THE 27TH IEEE INTERNATIONAL CONFERENCE ON
MICRO ELECTRO MECHANICAL SYSTEMS

MEMS 2014
FINAL PROGRAM

JANUARY 26-30, 2014

MEMS 2014 SAN FRANCISCO

THE 27TH IEEE INTERNATIONAL CONFERENCE ON MICRO ELECTRO MECHANICAL SYSTEMS

Conference Chairs:
Farrokh Ayazi
Georgia Institute of Technology, USA
Chang-Jin "CJ" Kim
University of California, Los Angeles, USA

Sponsored by:

IEEE Robotics & Automation Society

CONFERENCE AT A GLANCE

MEMS 2014

SUNDAY, JANUARY 26, 2014

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

MONDAY, JANUARY 27, 2014

08:00 - 08:20	**Welcome Address** Conference Chairs: Farrokh Ayazi & Chang-Jin "CJ" Kim
08:20 - 09:00	**PLENARY SPEAKER I** **MICROFABRICATED IMPLANTABLE WIRELESS SENSORS: PERMANENT AND BIODEGRADABLE IMPLEMENTATIONS** Mark G. Allen *University of Pennsylvania, USA*
09:00 - 10:00	SESSION I - BIOMEDICAL MICRODEVICES
10:00 - 10:45	Break & Exhibit Inspection
10:45 - 11:45	SESSION II - GYROS & ACCELEROMETERS
11:45 - 13:00	Lunch & Exhibit Inspection
13:00 - 15:00	POSTER/ORAL SESSION I
15:00 - 16:00	SESSION III - MATERIALS & PROCESS CHARACTERIZATION
16:00 - 16:30	Break & Exhibit Inspection
16:30 - 17:30	SESSION IV - FABRICATION
17:30	Adjourn for the Day

TUESDAY, JANUARY 28, 2014

08:00 - 08:05	Announcements
08:05 - 08:45	**PLENARY SPEAKER II** **BIONIC SKINS USING FLEXIBLE ORGANIC DEVICES** Takao Someya *University of Tokyo, JAPAN*
08:45 - 10:00	SESSION V - OPTICAL & MAGNETIC MICRODEVICES
10:00 - 10:45	Break & Exhibit Inspection
10:45 - 12:15	SESSION VI - FLUIDIC MICRODEVICES
12:15 - 12:30	MEMS 2015 Conference Announcement
12:30 - 14:00	Lunch on Own & Exhibit Inspection
14:00 - 16:00	POSTER/ORAL SESSION II
16:00 - 17:30	SESSION VII - RESONANT MICRODEVICES & SENSORS
17:30	Adjourn for the Day

CONFERENCE AT A GLANCE (con't.)

MEMS 2014

WEDNESDAY, JANUARY 29, 2014

08:00 - 08:05	Announcements
08:05 - 08:45	PLENARY SPEAKER III **CAVITY QUANTUM OPTOMECHANICS: COUPLING LIGHT AND MICROMECHANICAL OSCILLATORS** Tobias Kippenberg *Ecole Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND*
08:45 - 09:45	SESSION VIII - NANODEVICES
09:45 - 10:30	Break & Exhibit Inspection
10:30 - 11:30	SESSION IX - ENERGY HARVESTING & POWER
11:30 - 13:00	Lunch on Own & Exhibit Inspection
13:00 - 15:00	POSTER/ORAL SESSION III
15:00 - 16:00	SESSION X - MICRODEVICES FOR CELL MANIPULATION
16:00 - 16:30	Break & Exhibit Inspection
16:30 - 17:30	SESSION XI - BIO-INSPIRED MICROACTUATORS
17:30	Adjourn for the Day
19:00 - 22:00	Conference Banquet

THURSDAY, JANUARY 30, 2014

08:00 - 08:05	Announcements
08:05 - 08:45	PLENARY SPEAKER IV **COMMERCIALIZATION OF WORLD'S FIRST PIEZOMEMS RESONATORS FOR HIGH PERFORMANCE TIMING APPLICATIONS** Harmeet Bhugra *Integrated Device Technology, Inc., USA*
08:45 - 09:45	SESSION XII - RESONATORS & RF MEMS
10:00 - 12:00	POSTER/ORAL SESSION IV
12:00 - 12:45	SESSION XIII - CHEMICAL SENSORS & SYSTEMS
12:45 - 13:00	Award Ceremony
13:00	Conference Adjourns

