (continued)

Auditorium, Ground & Level 1

11:15 PROTEIN LEGO: 3D BIONANOARCHITECTURES WITH SHAPES AND FUNCTIONS ON DEMANDJ. Jiang¹, S. Zhang², L. Sun^{1,3}, N. Qin¹, Z. Zhou^{1,3}, and H. Tao^{1,2,3}¹Chinese Academy of Sciences, CHINA,²University of Texas, Austin, USA, and³University 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 ARRAYY. Iwata¹, S. Miyashita², and E. Iwase¹¹Waseda University, JAPAN and ²University 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 MECHANISMJ. Lim¹, S. Lee², D.-J. Won¹, I.H. Choi³, and J. Kim¹¹Pohang University of Science and Technology (POSTECH), KOREA,²Dong-Eui University, KOREA, and ³Samsung 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 AnnouncementShoji 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 AWARD NOMINEE***
100 nT/√Hz, 0.5 mm² MONOLITHIC, MULTI-LOOP LOW-POWER 3-AXIS MEMS MAGNETOMETER
 C.R. Marra¹, G. Laghi¹, M. Gadola¹, G. Gattere², D. Paci², A. Tocchio², and G. Langfelder¹
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 AWARD NOMINEE***
A HIGH-PERFORMANCE SINGLE-CHIP TIMING AND INERTIAL MEASUREMENT UNIT WITH ROBUST MODE-MATCHED GYROSCOPES
 H. Wen¹, A. Daruwalla¹, Y. Jeong², P. Gupta¹, J. Choi¹, C.-S. Liu¹, and F. Ayazi¹
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**
 F. Maspero^{1,2}, S. Delachanal^{1,2}, A. Berthelot^{1,2}, L. Joet^{1,2}, G. Langfelder³, 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**
 W.T. Pike¹, I.M. Standley², S.B. Calcutt³, and A.G. Mukherjee¹
¹*Imperial College London, UK*, ²*Kinematics, 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.

Session VII – Inertial (continued)

Auditorium, Ground & Level 1

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

C.R. Marra¹, F.M. Ferrari¹, S. Karman¹, A. Tocchio²,
F. Rizzini², and G. Langfelder¹

¹Politecnico di Milano, ITALY and ²STMicroelectronics, 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.

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

14:30 Poster presentations are listed by topic category with their assigned number starting on page 30.

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 AWARD NOMINEE* ON-CHIP PLATELET PRODUCTION USING THREE DIMENSIONAL MICROCHANNEL

H. Kumon¹, S. Sakuma¹, S. Nakamura², K. Eto², and F. Arai¹

¹Nagoya University, JAPAN and ²Kyoto 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

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.

Session VIII – Cells (continued)

Auditorium, Ground & Level 1

- 17:00 AWARD NOMINEE***
**LOAD DEPENDENCY MEASUREMENT OF IPS CELL-DERIVED
 CARDIOMYOCYTES' CONTRACTION**
 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 iPSC 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**
 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**
 H. Ito¹, C.-H.D. Tsai², and M. Kaneko¹
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**



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WEDNESDAY 24 JANUARY

Plenary Speaker III

Session Chair:

J. Ducreé, *Dublin City University, IRELAND*

Auditorium, Ground & Level 1

08:30 FROM WOW TO WORK: CYCLES OF MEMS EVOLUTION

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 Autònoma 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

J. Seo¹, J.-B. Lee², S.K. Chung¹, and D. Kim³

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

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

K. Kamiya¹, T. Osaki^{1,2}, S. Fujii¹, N. Misawa¹, 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 **AWARD NOMINEE*****MAGNETIC-FREE RADIO FREQUENCY CIRCULATOR BASED ON SPATIOTEMPORAL COMMUTATION OF MEMS RESONATORS**Y. Yu¹, G. Michetti¹, A. Kord², D. Sounas², F.V. Pop¹, P. Kulik¹,
M. Pirro¹, Z. Qian¹, A. Alu², and M. Rinaldi¹¹*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^2 .Q SILICON FIN BULK ACOUSTIC RESONATORS (FinBAR) FOR CHIP-SCALE MULTI-BAND SPECTRUM ANALYSIS**

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^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**

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**

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 Q_u 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.

Session X - Vibrating RF MEMS (continued)

Auditorium, Ground & Level 1

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

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**

W. Khan¹, Y. Jia², F. Madi¹, A. Weber¹, M. Ghovanloo², and W. Li¹
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 μ LED 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 μ LED. *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**

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 mm²) 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**

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.

Session XIa - Electrical & Optical Biointerfaces (continued)

Auditorium, Ground & Level 1

- 13:45 AWARD NOMINEE***
STRETCHABLE MICRO-DOUGHNUTS KIRIGAMI BIOPROBE
 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 minimized. 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 AWARD NOMINEE***
**INDEPENDENT ACTUATION AND MASTER-SLAVE CONTROL OF
 MULTIPLE MICRO MAGNETIC ACTUATORS**
 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 position 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**
 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**
 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.

Session XIb - Actuators & Power MEMS (continued)

Studio, Ground & Level 1

13:45 REDUCING THE CONTACT TIME OF DROPLET IMPACT BY ACTIVE CONTROL OF SUBSTRATE MOTION

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.

Poster/Oral Session III (Refreshments will be served at 15:30)

14:00 Poster presentations are listed by topic category with their assigned number starting on page 30.

Session XIIIa - 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

J. Xu¹, M. Bertke¹, X. Li¹, H. Mu², F. Yu¹, A. Schmidt¹,
A. Bakin¹, and E. Peiner¹

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 microcantilever 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 AWARD NOMINEE* SELECTIVE SENSING OF CHEMICAL VAPORS USING PHASE SPECTRA DETECTION ON CVD GRAPHENE FET

H. Liu^{1,2}, Y. Chu^{1,2}, Y. Liu², T. Hayasaka², N. Joshi²,
Y. Cui², X. Wang¹, Z. You¹, 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.

Session XIIa - Environmental Sensing (continued)

Auditorium, Ground & Level 1

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

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

T.V.P. Schut¹, D. Alveringh¹, W. Sparreboom², J. Groenesteijn²,
R.J. Wiegerink¹, and J.C. Lötters²

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

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 $34.9 \text{ mW} \cdot \text{g}^{-2} \cdot \text{cm}^{-3}$ 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

Y. Jia^{1,2}, S. Du¹, E. Arroyo¹, and A.A. Seshia¹

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.

Session XIIb - Energy Harvesting (continued)**Studio, Ground & Level 1****16:30 LOW-PROFILE ROTATIONAL ELECTRET GENERATOR USING PRINT CIRCUIT BOARD FOR ENERGY HARVESTING FROM ARM SWING**

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 μ W 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

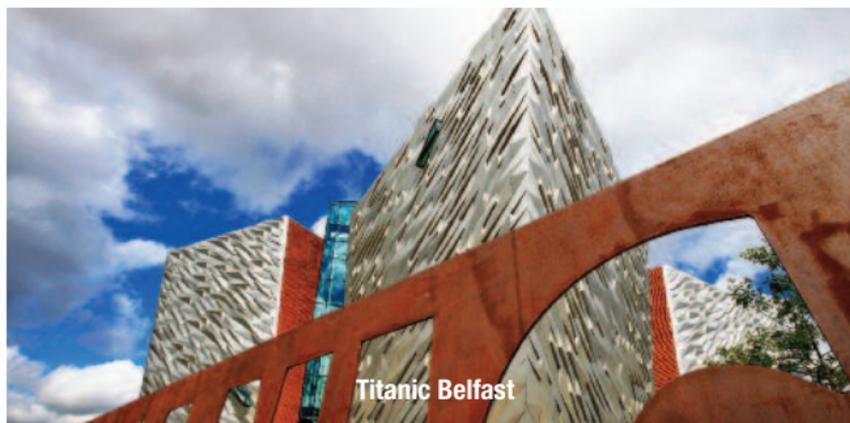
M. Salauddin, R.M. Toyabur, and J.Y. Park
Kwangwoon University, KOREA

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/m³ under a loading resistance of 700 Ω at 5Hz frequency and 0.5g acceleration.

17:00 Adjourn for the Day**Conference Banquet at Titanic Belfast****18:00 - 22:30**

Please join us Wednesday evening for the MEMS 2018 Conference banquet at Titanic Belfast. The evening will begin by exploring Titanic Belfast's interactive galleries. The multi-dimensional exhibit features special effects, full-scale reconstructions and innovative interactive features. Explore and travel to the depths of the ocean and uncover the true legend of Titanic, in the city where it all began. Enjoy a welcome drink after your tour in the atrium. Dinner service will begin at 20:00 in the Titanic Suite, inspired by RMS Titanic's opulent interiors and featuring a replica of the liner's Grand Staircase.

Please note that transportation will not be provided by the conference, however, Translink Belfast has generously provided travel cards that can be used on regional buses for the event. You will find yours included with your name badge and it will be good for 2 days of unlimited travel. Please check with your hotel front desk or the Translink Belfast website for directions and schedule.



THURSDAY 25 JANUARY
Plenary Speaker IV
Session Chair:

M. Despont, *CSEM, SWITZERLAND*
Auditorium, Ground & Level 1
08:30 MEMS AT BOSCH - INVENTED FOR LIFE
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

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 demonstrates how optical detection can provide greater stability.

09:30 FOCUSED ULTRASOUND TRANSDUCER WITH ELECTRICALLY CONTROLLABLE FOCAL LENGTH

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.

Session XIII - Acoustic MEMS (continued)

Auditorium, Ground & Level 1

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

H. Lhermet^{1,2}, T. Verdot^{1,2}, A. Berthelot^{1,2}, B. Desloges^{1,2}, and F. Souchon^{1,2}

¹Université Grenoble Alpes, FRANCE and ²CEA-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

Y. Zhang¹, R. Bauer¹, W.M. Whitmer², J.C. Jackson¹, J.F.C. Windmill¹, and D. Uttamchandani¹

¹University of Strathclyde, UK and ²University 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

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 $6 \times 10^{(-4)\%}$ 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

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.

Session XIV – Droplets (continued)

Auditorium, Ground & Level 1

- 11:15 AWARD NOMINEE***
SORT 'N MERGE: A DETERMINISTIC MICROFLUIDIC PLATFORM FOR CO-ENCAPSULATING DISTINCT PARTICLES IN MICRODROPLETS
 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**
 H. Yasuga¹, W. Guo², J. Hansson², T. Haraldsson²,
 N. Miki¹, and W. van der Wijngaart²
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 Outstanding Student Paper Awards and Final Remarks**
- 12:00 Conference Adjourns**



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Hall 1 and Hall 2, Level 1

MONDAY
14:30 - 16:30

TUESDAY
14:30 - 16:30

WEDNESDAY
14:00 - 16:00

TRACK/CLASSIFICATION

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

D. Blanchard¹, P.-M. Faure^{1,2}, S. Ihida¹, T. Kohno¹, H. Toshiyoshi¹, T. Levj^{1,2}, and A. Tixier-Mita²

¹University of Bordeaux, FRANCE and ²University 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

S. Fujii¹, N. Misawa¹, K. Kamiya¹, T. Osaki^{1,2}, and S. Takeuchi^{1,2}

¹Kanagawa Institute of Industrial Science and Technology, JAPAN and

²University 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

I.F. Pinto^{1,2}, D.R. Santos^{1,2}, C.R.F. Caneira¹, R.R.G. Soares^{1,2}, V. Chu¹, and J.P. Conde^{1,2}

¹Institute of Nanoscience and Nanotechnology, PORTUGAL and

²Universidade 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.

Biosensors and Bioreactors

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

S. Nagata¹, N. Kameshiro¹, D. Terutsuki², H. Mitsuno², T. Sakurai²,
K. Niitsu^{3,4}, K. Nakazato³, R. Kanzaki², and M. Ando¹
¹Hitachi, Ltd., JAPAN, ²University of Tokyo, JAPAN,
³Nagoya University, JAPAN, and
⁴Japan 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

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

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 electrically fused. We believe the method will be useful in artificial cell studies.

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

Y. Li^{1,2}, Y. Zhu¹, Z. Hao¹, C. Wang³, Z. Zhang¹, M. He², and Q. Lin¹
¹Columbia University, USA, ²Tsinghua University, CHINA, and
³Tianjin Normal University, CHINA

We develop a novel differential method for the label-free and undisturbed detection of 17 β -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 17 β -estradiol is realized.

Biosensors and Bioreactors

T-008 SIMULTANEOUS ELECTRICAL AND MECHANICAL CHARACTERIZATION OF SINGLE CELLS BY AN INTEGRATED DEVICE

Y. Takayama^{1,2,3}, G. Perret^{1,3}, M. Kumemura¹, C. Lagadec^{2,3},
S. Meignan^{2,3}, M. Ataka^{1,2}, H. Fujita¹, M.C. Tarhan^{1,2,3},
and D. Collard^{1,2,3}

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

³Centre Oscar Lambret, FRANCE

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.

W-009 DETECTION OF *E. COLI* IN A DIGITAL ASSAY

E. Iseri¹, S. Akay², and W. van der Wijngaart¹

¹KTH Royal Institute of Technology, SWEDEN and

²Ege University, TURKEY

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.

M-010 CELL-LADEN MICROPILLARS DETECT GASEOUS ODORANTS ON A LIQUID-AIR INTERFACE

Y. Hirata, Y. Morimoto, and S. Takeuchi

University of Tokyo, JAPAN

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

T-011 SIDEWALL ELECTRODE-CHAMBER FOR LIPID BILAYER FORMATION SUITABLE FOR RAPID ACCESS OF ODORS TO LIPID MEMBRANE

N. Misawa¹, S. Fujii¹, K. Kamiya¹, T. Osaki^{1,2}, and S. Takeuchi^{1,2}

¹Kanagawa Institute of Industrial Science and Technology, JAPAN and

²University of Tokyo, JAPAN

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.

Manufacturing for Bio- and Medical MEMS

W-012 THREE-BEAMS SPRING INTERCONNECTS FOR LONG-TERM HIGH DENSITY FLEXIBLE ELECTRODE ARRAYSS. Khan¹, J.S. Ordóñez², and T. Stieglitz¹¹University of Freiburg, GERMANY and ²Indigo Medical NV, BELGIUM

We report on the development and characterization of novel spring interconnects that overcome mechanical reliability issues of flexible electrode arrays. The spring comprises of three arcuate beams extending from a central junction to the outer annulus metal and allows microflex bonding. These interconnects reduce the warpage of the flexible arrays by mechanically decoupling the bulk material from the interconnects. The method allows reliable gasket-underfilling in high-density interconnections.

M-013 A MULTI WELL PLATE ORGAN-ON-CHIP (OOC) DEVICE FOR IN-VITRO CELL CULTURE STIMULATION AND MONITORINGN. Gaio¹, A. Waafi¹, M.L.H. Vlaming², E. Boschman³, P. Dijkstra⁴, P. Nacken², S.R. Braam², C. Boucsein⁵, P.M. Sarro¹, and R. Dekker^{1,6}¹Delft University of Technology, NETHERLANDS,²Ncardia, NETHERLANDS,³Boschman Technologies/APC, NETHERLANDS,⁴Philips Innovation Center, NETHERLANDS,⁵Multichannel System, GERMANY, and⁶Philips Research, NETHERLANDS

This work presents the first multi-well plate that simultaneously allows mechanical stimulation and electrical monitoring of multiple *in-vitro* cell cultures. Each well on the plate is equipped with an Organ-on-Chip (OoC) device consisting of a stretchable and low-impedance Microelectrode array (MEA).

T-014 A NOVEL METHOD TO TRANSFER POROUS PDMS MEMBRANES FOR HIGH THROUGHPUT ORGAN-ON-CHIP AND LAB-ON-CHIP ASSEMBLYW.F. Quirós-Solano^{1,4}, N. Gaio¹, C. Silvestri¹, Y.B. Arik², O.M.J.A. Stassen³, A.D. van der Meer², C.V.C. Bouten³, A. van den Berg², R. Dekker¹, and P.M. Sarro¹¹Delft University of Technology, NETHERLANDS,²University of Twente, NETHERLANDS,³Eindhoven University of Technology, NETHERLANDS, and⁴Instituto Tecnológico de Costa Rica, COSTA RICA

We present a novel method to easily and reliably transfer highly porous, large area, thin microfabricated Polydimethylsiloxane (PDMS) porous membranes on Lab-on-Chip (LOC) and Organ-on-Chip (OOC) devices. Using silicon as carrier substrate and a water-soluble sacrificial layer allows a simple and reproducible transfer of the membranes to any PDMS-based OOC/LOC.