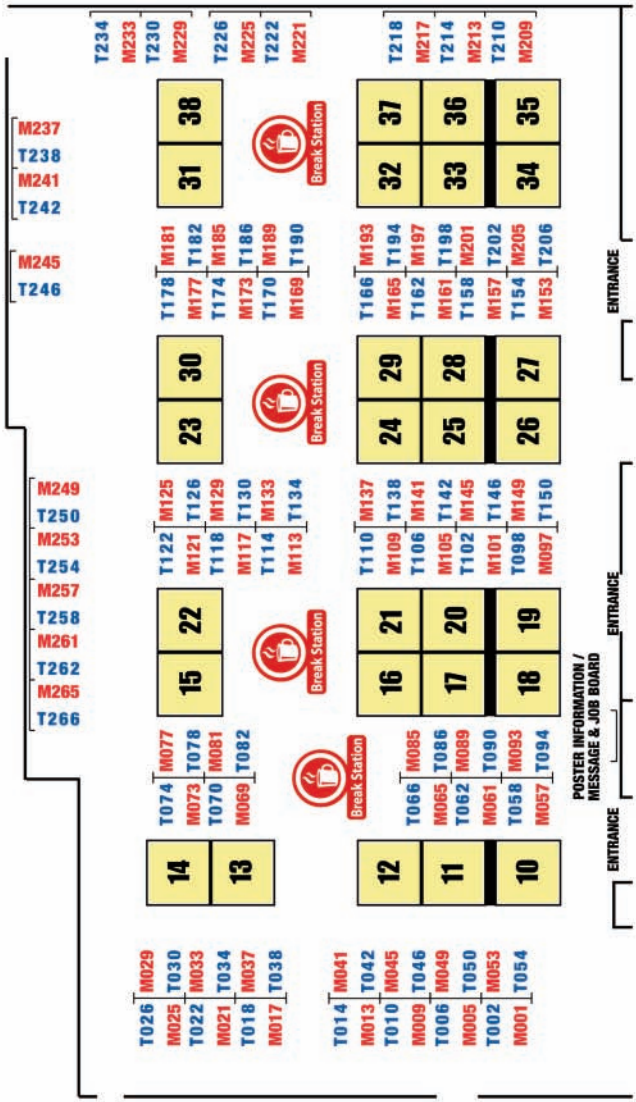
TABLE OF CONTENTS

MEMS 2014

POSTER FLOORPLAN

MEMS 2014

MONDAY & TUESDAY



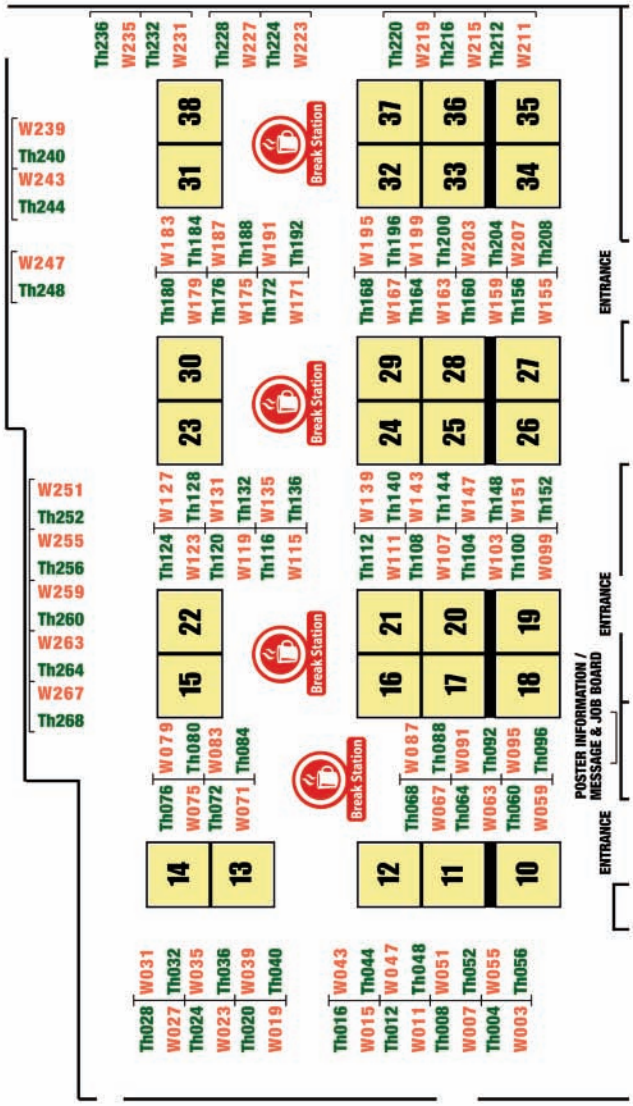
LEGEND

- Monday Posters
- Tuesday Posters

POSTER FLOORPLAN

MEMS 2014

WEDNESDAY & THURSDAY



LEGEND

- Wednesday Posters
- Thursday Posters

TECHNICAL PROGRAM INFORMATION

The Technical Program consists of four (4) plenary speaker presentations, a general session of contributed papers and four (4) poster/oral sessions.

Oral Sessions

All oral sessions will be held in the Grand Ballroom.

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.

Posters will be on display in two (2) groups. Monday and Tuesday posters will be on display Monday and Tuesday only. Wednesday and Thursday posters will be on display Wednesday and Thursday only. All poster papers are listed in this program by topic category with their assigned number starting on page 48. Authors will be available for questions throughout the entire assigned session.

SESSION I	SESSION III
Monday, January 27	Wednesday, January 29
13:00 – 15:00	13:00 – 15:00
Poster/Oral Presentation 1 – 13:30	Poster/Oral Presentation 1 – 13:30
Poster/Oral Presentation 2 – 14:00	Poster/Oral Presentation 2 – 14:00
Poster/Oral Presentation 3 – 14:30	Poster/Oral Presentation 3 – 14:30
SESSION II	**SESSION IV**
Tuesday, January 28	Thursday, January 30
14:00 – 16:00	10:00 – 12:00
Poster/Oral Presentation 1 – 14:30	Poster/Oral Presentation 1 – 10:30
Poster/Oral Presentation 2 – 15:00	Poster/Oral Presentation 2 – 11:00
Poster/Oral Presentation 3 – 15:30	Poster/Oral Presentation 3 – 11:30

Guide to Understanding Poster Numbering

Each poster is assigned a unique number which clearly indicates when and where the poster is presented. The number of each poster is shown on the left-hand side before the title.