W-015 TRANSENDOTHELIAL ELECTRICAL RESISTANCE (TEER) MEASUREMENT SYSTEM OF 3D TUBULAR VASCULAR CHANNEL

N. Mori, Y. Morimoto, and S. Takeuchi

University of Tokyo, JAPAN

We developed a system for measuring transendothelial electrical resistance (TEER) of 3D tubular vascular channel as an index of endothelial barrier integrity. By using electrodes integrated in a microfluidic device, TEER measurement of the vascular channel coated with endothelial cells (HUVECs) was achieved. Moreover, by perfusing the channel with culture medium, the influence of the perfusion on the TEER was measured during cultivation.

Manufacturing for Bio- and Medical MEMS

M-016 A DEVICE INTEGRATING MICRONEEDLE AND JIG OF PREVENTING NEEDLE BUCKLING/SKIN DEFORMATION INSPIRED BY MOSQUITO - 3D FABRICATION AND EXPERIMENT OF SKIN PUNCTURE/BLOOD SAMPLINGS. Aoyagi¹, M. Yamada¹, S. Yamamoto¹, T. Takahashi¹, M. Suzuki¹, R. Hosomi¹, K. Fukuaga¹, D. Uta², and T. Takazawa³¹Kansai University, JAPAN, ²Toyama University, JAPAN, and³Gunma University, JAPAN

A device integrating microneedle and jig is proposed and fabricated by 3D lithography, which is inspired by mosquito labium. A microneedle with thin plate-like holder is set inside a guiding slit of jig. With this slit, the needle can pierce the skin to its bottom. The constricted part of slit prevents the needle from moving out of central hole of jig, preventing its buckling. The surface of skirt-like bottom of jig is fixed to the skin surface, preventing the skin deformation.

T-017 DEVELOPMENT OF THIN FILM BASED FLEXIBLE PRESSURE SENSOR AND BIOMEDICAL APPLICATION TO REAL-TIME PRESSURE MONITORING DURING RADIOFREQUENCY ABLATION

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

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

Radiofrequency ablation (RFA) is the promising method to treat cancer. However, this method still has the safety problem named steam popping. Steam popping denotes the explosion of the ablated tissue due to its high inner pressure from vaporized intercellular liquid. To monitor this phenomenon, we developed flexible, biocompatible and temperature compensated pressure sensor which is used during radiofrequency ablation (RFA) procedure.

W-018 MICROFLUIDIC FORMATION OF MULTI CORE-SHELL CELL-LADEN FIBERS

F. Ozawa and S. Takeuchi

University of Tokyo, JAPAN

We develop a multi-core shell hydrogel fiber encapsulating multi type cell with lotus root structure. The cell distribution *in vivo* is extremely complex, and spatially anisotropic or heterogeneous tissues are widespread. We here took an approach to fabricate multi-core shell fibers with controlled heterogeneous cell-laden structures for construction of macro-size tissue.

M-019 PNEUMATICALLY DRIVEN PDMS MICROPILLARS FOR THE INVESTIGATION OF CELL-CELL INTERACTION

K. Furuike, A. Shima, Y. Morimoto, and S. Takeuchi

University of Tokyo, JAPAN

We propose a pneumatic PDMS actuator for the investigation of intercellular communication at a single cell level. Cells usually organize large and complex networks. For a detailed investigation of intercellular communication, downsizing the network is important. In this device, cell-sized pillars are actuated by air pressure so that the adjacent cells on the pillars contact each other at an arbitrary timing. This actuator is also able to apply mechanical stretch to the cells after cell coupling.

Bio and Medical MEMS

Materials for Bio- and Medical MEMS

T-020 DISSOLVABLE MATERIAL-SHEATHED MICRONEEDLE-ELECTRODE DEVICE SLID INTO A NARROW GAP OF THE BRAIN

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

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.

W-021 ULTRA-THIN LPCVD SILICON CARBIDE MEMBRANE: A PROMISING PLATFORM FOR BIO-CELL CULTURING

T.-K. Nguyen, H.-P. Phan, H. Kamble, R. Vadivelu, T. Dinh,
A. Iacopi, G. Walker, L. Hold, N.-T. Nguyen, and D.V. Dao
Griffith University, AUSTRALIA

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%.

M-022 A NOVEL POTENTIAL MODULATED AMINO ACID SENSING CHIP MODIFIED BY MXENE FOR TOTAL INTERNAL REFLECTION IMAGING ELLIPSOMETRY BIOSENSOR

W. Liu, S. Xu, B. Hu, and X. Wang
Tsinghua University, CHINA

We develop a potential modulated amino acid sensing chip by modifying Ti_3C_2Tx , 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.

T-023 NOVEL CIRCULAR MICROCHANNELS FABRICATION METHOD FOR ARTERY THROMBOSIS INVESTIGATION

T.-Q. Nguyen¹, S.-Y. Lee², and W.-T. Park¹
¹*Seoul National University of Science and Technology, KOREA* and
²*Korea Institute of Science and Technology (KIST), KOREA*

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.

Materials for Bio- and Medical MEMS

W-024 FLUORESCENT MICROPARTICLES FOR CONTINUOUS GLUCOSE MONITORING INSIDE 3D TISSUE CONSTRUCTS

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

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.)

M-025 POLLEN INSPIRED MICROSCRAPERS FOR MINIMALLY INVASIVE STATISTICAL TISSUE SAMPLING

A. Abramson, E. Gultepe, S. Pandey, and D.H. Gracias
Johns Hopkins University, USA

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.

T-026 A CALORIMETRIC FLOW SENSOR FOR ULTRA-LOW FLOW APPLICATIONS USING ELECTROCHEMICAL IMPEDANCE

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

We developed, fabricated, and tested a novel calorimetric flow sensor which uses high-frequency electrochemical impedance to measure temperature changes. Ultra-low flow velocities $\pm 200 \mu\text{m/s}$ are measurable with a 2σ LOD of $19.1 \mu\text{m/s}$, 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.

W-027 LONG, BIOCOMPATIBLE AND HIGHLY FLEXIBLE COLD ATMOSPHERIC MICROPLASMA JET DEVICE FOR PRECISE ENDOSCOPIC THERAPIES

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

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.

M-028 A MAGNETIC, MICRO-SPRING-SUSPENDED SYSTEM FOR THE SAFE ELECTRICAL INTERCONNECTION OF NEURAL IMPLANTS

K. Hoch, F. Pothof, F. Becker, O. Paul, and P. Ruther
University of Freiburg, GERMANY

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 .

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

- T-029 LIQUID METAL ELECTRODES MICRO-ARRAY FOR ELECTRICAL STIMULATION VIA DIRECT CONTACT**
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 50 μ m. 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**
X.C. Ong¹, W.-C. Huang², I.S. Kwon¹, C. Gopinath³, H. Wu¹, L.E. Fisher³, R.A. Gaunt³, C.J. Bettinger¹, and G.K. Fedder¹
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**
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**
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- μ m-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.

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

W-033 MEASUREMENT OF BOTH VISCOUS AND ELASTIC CONSTANTS OF A RED BLOOD CELL IN A MICROCHANNELA. Kirimoto¹, H. Ito¹, C.-H.D. Tsai², and M. Kaneko¹¹Osaka University, JAPAN and ²National 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 DETECTIONN. Song¹, P. Xie², W. Shen¹, M. Javanmard², and M.G. Allen¹¹University of Pennsylvania, USA and ²Rutgers 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 DIAGNOSTICSH. Ding^{1,2}, S. Akhbari³, B.E. Eovino², Y. Wu^{2,3}, J. Xie¹, and L. Lin^{2,3}¹Zhejiang University, CHINA, ²University of California, Berkeley, USA, and³Tsinghua-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 DELIVERYD. Huang¹, D. Zhao¹, Y. Huang², Z. Liang¹, and Z. Li¹¹Peking University, CHINA and ²Beijing 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.

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

M-037 SELF-POWERED PULSE SENSORS WITH HIGH SENSITIVITY TO REVEAL SINUS ARRHYTHMIAY. Chu^{1,2}, J. Zhong², H. Liu^{1,2}, N. Liu², Y. Song², X. Zang²,
Y. Dong¹, X. Wang¹, and L. Lin^{1,2}¹Tsinghua-Berkeley Shenzhen Institute, CHINA and²University 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.

T-038 MICRONEEDLE-BASED SYSTEM FOR MINIMALLY INVASIVE CONTINUOUS MONITORING OF GLUCOSE IN THE DERMAL INTERSTITIAL FLUID

F. Ribet, G. Stemme, and N. Roxhed

KTH Royal Institute of Technology, SWEDEN

We present a minimally invasive continuous glucose monitoring system, consisting in a hollow silicon microneedle and an ultra-miniaturized electrochemical sensor inserted in its lumen. The system is 50-fold smaller than state of the art commercial products, enabling monitoring in the dermis, together with a less invasive insertion procedure. Passive interstitial fluid filling of the lumen by capillary action is achieved. The ideal sensor position provides minimal delay in tracking glycaemia.

W-039 IN VITRO AND IN VIVO TESTS OF NANOPOROUS MEMBRANE COATED WITH BIOCOMPATIBLE FLUORINE-DOPED DIAMOND-LIKE CARBON FOR HEMOFILTRATION TREATMENTT. Ota¹, M. Nakayama¹, Y. Kanno², T. Suzuki¹, and N. Miki¹¹Keio University, JAPAN and ²Tokyo Medical University, JAPAN

We experimentally investigated the blood hemofiltration (HF) capacity of a nanoporous dialysis membrane (poly(ether sulfone), PES) whose surface was modified with fluorine-doped diamond-like carbon (f-DLC) without clogging the nanoporous. *In vitro* experiment revealed that the modified membrane successfully exhibited water permeability of one-tenth of untreated. *In vivo* experiments with HF device using SD rats were conducted for the first time, and proved that f-DLC coating can be used for HF.

M-040 SEEING ON THE SURFACE OF EYEBALLS: NON-INVASIVE VISUAL SUBSTITUTION WITH THE ELECTRO-TACTILE DEVICE ON CORNEAY. Zhang^{1,2}, Y. Chen³, B. Zhao¹, Y. Hu⁴, and Z. Li¹¹Peking University, CHINA, ²Chinese Academy of Sciences, CHINA,³Beijing Tian Tan Hospital, Capital Medical University, CHINA, and⁴Beijing Tsinghua Changgung Hospital, CHINA

In this work, using tactile sensation of the cornea of the blind, a novel visual substitution method and system were proposed for visual reconstruction. Unlike previous tactile-visual substitution, the electro-tactile device attaches on the cornea of the blind, a "useless" organ for a blind, and will not impede intrinsic function of human body. The *in vivo* experiments show the sensible threshold voltage of cornea is much lower than the tactile-visual substitution system previously reported.

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

- T-041 A HIGH-RESOLUTION LENSLESS FLUORESCENCE IMAGING SYSTEM USING MEMBRANE DEFLECTION FOR REDUCING GAP BETWEEN SAMPLES AND IMAGE SENSOR**
H. Shin^{1,2}, W. Choi¹, G.-W. Yoon³, S. Seo¹, N. Choi^{1,2}, J.-B. Yoon³, and I.-J. Cho^{1,2}
¹Korea Institute of Science and Technology (KIST), KOREA,
²Korea University of Science and Technology, KOREA, and
³Korea Advanced Institute of Science and Technology (KAIST), KOREA

We report on a high-resolution lensless fluorescence imaging system using membrane deflection. The presented system applied the principle of the total internal reflection of excitation light inside a PDMS chip to minimize excitation light to sensor array. We integrated a thin PDMS membrane as a flexible deflector. Thus, we achieved minimum distance of 7.5 μm between fluorescent samples and a sensor array. This reduced gap directly corresponds to a resolution as high as $\sim 7.5 \mu\text{m}$, based on PSF.

- W-042 PATTERN PROJECTOR USING SUPERPOSITION OF DOUBLE MICROLENS ARRAYS FOR HYBRID 3D ENDOSCOPE**
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 thermoplastic 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**
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**
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-SLITSK. Fujimoto¹, R. Iino², M. Tomishige³, H. Shintaku¹,
H. Kotera¹, and R. Yokokawa¹¹Kyoto University, JAPAN, ²Institute for Molecular Science, JAPAN, and ³Aoyama 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 TISSUESY. Kubota¹, R. Numano¹, A. Goryu², H. Sawahata¹, S. Yamagiwa¹,
M. Matsuo¹, M. Ishida¹, and T. Kawano¹¹Toyohashi University of Technology, JAPAN and
²Toshiba 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 NANOLITHOGRAPHYW. Lee¹, S. Zhang¹, Z. Zhou², and T.H. Tao¹¹University of Texas, Austin, USA and²Shanghai 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 NANO-ELECTRONICALLY BARCODED PARTICLES ENABLED THROUGH MACHINE LEARNING ANALYSIS

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.

Nanobiotechnology

M-049 A HIGHLY SENSITIVE MERCURY (II) ION DETECTION BASED ON NANOFUIDIC CRYSTAL SENSINGY. Wu¹, J. Gong², Y. Jin¹, and W. Wang¹¹Peking University, CHINA and ²National Institute for Communicable Disease Control and Prevention, CHINA

Water pollution caused by Hg²⁺ is a challenging environmental issue and the Hg²⁺ detection attracts the extensive attention. Here, based on the high-consistent nanofluidic crystal sensing chip, an electrical read-out Hg²⁺ detection with an ultra-high sensitive (around 1 pM) was developed. Differs from traditional methods, most of which rely on complicated optical systems, the Hg²⁺ 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 APPLICATIONSW. Hong¹, L. Tang^{1,2}, W. Sun¹, B. Yang¹, X. Chen¹, X. Wang¹, and J. Liu¹¹Shanghai Jiao Tong University, CHINA and ²MicroPort 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 MONITORINGT. Sun¹, B.B. Han¹, C.L. Sun^{1,2}, L.Y.L. Wong¹, and A.Y.D. Gu¹¹Agency for Science, Technology and Research (A*STAR), SINGAPORE and ²Wuhan 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 SENSORSK. Watanabe¹, M. Kinoshita¹, T. Mine¹, M. Morishita¹, K. Fujisaki¹, R. Matsui¹, M. Sagawa¹, S. Machida¹, H. Oba², Y. Sugiyama², N. Sugii¹, D. Ryuzaki¹, H. Kurata¹, and S. Nishimura¹¹Hitachi, Ltd., JAPAN and ²Hitachi 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

**T-053 TOWARDS SUB-MICROSCALE LIQUID METAL PATTERNS:
CASCADE PHASE CHANGE MEDIATED PICK-N-PLACE
TRANSFER OF LIQUID METALS PRINTED AND
STRETCHED OVER A FLEXIBLE SUBSTRATE**D. Kim¹, Y. Yoon¹, S.K. Kauh¹, and J. Lee²¹Seoul National University, KOREA and ²Sogang University, KOREA

This paper reports a novel manufacturing technique that enables eutectic gallium-indium (EGaln) patterns of single-digit micrometer width without a guide mold for the first time. With a custom direct printing setup, a 120- μm wide line is printed on an Ecoflex. Next, the as-printed EGaln line is stretched, frozen with water, and transferred to a unstretched Ecoflex substrate. Finally, gentle heating only leaves the stretched EGaln line. This process is cascaded to obtain a 2- μm wide EGaln line.

**W-054 THE TEMPERATURE DRIFT SUPPRESSION OF MODE-LOCALIZED
RESONANT SENSORS**

J. Zhong, J. Yang, and H. Chang

Northwestern Polytechnical University, CHINA

This paper experimentally demonstrates the amazing temperature drift suppression capability of mode-localized resonant sensors. For a mode-localized stiffness sensor, within a temperature range of [290, 350] K, the measurement error of the amplitude ratio readout is 9% while that of frequency is 1137%. The shift of the scale factor of amplitude ratio is 12% when that of the frequency readout is 62%. It proves that mode-localized sensors own excellent capability of temperature drift suppression.

**M-055 THE MICROSCOPIC ACTIVATION ENERGY ETCHING MECHANISM
IN ANISOTROPIC WET ETCHING OF QUARTZ**

H. Zhang, Y. Xing, J. Zhang, and Y. Li

Southeast University, CHINA

This study explores the effect of concentration and temperature on anisotropic etching of quartz. The proposed MAEE function confirms the relationship among the macroscopic etch rate, microscopic activation energies and atomic removal probabilities, and explains the cause of anisotropy in wet etching of quartz in terms of microscopic atomic energy and specifies the roles of different types atoms in etching, which leads to the successful predictions for structures and topography of Z-cut and AT-cut.

T-056 PATTERNING VERTICAL SIDEWALL USING STANDARD ALIGNERK. Wasa¹, S. Saito², F. Sahara², and M. Sasaki³¹Tecdia Incorporated, JAPAN, ²Aicello Corporation, JAPAN, and³Toyota Technological Institute, JAPAN

A novel method for patterning the vertical sidewall is proposed. The film, which consists of polyvinyl alcohol (PVA) and photoresist layers, is newly introduced. This film is pasted on the substrate with the trench making the bridge. The pattern transferred is the cantilever overhanging the trench. Then, PVA is dissolved in water, and the resist is developed. When the rinse water dries, the cantilever bends and adheres on the vertical sidewall. The pattern with a 10-micrometer width is confirmed.

Generic MEMS and NEMS Manufacturing

W-057 SELECTIVE METALLIZATION AND PASSIVATION OF DRY-TRANSFERRED CARBON NANOTUBES IN FIELD-EFFECT TRANSISTORSL.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 STRUCTURESI.B. Flader¹, Y. Chen², C.H. Ahn², D.D. Shin¹,
A.L. Alter¹, J. Rodriguez¹, and T.W. Kenny¹
¹Stanford University, USA and ²Apple 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 50 μ m 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 OPTIMIZATIONY. 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 METHODL. Song¹, Y. Xia², X. Li¹, J. Chen¹, and S. Ma²
¹Peking University, CHINA and ²Xiamen 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 1 μ m while microneedle height reaches as high as 100 μ m. 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 PLATFORMY. 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

Generic MEMS and NEMS Manufacturing

T-062 RAPID THERMAL NANOIMPRINTING ON SILK PROTEIN SUBSTRATES FOR CONTROLLED DEGRADATION OF TRANSIENT DEVICESZ. Gao^{1,2}, Z. Zhou^{1,3}, H. Tao^{1,3,4}, and N. Qin¹¹Chinese Academy of Sciences, CHINA, ²Shanghai University, CHINA,³University of Chinese Academy of Sciences, CHINA, and⁴University 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

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 LITHOGRAPHYZ. Liu^{1,2}, Z. Zhou^{2,3}, H. Tao^{2,3,4}, and K. Liu²¹Shanghai Normal University, CHINA,²Chinese Academy of Sciences, CHINA,³University of Chinese Academy of Sciences, CHINA, and⁴University of Texas, Austin, USA

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

T-065 AN INTEGRATED, DIRECT-WRITE TEMPERATURE SHOCK RECORDING CHIPZ. Shao¹, H. Liu^{1,2}, Y. Liu¹, H.-S. Jang¹, B. Liu¹,B. Zhao¹, A.M. Niknejad¹, and L. Lin^{1,2}¹University of California, Berkeley, USA and²Tsinghua-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*450 μm² 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.

Generic MEMS and NEMS Manufacturing

W-066 IMPROVED SENSITIVITY OF IONIC LIQUID-BASED PRESSURE SENSOR FOR BODY-ON-A-CHIP USING SIMULATION-BASED 3D LITHOGRAPHYY. 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 NANO-ELECTROMECHANICAL DOUBLY-CLAMPED BEAMS UP TO 330 MHZY. Tsuchiya¹, Y. Feng¹, C. Giotis¹, N. Harada^{1,2}, M. Shikida², C. Dupre³, E. Ollier³, F. Arab Hassani^{1,4}, and H. Mizuta^{1,5}¹University of Southampton, UK, ²Hiroshima City University, JAPAN, ³CEA-Leti, FRANCE, ⁴National University of Singapore, SINGAPORE, and ⁵Japan 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 AWARD NOMINEE* A NOVEL APPROACH TO BLACK TITANIA FABRICATION VIA ATOMIC LAYER DEPOSITION FOR ENERGY STORAGEE. 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-TiO_x); (2) deposition of b-TiO_x onto highly porous materials with Ångstrom-level precision; (3) increased solar response over TiO₂, as demonstrated by >10x photocurrent; (4) >7x improvement in capacitance over a TiO₂-based supercapacitor. As such, this work allows for robust and precise black titania deposition, opening up new possibilities of devices based on b-TiO_x.

W-069 SULFONATION OF POLY(PHTHALAZINON ETHER KETONE) FOR MEMS HUMIDITY SENSORX. Leng¹, Y. Wang¹, and F. Wang^{1,2}¹Southern University of Science and Technology (SUSTech), CHINA and ²Chinese 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.

Materials for MEMS and NEMS

M-070 **MOLYBDENUM DISULFIDE (MoS₂) NANO-ELECTROMECHANICAL RESONATORS WITH ON-CHIP ALUMINUM NITRIDE (AlN) PIEZOELECTRIC EXCITATION**H. Jia¹, X.-Q. Zheng¹, M. Faizan², T. Larsen²,
L.G. Villanueva², and P.X.-L. Feng¹¹Case Western Reserve University, USA and²École 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 (MoS₂) NEMS resonators in the high-frequency band. The piezoelectrically excited 2D NEMS resonators may enable remotely driven, ultrasensitive transducers.

T-071 **AWARD NOMINEE***
IMPROVEMENT OF PHOTORESPONSE IN MoS₂ BY SnO₂-FUNCTIONALIZATION AND ITS APPLICATION TO FLEXIBLE AND TRANSPARENT PHOTODETECTORS. Pyo¹, Y. Kang¹, J. Choi², and J. Kim¹¹Yonsei University, KOREA and ²Yeungnam University, KOREA

This paper reports an improved photoresponse of molybdenum disulfide (MoS₂) functionalized with tin oxide (SnO₂). SnO₂-functionalized MoS₂ induces the transfer of photo-generated electrons from MoS₂ to SnO₂ preventing the recombination of photo-excited electron-hole pairs. This photo-induced carrier separation process leads to p-type doping of MoS₂, resulting in an increase of current. Accordingly, the functionalized MoS₂ exhibited improved photoresponse compared to pristine MoS₂.

W-072 **VISIBLE RANGE SUBRACTIVE PLASMONIC COLOR FILTER ARRAYS USING Ag-AU ALLOYED NANOLANDS**

C.S.H. Hwang, Y. Lee, M.-S. Ahn, T. Chung, and K.-H. Jeong

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

This paper reports wide-range tuning of LSPR wavelength using Ag and Au alloyed nanolands 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.

M-073 **HIGHLY FLEXIBLE, STRETCHABLE, AND DURABLE LIQUID-REPELLENT ELECTRODE BASED ON SELF-SUSTAINABLE LUBRICATION**

A. Kim, S. Kim, M. Huh, and J. Kim

Pohang University of Science and Technology (POSTECH), KOREA

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****T-074 UNANTICIPATED RESULTS IN THE FIRST DIRECT MEASUREMENTS OF ANCHOR DAMPING IN MEMS RESONATORS**

J. Rodriguez¹, D.D. Gerrard¹, G.M. Glaze¹, S. Chandorkar¹,
Y. Chen², I.B. Flader¹, D.D. Shin¹, and T.W. Kenny¹
¹Stanford University, USA and ²Apple Inc., USA

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.

W-075 VACUUM ASSISTED LIQUIFIED METAL (VALM) TSV FILLING METHOD WITH SUPERCONDUCTIVE MATERIAL

J.A. Alfaro^{1,2}, P.M. Sberna¹, C. Silvestri¹, M. Mastrangeli¹,
R. Ishihara¹, and P.M. Sarro¹
¹Delft University of Technology, NETHERLANDS and
²Instituto Tecnológico de Costa Rica, COSTA RICA

A novel, simple, void-free, low-cost method for the filling of high aspect ratio (HAR) Through-silicon-via (TSV) is presented. For the first-time pure indium, a type-I superconductor metal, is used to fill HAR vias, 500 to 300 μm in depth and 50 to 100 μm in diameter. The low electrical resistivity achieved without sintering, straightforward steps and the short time required to fill large arrays of vias at wafer scale, make this method one of the simplest and quickest option for filling HAR TSVs

M-076 SILICA HERMETIC PACKAGES BASED ON LASER PATTERNING AND LOCALIZED FUSION BONDING

L. Du and M.G. Allen
University of Pennsylvania, USA

We develop a hermetic package process based on laser machining that simultaneously achieves dicing and localized fusion bonding of stacked, patterned bulk silica wafers. The interwafer bond line penetrates less than 200 microns laterally into the device, sparing the encapsulated chip the extreme heat of fusion bonding. Metallic feedthroughs can be incorporated without compromising the hermeticity and excimer laser patterning of fused silica had 100x shorter processing time than wet etching.

T-077 RELIABILITY STUDY ON THIN FILM CAPPED MONOLITHIC CMOS-MEMS RESONATOR WITH STANDARD PLASTIC PACKAGING

E.M. Ferrer¹, M.S. Pandian¹, A. Uranga², N. Barniol²,
W.S. Tay¹, and C.B. Fei¹
¹SilTerra Malaysia Sdn. Bhd., MALAYSIA and
²Universitat Autònoma de Barcelona, SPAIN

A detailed reliability study on monolithic CMOS-MEMS resonator devices with zero level packaging (ZLP) is reported in this paper. The unique ZLP process allows the standard plastic molding methods for the packaging of the electrostatic CMOS-MEMS resonators. This paper presents the electrical results on plastic packaged MEMS resonators with CMOS amplifiers after performing some of the most extreme reliability tests employed in the semiconductor IC certification.

Packaging and Assembly

W-078 THEORETICAL ANALYSIS AND EXPERIMENTAL VERIFICATION FOR 3D TGV PACKAGING TECHNOLOGY

Y. Kuang, D. Xiao, J. Zhou, W. Li, Z. Hou, H. Cui, and X. Wu
National University of Defense Technology, CHINA

We deduced the theoretical formula for glass reflow process, which is the critical step of fabricating TGV (Through Glass Via) substrate for wafer level vacuum packaging. The analogy of fluid equation and circuit equation are proposed for deducing process. The theoretical results have been also verified by simulation and experiments. Moreover, hermetic packaging is performed, indicating the feasibility of the TGV substrate for wafer level hermetic packaging.

MEMS Actuators and PowerMEMS

Actuator Components and Systems

M-079 AN ELECTROSTATIC ACTUATOR WITH INHERENT VARIABLE STIFFNESS TO SUPPRESS BOUNCE WITH ROBUSTNESS AGAINST GAP VARIATIONS

X.J. Xiang, X.H. Dai, K. Wang, S. Sun, G.F. Ding, and X.L. Zhao
Shanghai Jiao Tong University, CHINA

In this paper, we proposed an inherent variable stiffness approach to suppress bounce of electrostatic actuator caused by the gap deviation, which is unavoidable because of the micro-fabrication deviation, the tear and wear in the device life-cycle. It had been demonstrated that for the 0.3 μ m gap variation, the fluctuation of collision speed (from zero to 2.7cm/s) for the variable stiffness actuator was 62% less than that of constant stiffness (from zero to 7.18cm/s) for the dual pulse voltage.

T-080 A BI-AXIAL CAPACITIVE SCANNING MIRROR WITH CLOSED-LOOP CONTROL

H. Lin¹, T.W. Lin², A.C.-L. Hung², and M.S.-C. Lu¹
¹*National Tsing Hua University, TAIWAN and*
²*Opus Microsystems, TAIWAN*

Closed-loop control for a bi-axial capacitive raster-scanning micro-mirror is studied in this work. The implementation features the first attempt to use the shared electrodes for simultaneous driving and sensing in the quasi-axis trajectory control. To maintain stable operation, the controller design considers the nonlinearity of the vertical comb electrodes and the electronics noise. Successful closed-loop operation is demonstrated for triangular wave inputs from 5 to 60 Hz.

W-081 INTEGRATION OF FLEXIBLE STRAIN SENSOR USING LIQUID METAL INTO SOFT MICRO-ACTUATOR

S. Otake and S. Konishi
Ritsumeikan University, JAPAN

We report soft micro-fingers composed of soft microactuators and flexible microsensors. A strain sensor using liquid metal is integrated into the micro-finger. The strain sensor detects resistance change depending on the bending motion of a pneumatic balloon actuator (PBA). Both actuator and sensor can be formed by simple structures with channels sandwiched by two films. Consequently, proposed combination of flexible sensor and PBA is excellent in terms of both fabrication and performance.

Actuator Components and Systems

M-082 A MICRO ELECTROMAGNETICALLY-DRIVEN SCANNER BY 2-DOF SECOND-ORDER RESONANCE TO EXTEND SCANNING SCALE FOR ULTRA-THIN SINGLE-FIBER ENDOSCOPE APPLICATIONM. Zhao¹, Z. Yang¹, B. Sun², B. Dai³, H. Liu⁴, J. Yao¹, X. Xu⁵, G. Ding¹, and X. Zhao¹¹Shanghai Jiao Tong University, CHINA,²Chinese Academy of Science, CHINA,³University of Shanghai for Science and Technology, CHINA,⁴Shanghai Chest Hospital, CHINA, and⁵University of Technology Sydney, AUSTRALIA

We design a reasonable 2-DOF system structure including fiber, magnet and weight, which can execute high-order resonance modal to extend the scanning angle in the limited dimensional ultra-thin endoscope. Test result shows the scanner with the second-order resonance model successfully realizes 9.47° scanning scale, which is much larger than that (2.98°) obtained at the traditional first-order resonance model. The scanning locus of fiber tip is measured in xoy-plane by PSD.

T-083 SPRING-SHAPED STIMULI-RESPONSIVE HYDROGEL ACTUATOR FOR MAGNIFYING COMPRESSION AND EXPANSION MOTIONSK. Yoshida¹, S. Nakajima¹, R. Kawano², and H. Onoe¹¹Keio University, JAPAN and ²Tokyo University of Agriculture and Technology, JAPAN

This paper describes stimuli-responsive hydrogel micro-actuators for compressive/expanding actuation of stimuli-responsive hydrogels. Inspired by living bioactuators such as a stalk in vorticella, we applied this spring-shaped structure to engineered stimuli-responsive hydrogel actuators to magnify its degree of deformation. We achieved the shrinkage degree of ~0.2, which is the approximately 2 time smaller than that of bulk hydrogel material, without any modification of molecules.

W-084 PRE-CURVED PVDF/PI UNIMORPH STRUCTURES FOR BIOMIMIC SOFT CRAWLING ACTUATORSY. Wu^{1,2}, K.Y. Ho², K. Kariya², R. Xu², W. Cai², J. Zhong², Y. Ma², M. Zhang³, X. Wang^{1,3}, and L. Lin^{1,2}¹Tsinghua-Berkeley Shenzhen Institute, CHINA,²University of California, Berkeley, USA, and³Tsinghua University, CHINA

We report a pre-curved piezoelectric unimorph structure under a relatively low driving voltage for a soft inchworm actuator. Several unique accomplishments have been demonstrated: (1) PVDF-based actuator using 200 Volts (lowest in published reports); (2) biomimetic soft crawling actuation with a driving speed up to 1.9 mm/s; and (3) low power consumptions of 150μW/cm². As such, this new class of soft crawling actuator could open up new opportunities for the actuation of soft robots.

M-085 DIELECTROWETTING DRIVEN SPATIAL LIGHT STEERING DEVICE FOR 3D OPTICAL APPLICATIONS

D. Kim, Y. Park, D.Y. Lee, and S.K. Chung

Myongji University, KOREA

This paper presents a novel light steering device operated by dielectrowetting actuation for optical and telecommunication applications. The proposed dielectrowetting driven light steering device allows not only compact size but also a wide range of light steering angles compared to other light steering devices.

Actuator Components and Systems

- T-086** **ASYMMETRIC CHARGE TRANSFER PHENOMENON AND ITS MECHANISM IN SELF-EXCITED ELECTROSTATIC ACTUATOR**
Z. Liu¹, X. Yan^{1,3,4}, M. Qi^{1,2}, Y. Zhu¹, X. Zhang¹, and L. Lin²
¹Beihang University, CHINA, ²University of California, Berkeley, USA,
³Collaborative Innovation Center of the Advanced Aero Engine, CHINA, and ⁴National Key Laboratory of Science and Technology on Aero-Engine Aero-Thermodynamics, CHINA

We observe asymmetric charge transfer phenomenon and present its mechanism in self-excited electrostatic actuator for the first time. The cantilever is excited into oscillation under DC voltage and is observed to transfer more charge when it contacts negative electrode than contacting positive electrode. The mechanism of this asymmetric phenomenon indicates the key to increase transferred charge is to increase cantilever surface area and input DC voltage.

- W-087** **A DC DRIVE ELECTROSTATIC COMB ACTUATOR BASED ON SELF-EXCITED VIBRATION**
Y. Zhu¹, X. Yan^{1,3,4}, M. Qi^{1,2}, Z. Liu¹, X. Zhang^{1,4}, and L. Lin²
¹Beihang University, CHINA, ²University of California, Berkeley, USA, ³Collaborative Innovation Center of the Advanced Aero Engine, CHINA, and ⁴National Key Laboratory of Science and Technology on Aero-Engine Aero-Thermodynamics, CHINA

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.

- M-088** **CHARACTERIZATION OF ELECTROSTATIC GAP-CLOSING ACTUATOR ARRAYS IN AQUEOUS CONDITIONS**
R.M. Shih, D.S. Contreras, T.L. Massey,
J.T. Greenspun, and K.S.J. Pister
University of California, Berkeley, USA

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

- T-089** **MEMS-ENABLED SCALABLE FABRICATION OF HIGH PERFORMANCE LITHIUM ION BATTERY ELECTRODES**
M.J. Synodis, M. Kim, S.A.B. Allen, and M.G. Allen
University of Pennsylvania, USA

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.