A typical poster number shown here is: **Th-132**

The first character (i.e. **Th**) indicates the day of the Conference:
M = **Monday**, **T** = **Tuesday**, **W** = **Wednesday**, **Th** = **Thursday**

The next character (i.e. **132**) is the assigned poster board position on the floorplan.

See floorplans on pages 24 and 25.

Page Numbering

To assist you with finding the paper in the **Technical Digest**, we have provided the page number following each paper title.

MONDAY PROGRAM

MEMS 2014

SUNDAY, JANUARY 26

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

MONDAY, JANUARY 27

08:00 **Opening and Welcome Address**

PLENARY SPEAKER I

Session Chairs:
F. Ayazi, *Georgia Institute of Technology, USA*
CJ Kim, *University of California, Los Angeles, USA*

08:20 **MICROFABRICATED IMPLANTABLE WIRELESS MICROSYSTEMS: PERMANENT AND BIODEGRADABLE IMPLEMENTATIONS.....1**
Mark G. Allen
University of Pennsylvania, USA

SESSION I – BIOMEDICAL MICRODEVICES

Session Chairs:
K. Peterson, *Profusa, USA*
J. Lammertyn, *KU Leuven, BELGIUM*

09:00 **AN INTEGRATED MICROFLUIDIC SYSTEM FOR RAPID ISOLATION AND DETECTION OF LIVE BACTERIA IN PERIPROSTHETIC JOINT INFECTIONS.....5**
W.H. Chang[1], C.H. Wang[1], S.Y. Yang[2], Y.C. Lin[2], J.J. Wu[3], M.S. Lee[4], and G.B. Lee[1]
[1]*National Tsing Hua University (NTHU), TAIWAN,*
[2]*Jabil Circuit Inc., Ltd, TAIWAN,*
[3]*National Cheng Kung University, TAIWAN, and*
[4]*Chia-Yi Chang Gung Memorial Hospital, TAIWAN*

An integrated microfluidic system was presented in this work, which could distinguish the existence of live bacteria within 1 hour. This is the first time that a microfluidic platform was reported to detect live bacteria in periprosthetic joint infection samples.The results demonstrated that the proposed system can detect live bacteria successfully in the micro-environment of clinical samples. The proposed system can be a promising tool for the clinicians with timely medical decisions.

09:15 **A CABLE-TIE-TYPE PARYLENE CUFF ELECTRODE FOR PERIPHERAL NERVE INTERFACES 9**
H.Q. Yu, W.J. Xiong, H.Z. Zhang, W. Wang, and Z.H. Li
Peking University, CHINA

We design, fabricate and characterize a cable-tie-type parylene cuff electrode for peripheral nerve interfaces, whose diameter is adjustable to accommodate the nerve properly during implantation. Cuffs made of thin and flexible parylene minimize mechanical damage to surrounding tissues after implantation. Moreover, the integrated parylene cable and pads facilitate connection with external circuits through wired or wireless interfaces. The acute in vivo rat experiments were performed to verify the ability for the neural recording and selective stimulation of different nerve fascicles.

SESSION I (con't.)

09:30 **A SILICON ELECTRO-MECHANO TISSUE ASSAY SURGICAL TWEEZER** **13**

P.-C. Chen[1], C. Wu[2], F. Michelassi[1], and A. Lal[1]
[1] *Cornell University, USA and* [2] *University of Pennsylvania, USA*

This paper reports a first-ever silicon surgical tweezer for characterizing electromechanical properties of tissue. Unlike the other probe-like tissue stiffness tactile sensors, the tweezer structure provides a platform for the clinical use during surgery. We chose to pursue an all-silicon tweezer, instead of attaching sensors to existing tweezers, for repeatable tissue assessment across surgeries without external calibration.

09:45 **HIGHLY PACKED LIPOSOME ASSEMBLIES TOWARD SYNTHETIC TISSUE** **17**

H. Hamano[1], T. Tonooka[1], T. Osaki[1,2], and S. Takeuchi[1,2]
[1] *University of Tokyo, JAPAN and*
[2] *Kanagawa Academy of Science and Technology, JAPAN*

We present a highly-packed liposome assembly that implements lipid bilayer-lipid bilayer contact at the interfaces for mimicking cell-cell connection on living tissues. The closely packed liposomes, based on our previous technique producing a monodisperse liposome array, facilitate easy modification in size and components of the model structures as well as long-term observation of their interfaces. We believe that the assembly technique would help providing a synthetic tissue model.

10:00 **Break & Exhibit Inspection**

SESSION II – GYROS & ACCELEROMETERS

Session Chairs:

D. Horsley, *University of California at Davis, USA*
H. Külah, *Middle East Technical University, TURKEY*

10:45 **WHOLE-ANGLE-MODE MICROMACHINED FUSED-SILICA BIRDBATH RESONATOR GYROSCOPE (WA-BRG)** **20**

J.-K. Woo, J.Y. Cho, C.W. Boyd, and K. Najafi
University of Michigan, USA

We report the fused-silica birdbath resonator gyroscope (BRG) with a large angular gain, controlled in the whole angle (WA) mode. The BRG is fabricated using the micro-blow-torching process and exhibits good mechanical symmetry, which is ideal for WA mode operation. We adopted the control algorithm for the hemispherical resonator gyroscope (HRG). We report a large bandwidth and full-scale range of 700 deg/s with a large angular gain ($A_g = 0.27$).