Manufacturing for Actuators and PowerMEMS

W-090 FABRICATION OF FLEXIBLE THERMOELECTRIC GENERATORS WITH A LENS ARRAY FOR NEAR-INFRARED SOLAR LIGHT HARVESTINGY. Shimizu¹, M. Mizoshiri¹, M. Mikami², Y. Ito¹,
J. Sakurai¹, and S. Hata¹¹Nagoya University, JAPAN and ²National Institute of Advanced Industrial Science and Technology, JAPAN

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/m² and 11 uW/m², respectively.

M-091 WEARABLE STRETCHABLE DOUBLE-SIDED MICRO-SUPERCAPACITORS WITH POROUS CONDUCTIVE ELASTOMERSY. 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 HARVESTERY. Zhang¹, X. Guo¹, and F. Wang^{1,2}¹Southern University of Science and Technology (SUSTech), CHINA and
²Chinese 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 ROUTINGS. 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.

Manufacturing for Actuators and PowerMEMS

M-094 A SUB-MW ELECTROMAGNETIC MICRO-SPEAKER WITH BASS ENHANCEMENT USING A PARYLENE/GRAPHENE/PARYLENE COMPOSITE MEMBRANEP.R. Jadhav¹, Y.T. Cheng¹, S.K. Fan², and C.Y. Liang²¹National Chiao Tung University, TAIWAN and²National Taiwan University, TAIWAN

We demonstrate the first ultra-low-power electromagnetic micro-speaker 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 VIBRATIONSM.V. Le¹, S. Igarashi¹, and H. Kuwano^{1,2}¹Tohoku University, JAPAN and ²Sendai 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

W-096 GRAPHENE GAS PUMPS

D. Davidovikj, D. Bouwmeester, H.S.J. van der Zant, and P.G. Steeneken

Delft University of Technology, NETHERLANDS

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.

M-097 A TRANSIENT TRIBOELECTRIC NANOGENERATOR WITH OPTICAL FEEDBACKY. Zhang^{1,2}, F. Zheng¹, Z. Zhou^{1,2}, Y. Zhang³,F. Wang³, and H. Tao^{1,2,4}¹Chinese Academy of Sciences, CHINA,²University of Chinese Academy of Sciences, CHINA,³Southern University of Sciences and Technology, CHINA, and⁴University of Texas, Austin, USA

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

T-098 PERFORMANCE IMPROVEMENT OF FIBER SUPERCAPACITOR BY USING NiCo₂O₄ NANO-NEEDLES AND AG NANOWIRESG.-M. Seok and K.-S. Yun
Sogang University, KOREA

In this study, the NiCo₂O₄ nano-needle structure was used as the primary electrode layer and the empty space of NiCo₂O₄ 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 NiCo₂O₄ electrode. In addition, AgNWs are used to coat between CNT bundles to maximize capacitance by increasing electrical contact between CNT bundles.

W-099 ELECTROSTATIC ACTUATION OF THE PULSE-ACTIVATED PIEZO-NEMS SHUTTLE RELAYJ. Best and G. Piazza
Carnegie Mellon University, USA

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 $700 \pm 200 \omega$ was measured for the relay.

MEMS Actuators and PowerMEMS

PowerMEMS Components and Systems

M-100 ULTRA-LOW FREQUENCY PIEZOMEMS ENERGY HARVESTER FOR A LEADLESS PACEMAKERN. Jackson¹, O. Olszewski², A. Mathewson², and C. O'Murchu²
¹University of New Mexico, USA and ²Tyndall National Institute, IRELAND

This manuscript describes the development of an ultra-low frequency piezoelectric MEMS energy harvester for powering a leadless pacemaker. The cantilever based device was designed to enhance power generation for this particular application. Aluminum nitride was the piezoelectric material used because it is both biocompatible and CMOS compatible. Power obtained in a laboratory environment demonstrate that this method is potentially a viable option for powering a leadless pacemaker.

T-101 SOFT X-RAY-CHARGED MULTILAYERED PIEZOELECTRET WITH EMBEDDED ELECTRODE FOR PUSH-BUTTON ENERGY HARVESTINGJ. Lu and Y. Suzuki
University of Tokyo, JAPAN

A novel push-button-type kinetic energy harvester using a soft-X-ray-charged multilayered piezoelectret is proposed. With the aid of embedded electrodes, the bias voltage is directly applied to each unit cell. With our early 9-layer prototype, output power of 9.9 μ J has been obtained per a displacement of 0.75 mm. d_{33} as high as 14000 pC/N is realized, which is 10 times higher than that for previous piezoelectrets. Power generation by pushing with a finger has also been demonstrated.

PowerMEMS Components and Systems

W-102 FLEXIBLE ELECTROCHEMICAL FILM POWER SUPPLY WITH DISPOSABLE GLUCOSE-BASED ENERGY PATCH AS A RECONFIGURABLE EPIDERMAL ENERGY DEVICE

X. Zhang, Z. Pu, X. Lai, H. Yu, and D. Li
Tianjin University, CHINA

This paper reports a flexible electrochemical film power supply with disposable glucose-based energy patch as a reconfigurable epidermal energy device. The electrical power is independently generating from the electrochemical reaction between the glucose oxidase (GOx) and glucose molecules which are immobilized on the cathode. Moreover, the device is fabricated by inkjet printing to meet the requirement of flexible and stretchable substrates for epidermal electronics.

M-103 SEMI-TRANSPARENT FOLDABLE SUPERCAPACITOR FOR 3D STRUCTURED ENERGY STORAGE DEVICES

D. Shin¹, C. Shen¹, M. Sanghadasa², and L. Lin¹
¹*University of California, Berkeley, USA and*
²*US Army, Redstone Arsenal, USA*

We present a semi-transparent foldable supercapacitor with high specific capacitance and robustness against mechanical deformations such as cutting, folding and compression. We fold the supercapacitor into an origami crane that embraces and lights up an LED to demonstrate a new class of energy storage devices that may find applications in structural electronics.

T-104 A HIGH-EFFICIENCY MAGNETICALLY COUPLED CHARGING AND COMMUNICATION PLATFORM FOR MICROSENSORS

G. Duan, X. Zhao, and X. Zhang
Boston University, USA

A miniaturized double layer antenna (0.74mm square) was fabricated and integrated with a passive RFID chip to form a microsensor to work with a magnetically coupled reader antenna for charging and communication. Two techniques (local field enhancement package and metamaterial enhancement) were developed to boost the magnetic field strength more than 100 times passively. And magnetically coupled antenna array was leveraged to extend the coverage area of the reader antenna 4 times.

W-105 A KIRIGAMI-INSPIRED, EXTREMELY STRETCHABLE, HIGH AREAL-COVERAGE MICRO-SUPERCAPACITOR PATCH

R. Xu, A. Hung, A. Zverev, C. Shen, L. Irie, G. Ding,
M. Whitmeyer, L. Ren, B. Griffin, J. Melcher,
L. Zheng, X. Zang, and L. Lin
University of California, Berkeley, USA

We present an extremely stretchable micro-supercapacitor patch with high areal-coverage. Our device is 2.4-9.4 times more stretchable than stretchable supercapacitors using Accordion construct, and has 4 times higher areal-coverage than reported ones with Island-Bridge construct. The Kirigami design is the key to both high stretchability and high coverage. We envision our stretchable micro-supercapacitor patch to be highly desirable in future flexible, stretchable, and wearable systems.

M-106 DESIGN, FABRICATION, AND CHARACTERIZATION OF LATERAL-STRUCTURED CU-NI THERMOELECTRIC DEVICES

K.V. Selvan and M.S. Mohamed Ali
Universiti Teknologi Malaysia, MALAYSIA

This work reports a lateral-structured thermoelectric device using copper and nickel. The approach includes the usage of low cost photolithography and without the needs of copper deposition, leading to much easier and faster fabrication. The lateral device structure has never been implemented into any copper-nickel devices to date and has generated larger power than the previous vertically-structured device.

PowerMEMS Components and Systems

T-107 TUNABLE THERMO-TRIBOELECTRIC ENERGY HARVESTING USING HUMAN BODY HEAT FOR SELF-POWERED APPLICATIONS

D.G. Lee

Korea Polytechnic University, KOREA

We demonstrate a novel tunable thermo-triboelectric energy harvesting system for the use of human body heat as an energy source of self-powered applications. The proposed approach can convert thermal energy from human body heat into electricity by pairing triboelectric effect and MTG concept.

W-108 MAGNETICALLY-DRIVEN TRIBOELECTRIC GENERATOR AS A DIRECT POWER SOURCE FOR WIRELESS SENSORS

J. Qian, D.-S. Kim, and D.-W. Lee

Chonnam National University, KOREA

We describe a magnetically-driven rotating triboelectric generator (M-TEG) as a direct power source for wireless sensors. 4 M-TEGs are symmetrically placed on the wheel hub of a vehicle. Permanent magnets mounted on the brake caliper provides a non-contact magnetic force to generate a seesaw-like swing motion of the M-TEG in the tire. The unique advantage of the seesaw structure eliminates the influence of a large centrifugal force at a high rotating speed.

M-109 A FOOT-TREADING TYPE ELECTRIC POWER GENERATOR USING MICRO/NANO CHANNELS IN A POROUS GLASS FILTERY. Tanaka^{1,2} and Y. Yalikul^{1,2}¹RIKEN, JAPAN and ²Osaka University, JAPAN

We here firstly demonstrated an energy harvesting device using water and glass small channels driven by pressure derived from foot-treading. This device is suitable for slow movement scene like human behavior.

MEMS Actuators and PowerMEMS

Other Actuators and PowerMEMS

T-110 DEVELOPMENT OF A BISTABLE CMOS-MEMS MICROBEAM RESONATOR WITH ELECTROSTATIC ACTUATION

J. Barceló, S. Bota, J. Segura, and J. Verd

University of the Balearic Islands, SPAIN

We report, for the first time, experimental demonstration of bistability in simple, straight and non-axially-forced clamped-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.

W-111 UNDERWATER ENERGY HARVESTING TECHNOLOGY UTILIZING AN OPTOTHERMALLY PULSATING MICROBUBBLE

D. Jang, J. Lee, H. Song, H. Park, and S.K. Chung

Myongji University, KOREA

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)

M-112 MINIATURIZATION OF A GRATING-BASED SPR TYPE NEAR-INFRARED SPECTROMETER BY USING VIBRATION OF A MEMS CANTILEVERM. Oshita¹, H. Takahashi², and T. Kan¹¹University of Electro-Communications, JAPAN and²University of Tokyo, JAPAN

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.

T-113 DESIGN AND IMPLEMENTATION OF HIGH FILL-FACTOR STRUCTURES FOR LOW-COST CMOS MICROBOLOMETERS

O. Erturk and T. Akin

Middle East Technical University, TURKEY

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 SPECTROSCOPYS.S. Muttikulangara¹, M. Baranski¹, S. Rehman², L. Hu¹, and J. Miao¹¹Nanyang Technological University, SINGAPORE and²Singapore-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

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.

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

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

- M-118 RESONATORS FOR REAL-TIME CLOCKS BASED ON EPITAXIAL POLYSILICON PROCESS: A FEASIBILITY STUDY ON SYSTEM-LEVEL COMPENSATION OF TEMPERATURE DRIFTS**
G. Mussi¹, M. Bestetti¹, V. Zega¹, A. Frangi¹,
G. Gattere², and G. Langfelder¹
¹*Politecnico di Milano, ITALY and* ²*STMicroelectronics, ITALY*

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.

- T-119 MICRO ATOMIC FREQUENCY STANDARDS EMPLOYING AN INTEGRATED FBAR-VCO OSCILLATING ON THE ⁸⁷Rb CLOCK FREQUENCY WITHOUT A PHASE LOCKED LOOP**
M. Hara¹, Y. Yano¹, M. Kajita¹, H. Nishino², Y. Ibata², M. Toda²,
S. Hara¹, A. Kasamatsu¹, H. Ito³, T. Ono², and T. Ido¹
¹*National Institute of Information and Communications Technology, JAPAN,* ²*Tohoku University, JAPAN, and*
³*Tokyo Institute of Technology, JAPAN*

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 ($f_{\text{clock}}/2=3.42$ 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.

MEMS for Timing and Frequency Control

W-120 PARAMETRIC RESONANCE IN LINEAR MICRORESONATORS USING ANALOG FEEDBACKJ.J. Gorman¹ and V.J. Gokhale^{1,2}¹National Institute of Standards and Technology (NIST), USA and²University of Michigan, USA

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.

M-121 A VHF TEMPERATURE COMPENSATED LITHIUM NIOBATE-ON-OXIDE RESONATOR WITH Q > 3900 FOR LOW PHASE NOISE OSCILLATORSG.W. Fang¹, G. Pillai², M.-H. Li³, C.-Y. Liu¹, and S.-S. Li^{1,2}¹National Tsing Hua University, TAIWAN and²University of Illinois, Urbana-Champaign, USA

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 SiO₂ 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 AIN-ON-Si MEMS RESONATOR BOUNDED BY WIDE ACOUSTIC BANDGAP TWO-DIMENSIONAL PHONONIC CRYSTAL ANCHORS

M.W.U. Siddiqi and J.E.-Y. Lee

City University of Hong Kong, HONG KONG

We report an AIN-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 TRIMMINGB. Pei^{1,2}, P. Zhong^{1,2}, K. Sun¹, H. Yang¹, and X. Li¹¹Chinese Academy of Sciences, CHINA and²University 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

Photonic Components and Systems

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

M. Malak¹, T. Claes¹, V. Garcia-Munoz¹, H. Kumar Tyagi³, R. Van Hoof¹, G. Winderickx¹, S. Severi¹, W. Lee², D. Kim², S. Ahn², P. Van Dorpe¹, X. Rottenberg¹, P. Peumans¹, and H.A.C. Tilmans¹

¹Interuniversity Microelectronic Center, BELGIUM, and

²Samsung 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

B. Dong¹, H. Tian¹, M. Zervas², T.J. Kippenberg², and S.A. Bhave¹

¹Purdue University, USA and ²École 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.

W-126 ELECTRO-OPTICALLY CONTROLLED ACOUSTO-OPTIC RACETRACK MODULATOR ETCHED IN LNOI PLATFORM

M. Mahmoud, L. Cai, A. Mahmoud, T. Mukherjee, and G. Piazza
Carnegie Mellon University, USA

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 platform demonstrates important block for RF-photonic applications.

MEMS for Electromagnetics

RF MEMS Components and Systems

M-127 EXPLOITING PARALLELISM IN RESONATORS FOR LARGE VOLTAGE GAIN IN LOW POWER WAKE UP RADIO FRONT ENDS

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

This work reports the largest LiNbO₃ 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.

RF MEMS Components and Systems

T-128 LITHIUM NIOBATE LATERAL OVERTONE RESONATORS FOR LOW POWER FREQUENCY-HOPPING APPLICATIONSR. Lu, T. Manzanogue, Y. Yang, A. Kourani, and S. Gong
University of Illinois, Urbana-Champaign, USA

This work reports the first LiNbO₃ LOBAR. The fabricated device shows the highest reported Qs (1966, 1215, and 1513) for LiNbO₃ 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 LiNbO₃ LOBARs can be enabled for low-power and phase-continuous synthesis of OFC signals.

W-129 MAGNETIC-FREE ELECTRICAL CIRCULATOR BASED ON ALN MEMS FILTERS AND CMOS RF SWITCHESC. Xu, E. Calayir, and G. Piazza
Carnegie Mellon University, USA

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.

M-130 ACOUSTOELECTRIC EFFECT WITH RAYLEIGH WAVES IN A MONOLITHIC THIN FILM LITHIUM NIOBATE ON SILICON HETEROSTRUCTUREU.K. Bhaskar, M.J. Storey, and D. Weinstein
Purdue University, USA

We report the first demonstration of acoustoelectric (AE) attenuation in heterogeneously integrated Lithium Niobate thin film on Silicon substrate (LNOS). The strong coupling coefficient (K₂) delivers efficient excitation of Rayleigh waves, while the large permittivity of the LNOS configuration provides superior control of the semiconductor carrier density over previous approaches. Our results demonstrate that the monolithic LNOS configuration can overcome past obstacles faced by AE technology.

T-131 MATERIAL CONSTANTS EXTRACTION FOR ALSCN THIN FILMS USING A DUAL MODE BAW RESONATORF. Parsapour¹, V. Pashchenko¹, P. Nicolay², and P. Muralt¹¹*École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND and*²*CTR Carinthian Tech Research AG, AUSTRIA*

In this work, we extracted experimentally the piezoelectric and stiffness coefficients for 16% Sc doped AlN film, by fabricating and characterizing a dual mode bulk acoustic wave resonator. Beside the BAW mode, the longitudinal mode was excited due to the tilting of c-axis oriented grains, regarding growth direction. An analytical model developed to explain wave propagation in such a tilted c-axis frains system.