11:00 **100K Q-FACTOR TOROIDAL RING GYROSCOPE IMPLEMENTED IN WAFER-LEVEL EPITAXIAL SILICON ENCAPSULATION PROCESS** **24**

D. Senkal[1], S. Askari[1], M.J. Ahamed[1], E.J. Ng[2], V. Hong[2], Y. Yang[2], C.H. Ahn[2], T.W. Kenny[2], and A.M. Shkel[1]
[1] *University of California, Irvine, USA and* [2] *Stanford University, USA*

This paper reports a new type of degenerate mode gyroscope with measured Q-factor of > 100,000 on both modes at a compact size of 1760 µm diameter. The toroidal ring gyroscope consists of an outer anchor ring, concentric rings nested inside the anchor ring and an electrode assembly at the inner core. Devices were fabricated using high-temperature, ultra-clean epitaxial silicon encapsulation (Epi-Seal) process.

SESSION II (con't.)

11:15 **SINGLE PROOF-MASS TRI-AXIAL PENDULUM ACCELEROMETERS OPERATING IN VACUUM.....28**

D.E.Serrano[1,2], Y. Jeong[1], V. Keesara[2], W.K. Sung[2], and F. Ayazi[1,2]
[1] *Georgia Institute of Technology, USA and* [2] *Qualtré, USA*

This paper reports on the design, fabrication and characterization of single proof-mass tri-axial capacitive accelerometers coexisting in a wafer-level packaged (WLP) low-pressure environment with high-frequency gyroscopes, for the implementation of monolithic 6-degree-of-freedom (6-DOF) inertial measurement units (IMUs). The accelerometers are designed to operate as quasi-static devices (i.e. non-resonant sensors) in high vacuum levels (1 – 10 Torr) by increasing squeeze-film air damping through the use of capacitive nano-gaps (< 300 nm).

11:30 **SIMULTANEOUS DETECTION OF LINEAR AND CORIOLIS ACCELERATIONS ON A MODE-MATCHED MEMS GYROSCOPE.....32**

S. Sonmezoglu, H.D. Gavcar, K. Azgin, S.E. Alper, and T. Akin
Middle East Technical University (METU), TURKEY

This paper presents a novel "in operation acceleration sensing and compensation method" for a single-mass mode-matched MEMS gyroscope. In this method, the amplitudes of the sustained residual quadrature signals on the differential sense-mode electrodes are compared to measure the linear acceleration acting on the sense-axis of the gyroscope. Measuring the acceleration along the sense-axis, the sensitivity of the gyroscope output to linear accelerations along this axis is eliminated without using a dedicated accelerometer.

11:45 **Lunch & Exhibit Inspection**

13:00 **Poster/Oral Session I** *see page 48 for listing of presentations*

SESSION III– MATERIALS AND PROCESS CHARACTERIZATION

Session Chairs:
M. Despont, *CSEM, SA, SWITZERLAND*
H. Toshiyoshi, *University of Tokyo, JAPAN*

15:00 **A STATIC CAPACITANCE PROBE STRUCTURE FOR RESOLVING THE SIDEWALL SKEW ANGLE OF SILICON DEEP REACTIVE-ION ETCHING.....36**

K. Jia, A. Geisberger, A. Dickens, R. Steimle, D.C. Chang,
P. Winebarger, L. Liu, and A. McNeil
Freescale Semiconductor Inc., USA

This work presents a design that enables quantitative characterization of the silicon Deep Reactive-Ion Etching sidewall skew angle using static LCR prober at ambient pressure, which provides an easy, accurate and batch solution to the long existing challenge of resolving such process features in an industrial manufacturing environment.

SESSION III (con't.)

15:15 INVAR-36 MICRO HEMISPHERICAL SHELL RESONATORS 40
N. Mehanathan, V. Tavassoli, P. Shao, L. Sorenson, and F. Ayazi
Georgia Institute of Technology, USA

We report the successful fabrication as well as operational characterization of electroplated Invar micro-hemispherical shell resonators. Additionally, the heat treatment of the samples and its effect on the quality factor of the resonators is studied. We show that thermal annealing shifts the coefficient of thermal expansion (CTE) of the alloy towards its minimum, as a result of which the Q increases at least 3 times and reaches ~7500. An annealed electroplated Invar μHSR shows Q of 7500, where unannealed electroplated Invar μHSRs have Qs in the range 2000-3000.