W-132 A STUDY ON FLICKER FREQUENCY NOISE OF PIEZOELECTRIC ALUMINUM NITRIDE RESONATORS AS A FUNCTION OF ELECTRODE DESIGNH.J. Kim¹, S.I. Jung¹, J. Segovia-Fernandez², and G. Piazza²¹*Daegu Gyeongbuk Institute of Science and Technology, KOREA and*²*Carnegie Mellon University, USA*

This paper presents experimental studies of flicker frequency (1/f) noise of 1 GHz aluminum nitride (AlN) contour mode resonators as a function of electrode design. Resonators with various electrode dimensions and different top electrode materials (Al, Au, and Pt) are fabricated to give a wide range of thermoelastic damping (TED), which directly impacts the 1/f noise of CMRs. Results show that 1/f noise clearly depends on Q while providing the best noise performance for Pt.

RF MEMS Components and Systems

- M-133 AN RF-MEMS-RESONATOR-DRIVEN GRAPHENE TRANSISTOR**
J. Liang, X. Chen, M. Zhang, H. Zhang, D. Zhang, and W. Pang
Tianjin University, CHINA

For the first time, we achieved a tunable graphene transistor powered by an RF acoustic MEMS resonator beyond gigahertz. The acousto-electric-driven graphene transistor not only coins a unique method for the investigation of various nanomaterials, but also opens an avenue for development of novel wireless passive transistors and RF energy harvesters.

- T-134 SINGLE-CHIP MULTI-FREQUENCY WIDEBAND FILTERS BASED ON ALUMINUM NITRIDE CROSS-SECTIONAL LAMÉ MODE RESONATORS WITH THICK AND APODIZED ELECTRODES**
G. Chen¹, C. Cassella¹, T. Wu², and M. Rinaldi¹
¹*Northeastern University, USA* and ²*ShanghaiTech University, CHINA*

This work reports on three monolithic integrated contiguous 3rd order ladder filters formed by high kt2 Aluminum-Nitride Cross-Sectional-Lame-Mode resonators (CLMRs). The three devices operate around 1GHz and show a record high fractional bandwidth >3.9% and unprecedented levels of loss and spurious suppression (insertion loss < 1 dB) enabled by the combined use of thicker platinum electrodes and apodization techniques to suppress the coupling of undesired transverse modes in their passband.

- W-135 IDENTIFYING SPURIOUS MODES IN RF-MEMS RESONATORS USING PHOTOELASTIC IMAGING**
V.J. Gokhale^{1,2} and J.J. Gorman²
¹*National Institute of Standards and Technology (NIST), USA* and ²*University of Michigan, USA*

This paper reports on photoelastic imaging for identifying in-plane vibration modes in MEMS resonators. We map fundamental width-extensional modes, aspect ratio dependent unwanted spurious length-extensional modes, and detect unexpected modes in silicon resonators. The unexpected modes are persistent across designs, and potentially detrimental to the system unless addressed in design. We show the dependence of spurious modes on aspect ratio and discuss methods of mitigation.

- M-136 AN SHO LITHIUM NIOBATE TRANS-IMPEDANCE CHIRP COMPRESSOR WITH HIGH VOLTAGE GAIN**
T. Manzanogue, R. Lu, Y. Yang, and S. Gong
University of Illinois, Urbana-Champaign, USA

We present a new type of acoustic device that, for the first time, can simultaneously perform chirp compression and impedance transformation to achieve passive voltage amplification with a gain of 12. The device consists of an acoustic dispersive delay line for shear-horizontal waves in lithium niobate. SHO waves are employed due to their demonstrated high electromechanical coupling of 39%, low propagation loss, and a slow phase velocity of 3700 m/s.

- T-137 EXPERIMENTAL INVESTIGATION OF DAMPING FACTORS IN 20% SCANDIUM-DOPED ALUMINUM NITRIDE LATERALLY VIBRATING RESONATORS**
Z.A. Schaffer¹, L. Colombo¹, A.S. Kochhar¹, G. Piazza¹, S. Mishin², and Y. Oshmyansky²
¹*Carnegie Mellon University, USA* and ²*Advanced Modular Systems, USA*

We evaluate damping mechanisms in 20% Scandium-doped Aluminum Nitride laterally vibrating resonators operating at 250 and 500 MHz. Different resonator geometries are analyzed and devices are tested in air, under vacuum, and at cryogenic temperatures (11 K). Anchor losses and thermoelastic damping are evaluated and compared to Aluminum Nitride resonators of identical geometries.

RF MEMS Components and Systems

W-138 **MAGNETICALLY ACTUATED RECONFIGURABLE
PIXELATED ANTENNA**J. Pal¹, K. Deshpande¹, L. Chomas¹, S. Santhanam¹,
F. Donzelli², D. Piazza², J.A. Bain¹, and G. Piazza¹¹ *Carnegie Mellon University, USA* and ² *Adant Technologies, ITALY*

We present a 6-element pixelated antenna with reconfigurable resonance frequency and polarization. Reconfiguration is achieved by mechanically connecting/disconnecting 6 movable patches to/from fixed Cu patches, hence realizing antennas of different sizes and shape. Each movable patch is a cantilevered plate, micro-fabricated from a Ni layer plated on Duroid. The Ni patch is magnetically actuated by an EPM placed behind the ground plane of the antenna.

M-139 **WAVEFORM OPTIMIZATION FOR RESONANTLY DRIVEN MEMS
SWITCHES ELECTROSTATICALLY BIASED NEAR PULL-IN**A.M. Siddiqui, C.D. Nordquist, A. Grine, S. Lepkowski,
M.D. Henry, M.E. Eichenfield, and B.A. Griffin*Sandia National Laboratory, USA*

Biasing a MEMS switch close to static-pull in reduces the modulation amplitude necessary to achieve resonant pull-in, but results in a highly nonlinear system. In this work, we present a new methodology that captures the essential dynamics and provides a prescription for achieving the optimal drive waveform which significantly reduces the amplitude requirements of the modulation source. These findings are validated both experimentally and through numerical modeling.

T-140 **A CMOS-MEMS CC-BEAM METAL RESOSWITCH FOR ZERO
QUIESCENT POWER RECEIVER APPLICATIONS**

S.-C. Lu, C.-P. Tsai, and W.-C. Li

National Taiwan University, TAIWAN

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

W-141 **METAMATERIALS TO SEE IN TERAHERTZ IN "COLORS"**Z. Zhou¹, H. Li¹, T. Zhou¹, Z. Shi^{1,2}, J. Cao¹, and H. Tao^{1,3}¹ *Chinese Academy of Sciences, CHINA,*² *Huashan Hospital of Fudan University, CHINA, and*³ *University of Texas, Austin, USA*

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.

THz MEMS Components and Systems

M-142 A SILICON-BASED PARABOLIC SUB-THz REFLECTOR ANTENNA FOR GAIN ENHANCEMENT AND NEAR-FIELD FOCUS APPLICATIONSM.-T. Hsu¹, T.-Y. Chiu¹, S.-Y. Wu¹, Y.T. Cheng¹,
C.H. Li², and C.-N. Kuo¹¹National Chiao Tung University, TAIWAN and²National Central University, TAIWAN

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.

T-143 DIELECTRIC GRADIENT METASURFACE FOR EFFICIENT TERAHERTZ WAVE FOCUSINGD. Jia¹, Y. Tian¹, W. Ma¹, X. Gong¹, J. Yu², G. Zhao², and X. Yu¹¹Peking University, CHINA and ²Capital Normal University, CHINA

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

W-144 SURFACE PLASMONIC RESONANCE MODULATION BY MEMS-ELASTOMER HYBRID SYSTEM

Y.-T. Hu, S.-C. Lo, Y.-C. Chen, C.-L. Pan, and C.-Y. Lo

National Tsing Hua University, TAIWAN

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.

M-145 WAFERSCALE ELECTROSTATIC QUADRUPOLE ARRAY FOR MULTIPLE ION BEAM MANIPULATIONK.B. Vinayakumar¹, A. Persaud², Q. Ji²,P. Seidl², T. Schenkel², and A. Lal¹¹Cornell University, USA and ²University of California, Berkeley, USA

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.)

T-146 A WIRELESS DUAL-MODE MICRO THERMAL FLOW SENSOR SYSTEM WITH THE EXTENDED FLOW RANGE BY USING 0.18 μ m CMOS-MEMS PROCESS

W. Xu¹, B. Lijin², M. Duan¹, X. Wang¹, J. Wicaksana¹, M. A¹, M. Ahmed¹, R. Wang², N.X. Fang³, A. Bermak^{1,4}, and Y.-K. Lee¹

¹Hong Kong University of Science and Technology, HONG KONG, ²Hangzhou Dianzi University, CHINA, ³Massachusetts Institute of Technology, USA, and ⁴Hamad Bin Khalifa University, QATAR

For the first time, we report a wireless Dual-Mode Micro Thermal Flow (DMTF) sensor system with the extended flow range by using InvenSense 0.18 μ m 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.

W-147 PIEZOELECTRICALLY-DRIVEN CAPACITIVELY-SENSED SQUEEZE-FILM PRESSURE SENSORS

T.-H. Chen¹, C.-W. Cheng², and M.S.-C. Lu¹

¹National Tsing Hua University, TAIWAN and ²Taiwan Semiconductor Manufacturing Company (TSMC), TAIWAN

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

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

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.

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

W-150 INLINE RELATIVE PERMITTIVITY SENSING USING SILICON ELECTRODES REALIZED IN SURFACE CHANNEL TECHNOLOGYD. Alveringh¹, R.J. Wiegerink¹, and J.C. Lötters^{1,2}¹University of Twente, NETHERLANDS and²Bronkhorst 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 PROCESSM. Hermouet^{1,2}, M. Sansa^{1,2}, L. Banniard^{1,2}, A. Fafin^{1,2,3},M. Gely^{1,2}, P.E. Allain³, E. Gil Santos³, I. Favero³,T. Alava^{1,2}, G. Jourdan^{1,2}, and S. Hentz^{1,2}¹Université Grenoble Alpes, FRANCE, ²CEA-LETI, FRANCE, and³Université 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 FIELDSN. Krakover¹, B.R. Ilic², and S. Krylov¹¹Tel Aviv University, ISRAEL and ²National 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.

W-153 MICRO CORIOLIS MASS FLOW SENSOR DRIVEN BY INTEGRATED PZT THIN FILM ACTUATORSY. Zeng¹, J. Groenesteijn^{1,2}, D. Alveringh¹, R.J.A. Steenwelle¹,K. Ma¹, R.J. Wiegerink¹, and J.C. Lötters^{1,2}¹University of Twente, NETHERLANDS and²Bronkhorst High-Tech BV, NETHERLANDS

We have realized the first ever micro Coriolis mass flow sensor that is driven by integrated lead zirconate titanate (PZT) thin film actuators, allowing low voltage, low heating actuation compared to current actuation methods. The integrated PZT layer is deposited on top of a fluidic microchannel with pulsed laser deposition (PLD). Our first measurement using nitrogen confirms that the sensor output is proportional to flow rate.

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

M-154 BULK MODULUS MEASUREMENT OF MICROFLUIDICS BY LONGITUDINAL BULK ACOUSTIC WAVE SENSORSY. Lu, H. Zhang, Y. Jiang, H. Zhang, W. Pang, and M. Zhang
Tianjin University, CHINA

In this study, we measured bulk modulus of microfluidics with longitudinal acoustic waves (~GHz) excited by bulk acoustic wave (BAW) MEMS sensors. Experiments on 1 μ L glycerol-water sample droplets were carried out, and a 1-dimensional numerical model and analytical model were established. We showed that BAW sensors are sensitive to bulk modulus of microfluidics, and insensitive to liquid viscosity which is another important liquid property usually measured by shear acoustic wave sensors.

MEMS Physical Sensors

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

T-155 HYDROGEL TIP ATTACHED QUARTZ TUNING FORK USING ELASTOMERIC TIP MOLD REPLICATED FROM ELECTROCHEMICALLY ETCHED TUNGSTEN WIREJ. Ko¹, A. Jarzembski², K. Park², and J. Lee¹
¹*Sogang University, KOREA and* ²*University of Utah, USA*

This paper reports the first demonstration of soft hydrogel atomic force microscope (AFM) tip attachment to quartz tuning forks (QTFs) by using h-polydimethylsiloxane (h-PDMS) tip molds replicated from an electrochemically etched tungsten tip of ~10 nm radius. Using the h-PDMS tip molds, polyethyleneglycol-diacrylate (PEG-DA) tip is attached to QTFs without adhesive. QTFs with a PEG-DA tip attached are used for AFM imaging successfully. Tip attachment process can also be repeated multiple times.

W-156 ELASTICITY SENSOR USING DIFFERENT TACTILE PROPERTIES ON ONE CHIPR. Tanii, T.-V. Nguyen, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

We report a MEMS-based force sensor that can measure the elasticity of an object without information of contact force and object deformation. The sensor consists of a PDMS pad and a sensor chip with three piezoresistive cantilevers which measure the deformations of the center and the free ends of PDMS pad. We show that the elasticity of an object pressed against the sensor can be obtained from the cantilevers' outputs ratio which does not depend on the contact force nor the object deformation.

M-157 CONNECTION OF 48 SENSORS ON THE SAME SERIAL BUS LINE FOR HUMAN-INSPIRED EVENT-DRIVEN TACTILE SENSATION COVERING WIDE SPATIAL RANGE OVER 2 METERS AT MILLIMETER RESOLUTIONC. Shao¹, S. Asano¹, M. Muroyama¹, T. Nakayama²,
Y. Hata³, and S. Tanaka¹¹*Tohoku University, JAPAN,* ²*Toyota Motor Corporation, JAPAN, and*
³*Toyota Central R&D Labs., Inc., JAPAN*

This work is a part of the project which develops a bus-connected tactile sensor system for covering a wide area of robots at high resolution. To emulate a reported integrated tactile sensor, a discrete capacitive force sensor was combined with a sensor platform LSI, and 48 sensors were connected to the bus line of 2 m length. Human-inspired event-driven operation and data collision avoidance by carrier sensing were demonstrated, when the multiple sensors were stimulated at the same time.

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

T-158 SENSE OF TOUCH IN SUBMICRON REGION REALIZED BY NOVEL TWO-AXIS TACTILE SENSOR WITH A NEEDLE-LIKE CONTACTORT. Nakashima¹, K. Watatani¹, K. Terao^{1,2},
F. Shimokawa^{1,2}, and H. Takao^{1,2}¹Kagawa University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

This is the first report on “sense of touch in submicron region” realized by a novel 2-axis tactile sensor with needle-like contactor. Simultaneous measurement of surface shape and correlated minute frictional force is realized by 0.5 μ m-radius contactor tip in the highly sensitive tactile sensor. Contacting the slanted contactor tip to the measuring sample surface, small one-point contact is realized, and the spatial resolution of tactile sensing has been improved to submicron region (0.4 μ m).

W-159 HIGH SENSITIVE AND LARGE AREA FORCE PLATE FOR GROUND REACTION FORCE MEASUREMENT OF ANT RUNNINGS. Kohyama, H. Takahashi, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

This paper reports on a separately fabricated MEMS force plate for measurement of ground reaction forces (GRFs) of ants during running. To achieve both high force sensitivity and ensuring area for ants running several steps, the MEMS force plate is composed of two cantilever chips and one plate which are fabricated separately. The force resolution is under 0.5 μ N. Using the fabricated sensor, we measured the GRFs of running ants.

M-160 FINGERPRINT-INSPIRED TRIBOELECTRIC SLIDING SENSORH. Chen, Z. Song, Y. Song, X. Chen, L. Miao, Z. Su, and H. Zhang
Peking University, CHINA

Inspired by the structure of human fingerprint, we developed a novel sliding sensor composed of four CNT-PDMS spiral and alternate electrodes in this work. Based on triboelectric and electrostatic induction effects, four electrodes will generate voltage signals one after another when an external object move across the surface. The sequence of four signals can not only figure out sliding direction but also detect displacement and speed of the sliding object in a digital way.

T-161 UTILIZING LARGE HALL OFFSET VOLTAGE FOR CONVERSION FREE 4H-SiC STRAIN SENSORT.-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 45 $^{\circ}$ 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 GRASPINGC. 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.

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

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

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

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

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, LabVIEW 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

M-166 THREE-DIMENSIONAL HIERARCHICAL AND SUPERHYDROPHOBIC GRAPHENE GAS SENSOR WITH GOOD IMMUNITY TO HUMIDITYJ. Wu¹, K. Tao², J.M. Miao³, and L.K. Norford⁴¹*Sun Yat-sen University, CHINA*, ²*Northwestern Polytechnical University, CHINA*, ³*Nanyang Technological University, SINGAPORE*, and⁴*Massachusetts Institute of Technology, USA*

Superhydrophobic reduced graphene oxide (RGO) with unique 3D hierarchical structures is synthesized by exploiting one-step spark plasma sintering (SPS) within 60 s for high-performance NO₂ detection. The superhydrophobicity makes the fabricated RGO sensor exceptionally immune to high relative humidity (RH). Specifically, the RGO sensor exhibits a response degradation less than 5.5% to 1 ppm NO₂ when the RH increases from 0% to 70%.

Gas and Chemical Sensors

T-167 GAS SENSOR BASED ON A METAL OXIDE NANOWIRE FOREST BUILT ON A SUSPENDED CARBON NANO-HEATER

Y. Lim, S. Lee, Y.M. Kwon, J.M. Baik, and H. Shin
Ulsan National Institute of Science and Technology (UNIST), KOREA

This paper reports a novel metal oxide nanowire (MO_x NW) based gas sensor built on a suspended carbon nanowire heater allowing ultra-low power consumption. This sensing platform was fabricated using only wafer level batch fabrication processes such as carbon-MEMS, atomic layer deposition, and hydrothermal growth processes. In addition, the suspended high-aspect-ratio geometry of the carbon nanowire enables MO_x NWs to be heated with ultra-low power Joule heating.

W-168 RESONANT-GRAVIMETRIC PARTICLE SENSORS WITH AIR-FILTERING CANTILEVER FABRICATED IN LOW-COST NON-SOI SILICON

Y.Y. Bao^{1,2}, S. Cai¹, H. Yu¹, T. Xu¹, P. Xu¹, and X. Li^{1,2}
¹*Chinese Academy of Sciences, CHINA and*
²*ShanghaiTech University, CHINA*

The work studies a resonant-cantilever for sensing to air particles like PM_{2.5}. For filtering the particle size, a row of barrier bars is integrated in an air-flow micro-channel which is embedded in the cantilever. The micro-particle number with concerned diameter can be counted for air pollution analysis and monitoring. The single-wafer based sensors are single-sided low-cost fabricated in non-SOI silicon-wafers, thus facilitating volume production and applications.

M-169 AN ULTRASENSITIVE HUMIDITY SENSOR BASED ON SnO₂-MODIFIED MoS₂ NANOCOMPOSITE AT LOW-HUMIDITY RANGE

Y. Zhao, B. Yang, J. Liu, X. Chen, X. Wang, and C. Yang
Shanghai Jiao Tong University, CHINA

We develop an ultrasensitive capacitive humidity sensor for low-humidity detecting environment, which employs SnO₂-modified MoS₂ hybrid nanocomposite film as sensing layer and interdigital electrode with narrow gap of 15 μm on sapphire substrate. The SnO₂-modified MoS₂ nanocomposite is fabricated through one-pot hydrothermal method. The sensitivity of the sensor is 387.5 μF/%RH at the humidity range of 0-20% RH, which is higher than that of all reported humidity sensors at low-humidity range.

T-170 MICROFLUIDIC CHIP FOR DROPLET-BASED AUNPS SYNTHESIS WITH DIELECTRIC BARRIER DISCHARGE PLASMA AND ON-CHIP MERCURY ION DETECTION

D.-E. Li and C.-H. Lin
National Sun Yat-sen University, TAIWAN

This study presents a microfluidic chip for droplet-based AuNPs synthesis with dielectric barrier discharge plasma and on-chip mercury ion detection. Atmospheric DBD He plasma is generated in the microchip to provide ionized electrons for AuNPs reduction. Results show that the produced microfluidic device can colorimetrically detect Hg²⁺ ions of the concentration as low as 0.2 PPM. The developed microfluidic chip provides a simple yet high-performance platform for NP-based detection applications.

W-171 ZnO-NANOWIRES COATED WITH GAMMA-ORDERED MESOPOROUS ALUMINA (GAMMA-OMA) CATALYST FOR DETECTION OF FREON

P. Xu, Y. Chen, and X. Li
Chinese Academy of Sciences, CHINA

We develop a new method to detect Freon R134a by using gamma-phase ordered mesoporous alumina (gamma-OMA) as key catalyst. The inert R134a molecules are firstly broken down into several kinds of active radicals by gamma-OMA. Then, the produced active radicals can be easily detected with ZnO nanowire micro-sensor.

Gas and Chemical Sensors

- M-172 CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS FOR BIOCHEMICAL DETECTION WITH FLEXIBLE HIGH SENSITIVITY**
Y. Zhao, D. Lu, L. Zhao, Y. Xia, Z. Li, J. Li, J. Zhang,
C. Jia, J. Wang, and Z. Jiang
Xi'an Jiaotong University, CHINA

We have designed and fabricated the CMUTs by low temperature bonding process. The electrospinning technology is innovatively applied as a coating method for the functionalization. With the increase of direct current (DC) bias voltage, the mass effect on CMUTs' resonant frequency has been distinctly intensified. That is to say, the experiment about the influence of DC bias voltage on the CMUTs is firstly proposed, which is benefit to achieve a flexible high sensitivity in SO₂ detection.

- T-173 AN IMPROVED SENSITIVITY ALN MICROCANTILEVER HUMIDITY SENSOR USING INTERDIGITAL TRANSDUCERS ACTUATED VERY HIGH RESONANT MODE AND GRAPHENE OXIDE SENSING LAYER**
X. Le¹, F. Ma², D. Li¹, J. Pang¹, Z. Xu¹, C. Gao¹, and J. Xie¹
¹Zhejiang University, CHINA and ²Shaoxing Vocational & Technical College, CHINA

We present a novel interdigital transducers (IDTs) actuated AlN microcantilever humidity sensor coated with graphene oxide as sensing layer. Utilizing the IDTs, the microcantilever can operate at very high resonant mode to achieve significant high humidity sensitivity. Compare with the normal electrodes actuated microcantilever sensor, the sensitivity of the novel sensor is increased by more than 10 times. Moreover, little hysteresis, excellent repeatability of the sensor are obtained.

- W-174 FABRICATION OF C-DOPED WO₃ NANOAMTERIAL-BASED GAS SENSORS FOR HIGHLY SENSITIVE NO₂ DETECTION AT ROOM TEMPERATURE**
D.-H. Baek, S. Pyo, and J. Kim
Yonsei University, KOREA

This paper firstly reports a method to fabricate C-doped tungsten oxide (WO₃) nanomaterials using carbon nanotubes (CNTs) template and demonstrates its application to highly sensitive NO₂ gas sensing at room temperature. The fabricated sensor achieved a lower detectable limit at room temperature than the previously reported WO₃-based NO₂ 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.)

- M-175 LOW-COST, 30 NG/√HZ NOISE-FLOOR MEMS ACCELEROMETERS FOR LARGE SENSOR NETWORK**
Y. Kamada, A. Isobe, T. Oshima, Y. Furubayashi, N. Sakuma,
C. Takubo, Y. Tainaka, K. Watanabe, K. Mori, N. Mori,
H. Kazama, A. Matsumoto, and T. Sekiguchi
Hitachi, Ltd., JAPAN

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.

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

T-176 SELF-CLOCKED DUAL-RESONATOR MICROMACHINED LORENTZ FORCE MAGNETOMETER BASED ON ELECTROMECHANICAL SIGMA-DELTA MODULATIONF. Chen¹, W. Zhou¹, H. Zou¹, M. Kraft², and X. Li¹¹Chinese Academy of Sciences, CHINA and²Catholic University of Leuven, BELGIUM

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.

W-177 A MEMS RATE INTEGRATING GYROSCOPE BASED ON CATCH-AND-RELEASE MECHANISM FOR LOW-NOISE CONTINUOUS ANGLE MEASUREMENTR. Gando¹, S. Maeda¹, K. Masunishi¹, Y. Tomizawa^{1,2}, E. Ogawa¹, Y. Hatakeyama¹, T. Itakura¹, and T. Ikehashi¹¹Toshiba Corporation, JAPAN and²Device & System Platform Development Center, JAPAN

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.

M-178 DYNAMIC CONTROL OF AN ACCELEROMETER BANDWIDTH THROUGH TUNABLE DAMPING FACTOR AND EFFECTIVE MOMENT OF INERTIAB. Fain^{1,2}, F. Souchon^{1,2}, A. Berthelot^{1,2}, R. Anciant^{1,2}, P. Robert^{1,2}, and G. Jourdan^{1,2}¹Université Grenoble Alpes, FRANCE and ²CEA-LETI, FRANCE

We report the dynamic bandwidth control of an accelerometer by reducing both its damping factor and its effective inertia. The MEMS is coupled with two built-in resistors to tune the frequency response through a DC voltage. The conception, the fabrication and the electrical testing of the accelerometer are presented. The reduction of the effective moment of inertia is experimentally evidenced on the basis of an analytical model.

T-179 ROBUST, ULTRA SENSITIVE MOEMS INERTIAL SENSOR READ OUT WITH INFRARED LIGHTW. Hortschitz¹, A. Kainz², G. Kovacs¹, H. Steiner¹, M. Stifter¹, T. Sauter¹, J. Schalko², A. Jachimovics², and F. Keplinger²¹Danube University Krems, AUSTRIA and²Technische Universität Wien, AUSTRIA

High performance applications such as the detection of seismic activity or the monitoring of structural health require sensors with low resonance frequencies. We present extremely sensitive, optically read out devices with resonances as low as 45 Hz. This low resonance was mainly achieved by fabricating the complete seismic mass from one single crystal silicon block which is transparent at the operation wavelength of the readout of 1500 nm.

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

- W-180 ACCELERATION INSENSITIVE HEMISPHERICAL SHELL RESONATORS USING POP-UP RINGS**
M.M. Torunbalci, S. Dai, A. Bhat, and S.A. Bhave
Purdue University, USA

This work demonstrates a novel method for the fabrication of symmetric 3D hemispherical shell resonators (HSRs) based on HNA etching of <111> silicon using a pop-up ring mask. The proposed method is used to fabricate 650nm thick silicon dioxide HSRs with a diameter of 180 microns. The quality factor of the n=2 wine-glass mode is measured as 31,000 at 100kHz with a frequency mismatch of 500 Hz between two degenerate modes. We measure the linear acceleration sensitivity of the HSRs to X and Z acceleration.

- M-181 A MODE-LOCALIZED ACCELEROMETER BASED ON FOUR DEGREE-OF-FREEDOM WEAKLY COUPLED RESONATORS**
H. Kang, J. Yang, and H. Chang
Northwestern Polytechnical University, CHINA

We for the first time proposed a micromachined mode-localized accelerometer based on a four degree-of-freedom (4-DoF) weakly coupled resonator (WCR). The accelerometer was demonstrated in an open loop interface circuit and showed a huge sensitivity improvement compared with the reported state-of-the-art mode-localized accelerometer due to the increase of DoF of WCR. Thus the mode localized 4-DoF accelerometer has a great potential for improving the resolution under the closed loop circumstance.

- T-182 IMPACT EXPERIMENT ANALYSIS OF MEMS ULTRA-HIGH G PIEZORESISTIVE SHOCK ACCELEROMETER**
C. Jia, L. Zhao, W. Jiang, X. Liu, M. Yu, M. Huang,
Y. Xia, Y. Zhao, and Y. Zhao
Xi'an Jiaotong University, CHINA

This paper presents a novel structure of ultra-high g shock accelerometer chip with a target range up to 100,000 g. The design idea is to separate the functions of supporting and sensitive structures. The overall size of fabricated chip is 3 mm x 3 mm x 0.8 mm. The experimental test was carried out to verify the characteristic properties of shock accelerometer. The tested results demonstrate the proposed shock accelerometer has a simple structure, high sensitivity and large frequency bandwidth.

- W-183 A MODE-LOCALIZED MEMS ACCELEROMETER WITH 7 μ g BIAS STABILITY**
M. Pandit¹, C. Zhao¹, G. Sobreviela¹, A. Mustafazade¹,
X. Zou^{1,2}, and A.A. Seshia¹
¹University of Cambridge, UK and
²Chinese Academy of Sciences, CHINA

This paper reports the experimental characterization of the resolution, sensitivity and common mode rejection metrics for a novel mode-localized MEMS accelerometer. A bias stability of 7 μ g is achieved for closed-loop amplitude ratio measurements at an integration time of 30s representing a significant advance in the development of high-stability accelerometers employing this transduction principle.

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

M-184 FLUID DAMPING MODELING FOR MEMS SENSORS OPERATING IN THE 10 kHz - 100 kHz RANGE IN NEAR-VACUUMA. Frangi¹, P. Fedeli¹, G. Langfelder¹, A. Chiesa¹, and G. Gattere²
¹Politecnico di Milano, ITALY and ²STMicroelectronics, ITALY

The work proposes and experimentally verifies a new model for the prediction of the quality (Q) factor of MEMS operating in fluid damping regime in near-vacuum in a range of frequencies extending from ~10 kHz (typical of state-of-the-art inertial sensors) up to 100 kHz. The proposed method is validated through eight different test structures with varying resonance frequency and air gap. The agreement between Q factor prediction and measurement is within 8% even at the highest frequency.

T-185 HIGH STABILITY THERMAL ACCELEROMETER BASED ON ULTRATHIN PLATINUM ALD NANOSTRUCTURESC.L.M. Everhart, K.E. Kaplan, M.M. Winterkorn, H. Kwon, J. Provine, M. Asheghi, K.E. Goodson, F.B. Prinz, and T.W. Kenny
Stanford University, USA

We fabricate and demonstrate the performance of an ultra-thin platinum film thermal accelerometer based on Plasma Enhanced Atomic Layer Deposition (PEALD). The device harnesses the desirable sensor properties of platinum and PEALD to yield high stability and sensitivity as well as low drift. Device performance shows good agreement with simulation.

W-186 THERMAL EFFECTS OF OVENIZED CLOCKS ON EPISEAL ENCAPSULATED INERTIAL MEASUREMENT UNITSL. Comenencia Ortiz¹, I.B. Flader¹, G.D. Vukasin¹, D.D. Gerrard¹, S.A. Chandorkar¹, J. Rodriguez¹, D.D. Shin¹, R. Kwon¹, D.B. Heinz¹, Y. Chen², W. Park¹, K.E. Goodson¹, and T.W. Kenny¹
¹Stanford University, USA and ²Apple Inc., USA

In this paper, we demonstrate the thermal effects of micro-ovenized clocks embedded in the device layer of a vacuum sealed MEMS inertial measurement unit. We demonstrate a novel in-plane suspension and heater that provides improved thermal isolation within a mm-scale chip, compared to encapsulation heaters. We show the interaction of three resonators within a single die: an ovenized tuning fork, a resonant accelerometer, and a disk resonating gyroscope.

M-187 EXPERIMENTAL FRACTAL-LIKE INSTABILITY BANDS IN A RESONANT SILICON-SILICON CONTACT PULL-IN VIBRATION DETECTORV. Maiwald¹, I.B. Flader², M. Müller¹, Y. Chen², S. Plüss¹, D.D. Shin², C. Roman¹, D.B. Heinz², T.W. Kenny², and C. Hierold¹
¹ETH Zürich, SWITZERLAND and ²Stanford University, USA

We present theoretical and experimental data on instability bands in a low-power resonant pull-in based MEMS vibration detector. Both simulation and experiment show a complex stability region with a fractal-like boundary close to the effective resonance of the device due to the nonlinear dynamics of the system. The findings can be used to determine the triggering probability for low-power quasi-passive vibration detection.

T-188 DECOUPLING DESIGN OF STIFFNESS AND MASS FOR MICRO SHELL RESONATOR WITH HIGH SENSITIVITYW. Li, Z. Hou, D. Xiao, K. Lu, Y. Shi, Y. Wu, and X. Wu
National University of Defense Technology, CHINA

This paper proposes the decoupling design of stiffness and mass for micro shell resonator with high sensitivity using out-of-plane electrode. The shell cross-sectional shape can be designed analytically to change the effective stiffness (keff) while shell edge is just used to adjust the effective mass (Meff). Comparing with the conventional resonator using out-of-plane electrode, the present resonator reveals a smaller mode frequency and a 4.48 times improvement in drive amplitude.

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

W-189 HIGH DYNAMIC RANGE CMOS-MEMS CAPACITIVE ACCELEROMETER ARRAY

M.G. Guney, X. Li, V.P.J. Chung, J. Paramesh,
T. Mukherjee, and G.K. Fedder
Carnegie Mellon University, USA

This paper reports a high-g CMOS-MEMS capacitive accelerometer array with 92 mg bias stability and ± 50 kG designed input range. The small size and mass of individual accelerometer cells ensure high-g survivability. The on-chip integration of the readout circuitry and the MEMS transducer minimizes sense-node parasitic capacitance, hence improving sensitivity. The signals from the accelerometer cells are averaged across the array, which improves the signal to noise ratio and dynamic range.