15:30 IMPLEMENTATION OF SINGLE/MULTI-LAYER MAGNETIC-ANISOTROPY MAGNETIC POLYMER COMPOSITES FOR MAGNETIC PROPERTY MODULATION 44
F.-M. Hsu, W.-C. Chen, W.-M. Lai, Y.-C. Sun, and W. Fang
National Tsing Hua University (NTHU), TAIWAN

This study extends the two-stage solidification technology to fabricate the isotropic/anisotropic magnetic polymer composites (MPC, polymer with magnetic particles). Multilayer magnetic-anisotropy/isotropic MPC film can also be implemented using the two-stage solidification process layer by layer. Merits of proposed technology: (1) material properties of magnetic-anisotropy MPC layer is realized using the two stage solidification and anisotropic-magnetization processes, and (2) film of various magnetic properties can also be implemented using the different combination of multilayer magnetic-anisotropy MPCs. In applications, the multilayer polymer-NdFeB magnetic composites are realized in silicon substrate and further integrate with MEMS structures. The 1-4 layers of different magnetic-anisotropy MPC are demonstrated. Performances enhancement of magnetic-anisotropy 30wt%-NdFeB MPC (vs isotropic MPC) are: coercivity force (3.4%), remanence (304%), and saturation magnetization (268%). Anisotropic magnetostatic shielding effect (reduce from 0.45Telsa to 0.3-0.35Telsa) is achieved. Moreover, change of magnetic field distributions after stacking of different magnetic-anisotropy MPC layers is also demonstrated.

15:45 CNT BUNDLES GROWTH ON MICROHOTPLATES FOR DIRECT MEASUREMENT OF THEIR THERMAL PROPERTIES 48
C. Silvestri, B. Morana, G. Fiorentino, S. Vollebregt, G. Pandraud, F. Santagata, G.Q. Zhang, and P.M. Sarro
Delft University of Technology, THE NETHERLANDS

Vertically aligned Carbon Nanotubes (CNT) arrays were successfully grown on top of freestanding microheaters. This was made to investigate the thermal dissipation properties of CNTs bundles and their applicability as heat exchanger. The 70μm high bundles have a diameter of 20 and 200μm. A Platinum thin film microheater, integrated on a freestanding SiN membrane, is used as heat source and as temperature sensor. The power consumption of the micro-heaters with different CNTs patterns, is measured in air. At 300 ºC a power increase up to 31% was recorded for the microheaters equipped with the CNTs.

16:00 Break & Exhibit Inspection

SESSION IV– FABRICATION

Session Chairs:

J. Kim, *Pohang University of Science & Technology, SOUTH KOREA*

B. Pruitt, *Stanford University, USA*

16:30 **3D ICE PRINTING AS A FABRICATION TECHNOLOGY OF MICROFLUIDICS WITH PRE-SEALED REAGENTS** **52**

H.Z. Zhang, H. Li, M.X. Wu, H.Q. Yu, W. Wang, and Z.H. Li

Peking University, CHINA

We propose a innovative and inexpensive method to fabricate 3D structure featured by ice printing.This "bottom-up" 3D fabrication method is achieved by printing water onto the cold substrate and turning into ice structure layer by layer.Through this method, fluid with reagents, such as drugs and nanoparticles, is sealed into microfluidics during fabrication which can be used for drug delivery or other medical care applications.Moreover, a complex microchannels is easily fabricated using 3D ice structure as soft lithography mould, which can be used for microfluid-mixer, three dimensional flow focusing ect.

16:45 **LIQUID-FILLED SEALED MEMS CAPSULES FABRICATED BY FLUIDIC SELF-ASSEMBLY** **56**

M. Mastrangeli, L. Jacot-Descombes, M.R. Gullo, and J. Brugger

Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND

We present an innovative method based on fluidic self-assembly for the encapsulation of functional liquids into sealed picoliter MEMS capsules. Capsules self-assembly and liquid co-encapsulation are achieved through the interplay of global fluidic stirring and local capillary forces ensuing from a selectively-precipitated insoluble polymeric phase. Our encapsulation method is massively parallel, scalable and compatible with batch MEMS fabrication. It can address a large variety of applications, including distributed MEMS sensors, self-healing materials, fragrance release and drug delivery.

17:00 **3D MASK MODULES USING TWO-PHOTON DIRECT LASER WRITING TECHNOLOGY FOR CONTINUOUS LITHOGRAPHY PROCESS ON FIBERS** **60**

M. Hayashi[1,2], Y. Zhang[1], M. Hayase[2], T. Itoh[1], and R. Maeda[1]

[1] *National Institute of Advanced Industrial Science and Technology (AIST), JAPAN and* [2] *Tokyo University of Science, JAPAN*

In this paper, we report a new fabrication method of 3D mask modules using two-photon direct laser writing technology in 140 µm-diameter half-pipe structures on quartz substrates. For the first time, the two-photon direct laser writing technology is utilized for the high resolution patterning process on a curved surface. The minimum feature sizes of about 2 µm line and space are successfully fabricated across the whole 140 µm-diameter half-pipe structures. Using the new 3D mask modules, fine metal patterns are prepared on 125 µm-diameter fiber.

SESSION IV (con't.)

17:15 FABRICATION OF A MONOLITHIC MICRODISCHARGE-BASED PRESSURE SENSOR FOR HARSH ENVIRONMENTS.....64

X. Luo, C.K. Eun, and Y.B. Gianchandani
University of Michigan, USA

We present a 6-mask monolithic fabrication process for a pressure sensor that uses a differential microdischarge signal to sense diaphragm deflection. Microdischarge-based transduction is advantageous for harsh environments because of its immunity to temperature and inherently large signals. This work reports the first monolithic fabrication process that successfully addresses a number of challenges for microdischarge-based pressure sensors. Compared to prior work, it results in a ≈30× smaller exterior volume (0.05mm3), a ≈30× wider pressure range (40MPa), and backside terminals for appropriate packages.

17:30 Adjourn for the day

TUESDAY, JANUARY 28

08:00 **Announcements**

PLENARY SPEAKER II

Session Chairs:
H. Toshiyoshi, *University of Tokyo, JAPAN*
X. Wang, *Tsinghua University, CHINA*

08:05 **BIONIC SKINS USING FLEXIBLE ORGANIC DEVICES.....68**
Takeo Someya[1,2] and T. Sekitani[1,2]
[1]*University of Tokyo, JAPAN and*
[2]*Japan Science and Technology Agency (JST), JAPAN*

SESSION V – OPTICAL & MAGNETIC MICRODEVICES

Session Chairs:
N. Miki, *Keio University, JAPAN*
H. Zappe, *University of Freiburg, GERMANY*

08:45 **DEVELOPMENT OF MICRO VARIABLE OPTICS ARRAY.....72**
Y. Kwon[1], Y. Choi[1], K. Choi[1], Y. Kim[1], S. Choi[2], J. Lee[2], and J. Bae[1]
[1]*Samsung Electronics Co., Ltd., SOUTH KOREA and*
[2]*Seoul National University, SOUTH KOREA*

We develop a micro variable optics array which modulates the direction of a light beam. Each pixel of the device has an interface of two immiscible liquids at which the lights are deflected and the interface is actuated on the four separated wall electrodes of the pixel by electrowetting. The four separated electrodes enable the every single pixel to work independently with multiple degrees of freedom, e.g. various tilting angles in every direction for prism or a large number of curvatures for lens mode.

09:00 **MINIATURIZED MAGNETOELASTIC TAGS USING FRAME-SUSPENDED HEXAGONAL RESONATORS.....76**
J. Tang, S.R. Green, and Y.B. Gianchandani
University of Michigan, USA

Magnetoelastic resonators are of considerable interest for passive wireless interrogation and detection. This paper presents miniaturized magnetoelastic tags using hexagonal resonators with an overall size of about ø1.3mm X 27μm, and a resonant frequency as high as 2.13MHz. The tags are 100X smaller than typical commercial tags. The frame-suspension results in ≈75X improvement in signal amplitude of hexagonal tags compared to that of non-suspended disc tags. This paper also demonstrates that the signal amplitude can be boosted by utilizing signal superposition of an ensemble of tags.

09:15 **SINGLE-STRUCTURE 3-AXIS LORENTZ FORCE MAGNETOMETER WITH SUB-30 nT/√Hz RESOLUTION.....80**
M. Li[1], E.J. Ng[2], V.A. Hong[2], C.H. Ahn[2], Y. Yang[2], T.W. Kenny[2], and D.A. Horsley[1]
[1]*University of California, Davis, USA and* [2]*Stanford University, USA*

This work demonstrates a 3-axis Lorentz force magnetometer for electronic compass purposes. The magnetometer measures magnetic flux in 3 axes using a single structure with sub-30 nT/√Hz resolution. Assuming 10 μT Earth's field, the magnetometer has an angular resolution of 0.17 deg/√Hz with 1 mW power consumption. Compared to the 3-axis Hall sensors currently used in smartphones, the 3-axis magnetometer shown here has the advantages of 10× lower noise floor and the ability to be co-fabricated with MEMS inertial sensors.

SESSION V (con't.)

09:30 **DESIGN, FABRICATION AND CHARACTERIZATION OF TUNABLE PERFECT ABSORBER ON FLEXIBLE SUBSTRATE.....84**

X. Zhao[1], K. Fan[1], J. Zhang[1], H.R Seren[1], G.D. Metcalfe[2], M. Wraback[2], R.D. Averitt[1], and X. Zhang[1]

[1]*Boston University, USA and* [2]*U.S. Army Research Laboratory, USA*

This paper reports our recent progress on a highly flexible actively tunable metamaterial (MM) perfect absorber at terahertz frequencies. The MM array on GaAs thin-film was patterned on 5μm polyimide substrate via transfer printing technique, and the backside of the substrate was coated with gold. THz time-domain-spectroscopy measurements show that the absorptivity at resonance frequency of 1.59THz can be tuned up to 60% by photo-excitation of free carriers in GaAs patches. Our flexible tunable MM perfect absorber has potential applications in energy harvesting, and imaging.

09:45 **TUNABLE META-FLUIDIC-MATERIALS BASE ON MULTILAYERED MICROFLUIDIC SYSTEM.....88**

W.M. Zhu[1], B. Dong[1], Q.H. Song[2], W. Zhang[1], R.F. Huang[3], S.K. Ting[3], and A.Q. Liu[1,2]

[1]*Nanyang Technological University, SINGAPORE,*
[2]*Xi'an Jiao Tong University, CHINA, and*
[3]*Temasek Laboratories, SINGAPORE*

We demonstrate a multilayered microfluidic system with a flexible substrate, which has tunable optical chirality within THz spectrum range. The optical properties of the multilayered microfluidic system can be tuned by either changing the liquid pumped into each layer or stretching the flexible substrate. It is feasible for the multilayered microfluidic structure to be integrated to an optofluidic system, where strong or tunable optical chirality are needed, which not only can be used as traditional optic components such as THz polarizers and filters but also has potential applications on imaging and sensor of bio-materials.