M-190 HIGH-Q MONOCRYSTALLINE SILICON CARBIDE DISK RESONATORS FABRICATED USING DRIE OF THICK SiC-ON-INSULATOR SUBSTRATES

S.-D. Ko, B. Hamelin, J. Yang, and F. Ayazi
Georgia Institute of Technology, USA

This paper presents for the first-time high-Q BAW modes in disk resonators implemented on custom-made 100 μ m thick 4H-SiC-on-insulator (SiCOI) substrates. SiC exhibits very low intrinsic Akhiezer dissipation which is ideal for high-Q BAW gyroscopes while operating impeccably in harsh-environments. Front-side perforations in disk resonators define the frequency split (215Hz) of the secondary elliptical modes and the Q-factor (170k at 843kHz) which is the highest reported for SiC disk resonators.

T-191 FABRICATION OF HEMISPHERICAL FUSED SILICA MICRO-RESONATOR WITH TAILORED STIFFNESS AND MASS DISTRIBUTION

T. Nagourney, S. Singh, B. Shiari, J.Y. Cho, and K. Najafi
University of Michigan, USA

Fine resolution and high shock tolerance tend to be mutually exclusive for MEMS gyroscopes, as they require low stiffness and high mass which increase sensitivity to shock and vibrations. We present the fabrication of a fused silica resonator with controllable stiffness and mass distribution in 3D. This micro-shell resonator is formed and fused to a solid anchor with blowtorch molding in seconds. It has a controllable thickness profile from center to rim with both gradual and abrupt transitions.

W-192 MUTUAL CANCELLATION PHENOMENON OF THE NONLINEARITIES IN MICRO-MACHINED DOUBLE-CLAMPED BEAMS RESONATOR

D. Chen¹, X. Chen¹, Y. Guan¹, Y. Wang¹, Z. Xu¹, Y. Wang¹,
H. Lin², H. Liu², and J. Xie¹
¹Zhejiang University, CHINA and ²Soochow University, CHINA

We comprehensively analyze the interactions of electrical and mechanical nonlinearities that widely exist in general MEMS double-clamped beams resonators. The inside plate-capacitors are designed to intuitively verify the mutual cancellation between the nonlinearities. Under the mutual cancellation, the discontinuity of the resonator spectral curves is alleviated meanwhile the frequency stability and quality factor are improved.

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

M-193 EPITAXIALLY-GROWN THICK POLYSILICON FOR BAW DISK RESONATOR GYROSCOPES WITH VERY LOW DISSIPATIONA. Daruwalla, H. Wen, R. Mirjalili, and F. Ayazi
Georgia Institute of Technology, USA

This paper reports, for the first time, on characterization of gyroscopic modes in solid epi-poly disk resonators, showing Q_s exceeding 1M with a maximum $f.Q$ of $4.2e12$, and on fabrication challenges associated with implementation of solid disk BAW gyroscopes on thick 45um epitaxially-grown polysilicon. Using these, a modified HARPSS process is developed to fabricate an epi-poly $n=3$ solid-disk BAW gyro having nano-gaps with Q of 350k at 3MHz and linear scale factor in mode-matched operation.

T-194 TEMPERATURE COMPENSATION OF RESONANT ACCELEROMETER VIA NONLINEAR OPERATIOND.D. Shin¹, Y. Chen², I.B. Flader¹, and T.W. Kenny¹
¹Stanford University, USA and ²Apple Inc., USA

This paper demonstrates a simple method to improve bias stability of resonant accelerometer over large temperature range. We use nonlinear amplitude-frequency effect to reduce temperature dependence of passively temperature-compensated differential signal from two sensing resonators. Driving one resonator nonlinearly with large amplitude moves its $f-T$ characteristic closer to that of the other resonator. Preliminary results show near fivefold improvement in bias stability over -20°C to 80°C .

W-195 RESEARCH ON THE HIGH FABRICATION ERROR IMMUNITY OF THE HONEYCOMB-LIKE DISK RESONATOR GYROSCOPEQ. Li, D. Xiao, X. Zhou, Z. Hou, Y. Xu, Q. Hu, and X. Wu
National University of Defense Technology, CHINA

This paper proposes a theory of how does structural design affect the fabrication error immunity (FEI) of the mode-matched MEMS gyroscope, based on which, the high FEI of a novel honeycomb-like disk resonator gyroscope (DRG) is explicitly explained. The theory prediction coincides well with the results of simulation and statistical experiments.

M-196 STIFFNESS-MASS DECOUPLED DISK RESONATOR GYROSCOPE WITH ENHANCED PERFORMANCEX. Zhou, D. Xiao, Q. Li, Y. Xu, P. Wang, Q. Hu, Z. Hou, Y. Wu, and X. Wu
National University of Defense Technology, CHINA

This paper demonstrates a disk resonator gyroscope (DRG) that can provide inertial-grade figure of merit (FOM), which is one order of magnitude smaller than the state of the art DRG. 15-fold improvement in decaying time constant is realized by engineering thermo-elastic damping (TED). Several ways of manipulating TED are elaborated. This study may provide constructive inspirations for making batch-fabricated inertial-grade MEMS gyroscope.

MEMS Physical Sensors

Manufacturing for Physical Sensors

T-197 LOW COST THIN FILM ENCAPSULATION FOR ALN RESONATORST. Wu¹, Z. Qian², and M. Rinaldi²
¹ShanghaiTech University, CHINA and ²Northeastern University, USA

We report a hermetic thin film packaging process integrated on AlN RF resonators using low cost and bio-compatible SU-8 material. The process flow includes low-stress PECVD silicon oxide deposition, releasing hole etching and SU-8 encapsulation. The encapsulated devices are reported to survive in DI water testing without performance degradation. Both fabrication outcome and measurement results indicate high possibility in cost effective and bio-sensing applications using AlN resonators.

Manufacturing for Physical Sensors

W-198 GIANT ENHANCEMENT ON RESPONSE-SPEED OF ELECTROSPUN-BASED UV PHOTODETECTOR VIA POLYDIMETHYLSILOXANE COATING

Y. Xia, L. Zhao, D. Lu, L. Li, Y. Luo, G. Luo, Y. Zhao,
C. Jia, and Z. Jiang
Xi'an Jiaotong University, CHINA

We developed an easy and cost-effective packaging method to fasten photo response for UV photodetector by 104 times with spin-coated polydimethylsiloxane (PDMS) on electrospun-fabricated ZnO nanofibers. This research is the biggest enhancement in response-speed of PDMS coated photodetectors so far. The big enhancement in response speed was mainly attributed to gas isolation and passivation surface electron state caused by dangling bonds.

M-199 VALIDATION OF OUTPUT VOLTAGE MULTIPLICATION BY USING SERIES-CONNECTED PIEZOELECTRIC ELEMENTS FOR PHYSICAL SENSORS

K. Kanda, T. Ushita, T. Fujita, and K. Maenaka
University of Hyogo, JAPAN

For the first time, it is experimentally validated that the output voltage from series-connected piezoelectric elements on MEMS structure can be multiplied without degradation. The output voltage has been degraded for conventional devices (piezoelectric sensors) based on the series-connected piezoelectric elements because of parasitic capacitance. The elimination of the parasitic capacitance by using not Si but polymer for structural material achieves output voltage multiplication.

T-200 A NOVEL 3-AXIS TINY TACTILE SENSOR DEVELOPED BY 3-D MICROSTRUCTURING USING PUNCH CREEP FORMING PROCESS

K. Osaka, S. Nakata, K. Yamamoto, T. Toyoda,
K. Sugano, and Y. Isono
Kobe University, JAPAN

This research has newly developed a high temperature punch creep forming technique combined with a diffusion process of dopant for a downsizing of 3-axis piezoresistive tactile sensor made of Si film. We clarified creep parameters by a backward analysis to predict creep deformation behaviour of the Si films. Finite element creep analyses determined the shape and dimensions of the tactile sensor. Consequently, we succeeded in fabricating the 3-D formed tactile sensor by the punch creep forming.

MEMS Physical Sensors

Materials for Physical Sensors

M-201 *IN-SITU* PHOSPHORUS DOPED ULTRA-HIGH VACUUM E-BEAM EVAPORATED SILICON FOR HIGH GAUGE FACTOR POLYSILICON

I. Chuang, A. Michael, A. Soeriyadi, and C.Y. Kwok
University of New South Wales, AUSTRALIA

We developed a method in fabricating a controllable, high gauge factor piezoresistor under low temperature using Aluminium Induced Crystallisation. By introducing phosphorus dopants in the precursor amorphous silicon, we were able to significantly improve the piezoresistive characteristics of the AIC polysilicon film.

Materials for Physical Sensors

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

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

This paper shows the evaluation of piezoresistive property of vanadium oxide (VO_x) film. The VO_x films is deposited and patterned as a piezoresistor on an edge of suspended silicon membrane. The resistance of the VO_x 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 VO_x is 259.

MEMS Physical Sensors

Nanoscale Physical Sensors

W-203 MULTI-FREQUENCY SILICON NANOFRACTAL RESONATOR

V. Tzanov¹, J. Llobet^{2,3}, F. Torres¹, F. Pérez-Murano³,
and N. Barniol¹

¹*Universitat Autònoma de Barcelona, SPAIN,*

²*International Iberian Nanotechnology Laboratory, PORTUGAL, and*

³*Institut de Microelectrònica de Barcelona, SPAIN*

Novel top down Si-based electrostatically driven clamped-clamped resonator was manufactured. The resonating body (12 [μm] in length) is a fractal with a hexagonal shape based on a cell-triangle with a side of 3.354 [μm]. 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

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 (f_{res}~24MHz).

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

S. Jang¹, B. Chang¹, J. Sung¹, T. Kim¹, H. Ko²,
K.-I. Koo³, and D.-I. Cho¹

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.)

W-206 SNR ENHANCEMENT OF A SPIN-MEMS MICROPHONE BY OPTIMUM BIAS MAGNETIC FIELD AND DEMONSTRATION OF OPERATION SOUND MONITORING OF ROTATING EQUIPMENT

Y. Higashi, Y. Fuji, S. Kaji, K. Masunishi, T. Nagata, A. Yuzawa, K. Otsu, K. Okamoto, S. Baba, T. Ono, and M. Hara
Toshiba Corporation, JAPAN

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.

M-207 BANDWIDTH AND SNR ENHANCEMENT OF MEMS MICROPHONES USING TWO POLY-SI MICROMACHINING PROCESSES

S.-C. Lo¹, S.-K. Yeh¹, J.-J. Wang¹, M. Wu², R. Chen¹, and W. Fang¹
¹*National Tsing Hua University, TAIWAN* and
²*GlobalMEMS Co., Ltd., TAIWAN*

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.

T-208 NEW INTEGRATED FULL-RANGE MEMS SPEAKER FOR IN-EAR APPLICATIONS

F. Stoppel¹, A. Männchen², F. Niekie¹, D. Beer²,
T. Giese¹, and B. Wagner¹

¹*Fraunhofer Institute for Silicon Technology (ISIT), GERMANY* and
²*Fraunhofer Institute for Digital Media Technology (IDMT), GERMANY*

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.

W-209 DEVELOPMENT OF CAPACITIVE MEMS MICROPHONE BASED ON SLIT-EDGE FOR HIGH SIGNAL-TO-NOISE RATIO

I. Yoo, J. Sim, S. Yang, and H. Kim
Hyundai Motor Company, KOREA

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.

Sonic and Ultrasonic Transducers (Microphones, PMUTs, etc.)

M-210 THROUGH-PACKAGE WIRELESS POWERING VIA PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS

E. Mehdizadeh and G. Piazza
Carnegie Mellon University, USA

This work reports on chip scale ultrasonic power delivery through plastic packaging media using piezoelectric micromachined ultrasonic transducers (pMUT). Bulk acoustic waves generated by a commercial probe travel through a thick package and are absorbed and converted to an electrical signal using a pMUT. PMUTs as small as $200 \times 200 \mu\text{m}^2$ are used showing -29 dB power transfer efficiency in the case of a 1mm thick lossy polymer substrate.

T-211 A MEMS ACOUSTIC PARTICLE VELOCITY SENSOR BASED ON ELECTROCHEMICAL METHOD

Z. Li, W. Chang, C. Gao, and Y. Hao
Peking University, CHINA

We propose a novel method for acoustic particle velocity measurement based on electrochemical principle for the first time. A planar four electrodes structure sensor together with its packaging structure and signal processing circuit are designed based on the method, which can realize underwater sound direction localization in a single sensor cell. Without any movable microstructure, this sensor has high reliability and can bear much higher hydrostatic pressure undersea.

W-212 A SINGLE-CHIP FLOW SENSOR BASED ON BIMORPH PMUTS WITH DIFFERENTIAL READOUT CAPABILITIES

B.E. Eovino¹, Y. Liang¹, S. Akhbari², and L. Lin¹
¹*University of California, Berkeley, USA and*
²*TDK-InvenSense, USA*

This work reports the measurement of airflow for both magnitude and direction based on PMUTs for the first time. Operating in pulse-echo mode, the sensor achieves the highest sensitivity of MUT-based flow meters due to the high-performance PMUT design, separation of the Tx and Rx transducer elements, and differential readout. The improved functionality displayed by our single-chip sensor should increase the usage of ultrasonic flow meters by reducing cost and complexity of implementation.

M-213 ACOUSTIC TWEEZERS FOR SUB-MM MICROPARTICLE MANIPULATION

L. Zhao and E.S. Kim
University of Southern California, USA

We report a new design of an acoustic tweezers that can trap microparticle up to 0.5mm in diameter through a 3-dimensional energy well formed in a bulk of liquid. The acoustic tweezers is built on PZT substrate with symmetric sectors of air-cavity Fresnel lens. Each sector is designed to have a different focal length to produce a Bessel beam zone with negative axial radiation force, which traps and holds particles (0.3 to 0.5mm in diameter) at 5mm away without physical contact to any rigid body.

MEMS Physical Sensors

Other Physical Sensors

T-214 HIGH SENSITIVITY MICRO ELECTROMETER BASED ON CLAMPED FREE CURVED BEAMS RESONATOR WITH WEAKENED NONLINEARITYD. Chen¹, X. Liu¹, Y. Wang¹, Z. Xu¹, H. Lin², H. Liu², and J. Xie¹
¹Zhejiang University, CHINA and ²Soochow University, CHINA

A high performance micro electrometer based on clamped-free curved beams (CFCB) resonator is proposed. The CFCB resonator vibrated at elastic mode aims to eliminate the nonlinearity that existed in traditional resonators and lower the temperature coefficient of frequency. By using new sensing scheme of vibration perturbation to lead a frequency modulation, the sensitivity of proposed electrometer is higher than the dual beams counterparts of state of the art over order of magnitude.

W-215 FLEXIBLE ELECTRONIC-WALLPAPER INTEGRATED WITH FGRAM-BASED TACTILE MEMORY AND TEMPERATURE SENSORSS. 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 ENVIRONMENTK. 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 SENSORY. 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.

Other Physical Sensors

W-218 A CMOS COMPATIBLE GHZ ULTRASONIC PULSE PHASE SHIFT BASED TEMPERATURE SENSORM. 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

M-219 8-CHANNEL SINGLE EMBRYO PIPETTE FOR ACCURATE C. ELEGANS BIOASSAYSL. Dong, J. Zhang, T. Lehnert, and M.A.M. Gijs
École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We propose a "Single Embryo Pipette" (SEP) that is specifically designed for dispensing single *C. elegans* embryos into standard microtiter plates. Our microfluidic device takes advantage of a flexible embryo trap which can easily capture or release a single embryo on-demand by mean of tuning the loading pressure.

T-220 A MICROFLUIDIC PLATFORM WITH INTEGRATED SENSING PILLARS FOR PROTRUSIVE FORCE MEASUREMENTS IN NEUROSPORA CRASSAY. Sun, A. Tayagui, H. Shearer, A. Garrill, and V. Nock
University of Canterbury, NEW ZEALAND

We report the development of a Lab-on-a-Chip platform containing elastomeric micropillars in channel constrictions, which enable the measurement of protrusive forces exerted by individual hypha of fungi and oomycetes. The fungi *Neurospora crassa* was cultured on-chip and the force exerted by individual hyphae measured via the micropillars. The platform provides a tool to help understand the molecular dynamics that underlie protrusive growth and combat loss of biodiversity due to these organisms.

W-221 LASER-BASED SINGLE MICROSTRUCTURE ISOLATION PLATFORM FOR WHOLE GENOME SEQUENCING OF SINGLE CIRCULATING TUMOR CELLSA.C. Lee, Y. Lee, O. Kim, D. Lee, and S. Kwon
Seoul National University, KOREA

We develop a platform where we can isolate single circulating tumor cells and analyze each of their whole genomes separately using Next Generation Sequencing. By converging the fields of microfluidics, genomics, and optics, a pulsed-laser based single microstructure isolation system is used and applied to a breast cancer patient's whole blood.