10:00 **Break & Exhibit Inspection**

SESSION VI – FLUIDIC MICRODEVICES

Session Chairs:

G.-B. Lee, *National Tsing Hua University (NTHU), TAIWAN*
A. Dietzel, *Technische Universität Braunschweig, GERMANY*

10:45 **MULTIPLE SIZE-ORIENTED PASSIVE DROPLET SORTING DEVICE AND BASIC APPROACH FOR DIGITAL CHEMICAL SYNTHESIS.....92**

S. Numakunai, A. Jamsaid, D.H. Yoon, T. Sekiguchi, and S. Shoji
Waseda University, JAPAN

This paper presents a multiple size-oriented passive droplet sorting utilizing a balance between surface free energy and flow force. We propose a multi-stage sorting structure and passive five different-sized droplets sorting of about 100 droplets/sec is achieved without any active elements. Also, we fabricated a prototype of the integrated micro fluidic system with droplet generation, merging and sorting for digital chemical synthesis.

SESSION VI (con't.)

11:00 SURFACE ENERGY MICROPATTERN INHERITANCE FROM MOLD TO REPLICA 96

G. Pardon, T. Haraldsson, and W. van der Wijngaart
KTH Royal Institute of Technology, SWEDEN

We report a novel surface energy patterning phenomenon, in which a novel polymer composition inherits the surface energy of the medium it is in contact with during polymerization. This process occurs via spontaneous alignment of hydrophilic and hydrophobic monomers contained in the prepolymer. This single-step method for simultaneous structuring and surface energy micropatterning of polymer structures is potentially more robust and lower cost than state-of-the-art. We further demonstrate the self-assembly of a liquid droplet array on the replicated polymer surfaces.

11:15 ELECTROSPRAY DEPOSITION FROM AFM PROBES WITH NANOSCALE APERTURES.....100

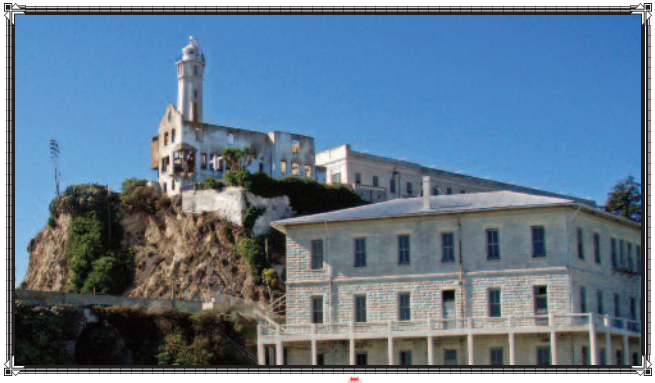
J. Geerlings[1], E. Sarajlic[1,2], J.W. Berenschot[1], R.G.P. Sanders[1], L. Abelmann[1,3], and N.R. Tas[1]
[1]*MESA+, University of Twente, THE NETHERLANDS,*
[2]*SmartTip B.V., THE NETHERLANDS, and*
[3]*Korea Institute of Science and Technology (KIST) – Europe, GERMANY*

In this contribution we present for the first time extraction of liquid from nano-sized apertures in fountain pen AFM probes by means of electrospray. This technique allows for contactless deposition and we show that droplets with radii in the order of one micrometer can be deposited. The required onset voltage for electrospray as function of gap spacing and applied pressure is studied and a simple model is presented which is in qualitative agreement with our measurements.

11:30 A MICROBUBBLE PRESSURE TRANSDUCER WITH BUBBLE NUCLEATION CORE 104

L. Yu and E. Meng
University of Southern California, USA

We present a microchannel-based microbubble (μB) pressure transducer (μBPT) with μB nucleation core for characterization of μB dynamics and pressure transduction in wet environments with low power consumption. The transducer leverages electrochemical impedance-based measurement to monitor the instantaneous response of μB size induced by hydrostatic pressure changes. We demonstrated on-demand μB nucleation and real-time pressure tracking (0-350 mmHg). Biocompatible construction and liquid-based operation of μBPTs are ideal for in vivo pressure monitoring.



SESSION VI (con't.)

11:45 **MICROFLUIDIC ELECTROCHEMILUMINESCENCE (ECL) INTEGRATED FLOW CELL FOR PORTABLE FLUORESCENCE DETECTION.....108**

M. Tsuwaki[1], J. Mizuno[1], T. Kasahara[1], T. Edura[2], E. Kunisawa[2], R. Ishimatsu[2], S. Matsunami[2], T. Imato[2], C. Adachi[2], and S. Shoji[1]
[1]*Waseda University, JAPAN and* [2]*Kyushu University, JAPAN*

We propose a portable electrochemiluminescence (ECL)-induced fluorescence chip which consists of flow channels for fluorescence sample and multi-color emitting ECL excitation source. A prototype ECL-induced fluorescence chip was fabricated by conventional photolithography and bonding technique. Device performance was evaluated using ECL of rubrene as excitation source and resorufin as fluorescent dye. Fluorescence of 500 μM resorufin (600 nm) was successfully detected using 10 mM rubrene solution (560 nm) under the applied voltage of 4 V. The proposed principle is applicable for portable and on-demand multi fluorescence detection device using its freedom of choice for combination of the ECL light source.