Biological and Medical Microfluidics and Nanofluidics

M-222 AN INTEGRATED MICROFLUIDIC SYSTEM FOR IDENTIFICATION OF LIVE MYCOBACTERIUM TUBERCULOSIS BY REAL-TIME POLYMERASE CHAIN REACTIONK.-U. Ip¹, J.-R. Chang², T.-H. Liu¹, H.-Y. Dou², and G.-B. Lee¹¹National Tsing Hua University, TAIWAN and²National Health Research Institutes, TAIWAN

We develop integrated microfluidic system identify "live" Mycobacterium tuberculosis (TB) low concentration automatically. By PMA, RT-PCR. The PMA-RT-PCR detect live TB as low as 10 colony CFU by Ct value in calibration curve. PMA distinguish dead TB that no PCR products generated. Procedure within 2 hours. As molecular diagnostics for prognosis monitoring of TB treatment. The bactericidal activity of antibiotic cocktails detecting live TB after treatment.

T-223 VIBRATION BASED VIRTUAL VORTEX GEARH. Miyashiro¹, T. Takayama¹, C.-H.D. Tsai², and M. Kaneko¹¹Osaka University, JAPAN and ²National Chiao Tung University, TAIWAN

We introduce an interesting phenomenon named Vibration based Virtual Vortex Gear (V3G) for the applications of microfluidic mixing. V3G is a microfluidic vortex flowing like a rack and pinion gear while applying a pressure vibration. Experiments with different configurations and different structural stiffness of the chamber designs were performed. The results show that the design with asymmetric shape and softened structure can perform the most efficient mixing.

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

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" PLATFORMD.J. Kinahan¹, L.A.N. Julius¹, C. Schoen², T. Dreo³, and J. Ducreé¹¹Dublin City University, IRELAND,²Wageningen University & Research, NETHERLANDS, and³National 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

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.

Biological and Medical Microfluidics and Nanofluidics

M-227 A PDMS-BASED DIGITAL PCR CHIP WITH VACUUM ASPIRATION AND WATER-FILLING CAVITY INTEGRATED FOR SAMPLE LOADING AND EVAPORATION REDUCTIONT. Xu¹, X. Wang¹, X. Zhu², Y. Bao¹, S. Cai¹, G. Li³, and X. Li¹¹Chinese Academy of Sciences, CHINA,²Fujian Agriculture and Forestry University, CHINA, and³Chongqing 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

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 CHANNELC.-H. Li¹, K.-W. Chen², C.-L. Yang², C.-H. Lin¹, and K.-C. Hsieh¹¹National Sun Yat-sen University, TAIWAN and²National 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

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.

Generic Microfluidics and Nanofluidics

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

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 $\mu\text{g L}^{-1}$ (0.14 ppb).

M-232 GENERATION OF HANGING DROPS WITH DEFINED SOLUTION CONCENTRATIONS USING A SLIDING HANGING DROP CHIPC.-Y. Tang¹, C.-C. Fu¹, 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.

T-233 FAST AND CONTROLLABLE ELASTOCAPILLARY FLOW CHANNELS USING SUSPENDED MEMBRANESS.J. Fishlock, D. Steele, S.V. Puttaswamy, G.V. Lubarsky,
C. Navarro, W.P. Burns, and J. McLaughlin*Ulster University, UK*

This paper reports a novel elastocapillary flow channel design, for fluid flow in porous membranes, which enables a 400% increase in flow velocity compared with a porous membrane used in a standard format. The increase in flow rate is controllable and is enabled by using an elastocapillary action, where the flexible porous membrane is suspended over a rigid substrate and deformed during fluid imbibition.

W-234 SINGLE-PHASE ISOLATION OF PAIRED HETERO PARTICLES WITHIN A MICROFLUIDIC DEVICE FOR MULTIPLEX ANALYSIS WITHOUT CROSS-CONTAMINATION

W. Lee, H. Kim, S. Lee, and J. Kim

Pohang University of Science and Technology (POSTECH), KOREA

We propose an array-format microfluidic device that facilitates a multiplex analysis of paired hetero particles within confined micro-chambers. Without changing flow direction, a one-to-one pair array of microparticles is simply formed by sequential loading of the hetero particles. Cross-contamination between particle pairs is prevented for a multiplex analysis with incorporating a single-phase isolation method playing a role as same manner as well-known air curtains.

M-235 EFFECT OF BUBBLE INTERFACE POSITION ON PROPULSION AND ITS CONTROL FOR OSCILLATING-BUBBLE POWERED MICROSWIMMER

F.-W. Liu, Y. Zhan, and S.K. Cho

University of Pittsburgh, USA

Developing an acoustically oscillating bubble powered microswimmer. we report two new major contributions: we discovered that the propulsion direction could be reversed and controlled; and the position of bubble interface and thus bubble length were well controlled by introducing physical structures in the tube opening. As a result, we achieved more consistent and predictable bubble resonance and propulsion.

Generic Microfluidics and Nanofluidics

T-236 SUBMICRON DIELECTROPHORETIC CHROMATOGRAPHY

K. Kikkeri, B. Ngu, and M. Agah
Virginia Polytechnic Institute and State University, USA

This paper reports, for the first time, the integration of two unique separation methods: chromatography and dielectrophoresis (DEP). The combination of preconcentrating and separation regions governed by DEP forces and an impedance detection region, has enabled the characterization and separation of micro and submicron particles from heterogeneous mixtures.

W-237 IONIC LIQUID MICRODROPLET MANIPULATION BY ELECTROWETTING-ON-DIELECTRIC FOR ON/OFF DIFFUSION CONTROL

F. Ribet, L. De Pietro, N. Roxhed, and G. Stemme
KTH Royal Institute of Technology, SWEDEN

We present a device able to control gas diffusion and evaporation through a perforated membrane. This microfabricated system is based on electrowetting-on-dielectric actuation of ionic liquid microdroplets and can be electrically toggled (ON/OFF) from an open to a closed state, in which droplets cover or uncover membrane openings. The system was designed to be integrated onto electrochemical gas microsensors, to insulate or expose the sensing compartment on command, thus extending the lifetime.

Micro- and Nanofluidics

Integrated/Embedded Microfluidic and Nanofluidic Systems & Platforms

M-238 LASER-ACTUATED CENTRIFUGO-PNEUMATIC FLOW CONTROL TOWARDS "SAMPLE-TO-ANSWER" INTEGRATED DETECTION OF MULTI-MARKER PANELS AT THE POINT-OF-CARE

R. Mishra¹, G. Reilly¹, M. Agnew¹, A. Garvey¹, C. Rogers¹,
E. Andrade¹, H. Ma¹, S. Fitzgerald¹, J. Zapatero¹,
R. O'Kennedy^{1,2}, and J. Ducreé¹
¹*Dublin City University, IRELAND and*
²*Hamad Bin Khalifa University, QATAR*

We demonstrate advanced on-demand microfluidic flow control using Laser-actuated, Centrifugo-Pneumatic Valves allowing for large-scale integration of flexibly customizable and operationally robust centrifugal microfluidic systems. We further demonstrate the technology with the sample-to-answer automation of an immunoassay for cardiovascular disease multi-biomarker panel towards point-of-care diagnostics.

T-239 AN INTEGRATED ION CHROMATOGRAPHY MICROCHIP FOR ULTRA FAST MEASUREMENT OF GLYCATED HEMOGLOBIN LEVELS

D. Li, X. Li, and H. Chang
Northwestern Polytechnical University, CHINA

We develop an integrated ion chromatography microchip for ultrafast measurement of glycated hemoglobin (HbA1c). Except the pump, all chromatography components including four microvalves, a packed column, two porous frits and an optical detector cell are integrated on the single chip. Compared to the state-of-the-art nanoflow liquid chromatography microchip (4 μ l & 50 mins), the HbA1c levels can be precisely measured by our microchip with fewer samples (1 μ l) in a shorter period of time (5 mins).

Integrated/Embedded Microfluidic and Nanofluidic Systems & Platforms

**W-240 A 3D MICROFLUIDIC DEVICE FOR CARBON CAPTURE
MICROCAPSULES PRODUCTION**D. Wang^{1,2}, W. Yu^{1,3}, M. Gao¹, K. Liu², T. Wang³, A. Park¹, and Q. Lin¹¹Columbia University, USA, ²Northeastern University, CHINA, and³Zhejiang University, CHINA

This paper presents a novel approach to produce microcapsules for carbon capture in a microfluidic device with 3D architecture. Carbon capture material is encapsulated efficiently. Using the microencapsulation method, capture kinetics has been enhanced significantly. An order-of-magnitude increase in carbon capture rate is eventually gained.

**M-241 A SIMPLE AND FLEXIBLE ATMOSPHERIC MICROPLASMA
GENERATION DEVICE WITH PATTERNABLE
MICROFLUIDIC CHANNELS**

T. Wang, M.S. Hu, B. Yang, X.L. Wang, and J.-Q. Liu

Shanghai Jiao Tong University, CHINA

We develop a novel simple-arranged and flexible microplasma generation device (μ PGD) with predefined microfluidic channels and a sealed membrane which can generate uniform microplasmas of different micropatterns with controlled gas discharge in the air atmosphere. This fabricated device will allow maskless microfabrication on both flat and non-flat surfaces with specified working gas in the ambient air.

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

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**

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**W.-B. Lee¹, K.-M. Shen¹, H.-L. You², M.S. Lee², and G.-B. Lee¹¹National Tsing Hua University, TAIWAN and²Chang 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.

Integrated/Embedded Microfluidic and Nanofluidic Systems & Platforms

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

D.J. Kinahan¹, S.M. Delgado^{2,3}, L.A.N. Julius¹, A. Mallette^{1,4},
D. Saenz-Ardila^{2,3}, R. Mishra¹, C.M. Miyazaki^{1,5}, J. Korvink⁴,
D. Mager⁴, and J. Duce¹

¹Dublin City University, IRELAND, ²University of Freiburg, GERMANY, ³Karlsruhe Institute of Technology, GERMANY, ⁴University of Notre-Dame, USA, and ⁵Universidade 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.

W-246 EMBEDDED PASSIVE NANO-LITER MICROPUMP FOR SWEAT COLLECTION AND ANALYSIS

E. Garcia-Cordero¹, F. Wildhaber², F. Bellando¹, J. Longo²,
M. Fernández-Bolanños¹, H. Guerin², and A.M. Ionescu¹

¹École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND and ²Xsensio, SWITZERLAND

We present a method to integrate biocompatible zero energy microfluidic systems within a sensing platform to allow continuous analysis of sweat in a wearable fashion. The microfluidics are designed to work with sub-nano-liter concentrations of liquid to enable sweat analysis even if a person is in steady state. The process is compatible with standard semiconductor techniques making it robust, scalable and ideal for integration with different sensing technologies.

M-247 MICROFLUIDIC OXYGEN SENSOR BASED ON SILICA GELS FOR LONGTERM EXPERIMENTS

F. Bunge¹, S. van den Driesche¹, A. Waite²,
U. Mirastschijski¹, and M.J. Vellekoop¹

¹University of Bremen, GERMANY and
²Alfred-Wegener-Institute, GERMANY

We present a microfluidic chip made of glass and silicon with integrated phosphorescent elements with a matrix out of silica gel and the oxygen sensitive dye PtTFPP. The influence of the temperature is eliminated by the integration of a temperature sensor and heating elements on the chip. Our device shows a 36 times lower oxygen consumption due to photooxidation of the film compared to a conventional film with an organic matrix. So the presented chip is well suited for long-term oxygen sensing.

T-248 PAPER BASED INTEGRATED MICROFLUIDIC SYSTEM USING ELECTRO-OSMOTIC PUMPS WITH LIQUID BRIDGES

A.Y. Celik, K. Kaya, and S. Mutlu
Bogazici University, TURKEY

We develop paper based electro-osmotic pumps with liquid bridge connections, their design optimization and integration for the first time. Electrodes are placed to reservoir openings of liquid bridges not to expose the sample liquid to electric field. This results in a standard EOP design implemented on paper substrates via wax printing with width and length parameters. Computational optimization is used to design. An example system with two paper EOPs demonstrate their integration capability.

Integrated/Embedded Microfluidic and Nanofluidic Systems & Platforms

W-249 AUTOMATED FLOW-BASED/DIGITAL MICROFLUIDIC PLATFORM INTEGRATED WITH ONSITE ELECTROPORATION PROCESS FOR MULTIPLEX GENETIC ENGINEERING APPLICATIONS

K. Iwai^{1,2}, D. Ando^{1,3}, P.W. Kim^{1,2}, P.C. Gach^{1,2}, M. Raje^{1,2},
T.A. Duncomb^{1,2}, J.V. Heinemann^{1,3}, T.R. Northen^{1,3,4},
H.G. Martin^{1,3}, N.J. Hillson^{1,3,4}, P.D. Adams^{1,3}, and A.K. Singh^{1,2}
¹Joint Bio Energy Institute, USA, ²Sandia National Laboratories, USA,
³University of California, Berkeley, USA, and ⁴DOE Joint Genome
Institute, USA

We present a novel automated flow-based/digital microfluidic platform integrated with onsite electroporation function. In addition to high-throughput arraying and mixing of DNA parts and cells in microdroplets, proposed platform is capable of multiplexed electroporation processes and dual optical detection of expressed fluorescence on chip. Our platform would allow completely automated and robust genetic engineering steps towards cost-effective synthetic biology applications.

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

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 CHARACTERIZATION OF NANOPOROUS ALUMINUM OXIDE MEMBRANES IN MICROFLUIDIC CHIPS

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

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.

Manufacturing for Micro- and Nanofluidics

- M-253 A NEW METHOD TO MANUFACTURE PARYLENE MICROCAPILLARIES**
T.-C. Chou¹, Y. Pi^{1,2}, H. Xu², and Y.-C. Tai¹
¹California Institute of Technology, USA and ²Peking 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**
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**
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 SIMULTANEOUS IMPROVEMENT OF SURFACE FINISH AND BONDING OF CENTRIFUGAL MICROFLUIDIC DEVICES IN CYCLO-OLEFIN POLYMERS**
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 of nanometers, and to achieve robust bonding. Here we report that a chemical polishing step, used for smoothing 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**
M.A. Indianto, M. Toda, and T. Ono
Tohoku University, JAPAN

This research offers simple fabrication of the microchannel resonator by assembling 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.

Manufacturing for Micro- and Nanofluidics

W-258 A FACILE ALIGNMENT OF PDMS LAYERS FOR THE FABRICATION OF 3D MICROFLUIDIC DEVICES USING SYNERGISTIC ZIPPER STRUCTURESL. Wu¹, T. Xu¹, G. Li², X. Zhu³, and J. Zhao¹¹Chinese Academy of Sciences, CHINA,²Chongqing University, CHINA, and³Fujian 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

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

T-260 PHASE SHIFT EFFECT OF DOUBLE DIELECTRIC LAYERS IN ELECTROWETTING ON DIELECTRIC MICROFLUIDIC DEVICE

M. Torabinia, A. Venkatesan, and H. Moon

University of Texas, Arlington, USA

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

W-261 MICROFLUIDIC FABRICATION APPROACH FOR ATOMIC FORCE MICROSCOPE CANTILEVERS WITH PHOTOCURABLE RESINS

B. Lee, Y. Yoon, and J. Lee

Sogang University, KOREA

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.

Other Micro- and Nanofluidics

M-262 EFFECT OF CONTACT DIAMETER OF THE SESSILE DROPLET ON SAW ATTENUATION FOR POTENTIAL MICROFLUIDIC APPLICATIONS

Y. Wang, D. Chen, X. Chen, Z. Xu, and J. Xie
Zhejiang University, CHINA

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.

T-263 THREE-DIMENSIONAL (3D) MAGNETIC DROPLET MANIPULATION FOR BIOMEDICAL APPLICATIONS

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

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 speed for molecular diagnostic applications.

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

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 growing nanoparticles to a diameter greater than $1\mu\text{m}$, the proposed device enables optical methods to detect the individual nanoparticles which cannot be seen optically due to their small size. The proposed device shows the potential of realizing 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

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% H_2O_2 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

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.

Other Micro- and Nanofluidics

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

M. Toda¹, T. Yamagami¹, N. Inomata¹, T. Fujii², and T. Ono¹

¹Tohoku University, JAPAN and ²National 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 CO₂ 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 CO₂ 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.



The poster features logos for EPFL (École Polytechnique Fédérale de Lausanne), OMN 2018, and IEEE. The main title is "INTERNATIONAL CONFERENCE ON OPTICAL MEMS AND NANOPHOTONICS" held in "LAUSANNE, SWITZERLAND" from "29 JULY - 2 AUGUST 2018". A photograph of a modern building with a curved roof is shown at the bottom. The poster lists the General Chair as Niels Quack (EPFL), Nanophotonics Program Chair as Hans Peter Herzig (EPFL), and Optical MEMS Program Chair as Yves Alain Peter (Polytechnique Montréal). It also includes the abstract deadline of 22 April 2018 and the website www.omn2018.org. At the bottom, logos for EDS Polytechnique Montréal, Swiss Photonics, csem, MEMS Journal, and IEEE Photonics Society are displayed.

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