12:00 **A MONOLITHIC KNUDSEN PUMP WITH 20 sccm FLOW RATE USING THROUGH-WAFER ONO CHANNELS.....112**

S. An, Y. Qin, and Y.B. Gianchandani
University of Michigan, USA

We report a lithographically microfabricated Knudsen pump for high gas flow. Knudsen pumps operate by thermal transpiration and require no moving parts. To achieve high gas flow, high-density arrays of microchannels are used in parallel (with over 4000 channels/mm^2). These vertically oriented microchannels have 2×120 μm^2 openings surrounded by 0.1 μm-thick silicon oxide-nitride-oxide (ONO) sidewalls. The thin ONO sidewalls provide thermal isolation between a heat sink formed within the Si substrate, and a Cr/Pt thin film heater formed above the microchannels that provides a temperature bias for thermal transpiration. The Knudsen pump is monolithically microfabricated on a single SOI wafer using a four-mask process. It has a total footprint of 8×10 mm^2. It produces a measured air flow of 20 sccm, with typical response times of 0.1-0.4 sec.

12:15 **MEMS 2015 Announcement**

12:30 **Lunch on Own & Exhibit Inspection**

14:00 **Poster/Oral Session II** *see page 48 for listing of presentations*

SESSION VII – RESONANT MICRODEVICES & SENSORS

Session Chairs:
M. Rais-Zadeh, *University of Michigan, USA*
L. Buchaillot, *IEMN, FRANCE*

16:00 SUSPENDED NANOCHANNEL RESONATORS AT ATTOGRAM PRECISION.....116

S. Olcum[1], N. Cermak[1], S.C. Wasserman[1], K. Payer[1], W. Shen[2], J. Lee[3], and S.R. Manalis[1]
[1]*Massachusetts Institute of Technology, USA,*
[2]*Innovative Micro Technology, USA, and*
[3]*Sogang University, SOUTH KOREA*

We developed a nanomechanical resonator that can directly measure the mass of individual nanoparticles down to 10 nm in solution at room temperature with single-attogram precision, also enabling access to many of the engineered nanoparticles used in nanomedicine, most of the virions like HIV, HCV, and natural sub-cellular structures like exosomes. To achieve this, we demonstrate an oscillator system with frequency stability down to 4 ppb, approaching the fundamental limit imposed by intrinsic thermomechanical fluctuations of the resonator.

16:15 DUAL-MODE VERTICAL MEMBRANE RESONANT PRESSURE SENSOR 120

R. Tabrizian and F. Ayazi
Georgia Institute of Technology, USA

We present a novel dual-mode resonant pressure sensor operating based on mass loading of air molecules on transversely vibrating verticalsilicon membranes. Identical piezoelectrically-transduced silicon bulk acoustic resonators are acoustically coupled through thin vertical membranes, resulting in two high-Q resonance modes with small frequency split, but large difference in pressure sensitivity. Being proportional to the flexural resonance frequency of the thin membranes, the small beat frequency (fb) extracted from subtraction of the two coupled modes shows amplified pressure sensitivity. A proof-of-concept device implemented on silicon substrate and transduced by aluminum nitride film shows an fb of 370 kHz with a linear pressure sensitivity of 280 ppm/kPa.

16:30 HIGHLY RESPONSIVE CURVED ALUMINUM NITRIDE PMUT 124

S. Akhbari[1], F. Sammoura[1,2], S. Shelton[3], C.Yang[1], D. Horsley[3], and L. Lin[1]
[1]*University of California, Berkeley, USA,*
[2]*Masdar Institute of Science and Technology, UAE, and*
[3]*University of California, Davis, USA*

We have successfully demonstrated highly responsive, curved piezoelectric micromachined ultrasonic transducers (PMUT) based on a CMOS-compatible fabrication process using AlN as the transduction material for the first time. A prototype device using a 2μm-thick AlN layer on a curved diaphragm surface with a radius of curvature of 1065μm and physical size of 140μm in diameter has shown a measured resonant frequency at 2.19MHz. The DC response has been experimentally measured as 1.1nm/V, which is 50X higher than that of a planar device with same size and operation conditions. As such, this new class of curved PMUT could replace the state-of-art, planar PMUT to achieve high electromechanical coupling for various ultrasonic transduction applications, including gesture recognition and medical imaging.

SESSION VII (con't.)

16:45 ENCASED CANTILEVERS FOR LOW-NOISE FORCE AND MASS SENSING IN LIQUIDS.....128

D. Ziegler[1], A. Klaassen[2], D. Bahri[1], D. Chmielewski[1], A. Nievergelt[1], F. Mugele[2], J.E. Sader[3], and P.D. Ashby[1]
[1]*Lawrence Berkeley National Laboratory, USA,*
[2]*MESA+, University of Twente, THE NETHERLANDS, and*
[3]*University of Melbourne, AUSTRALIA*

Viscous damping severely limits the performance of cantilever based sensing in liquids. Encased cantilevers achieve low damping in liquids by keeping the resonator dry. This is achieved by fabricating a hydrophobic encasement from which only few microns of the sensing tip protrude into the liquid. We achieve Q-factors and associated noise levels as if operating in air. We discuss fabrication of these devices and demonstrate successful application for low-noise mass sensing and gentle AFM imaging of soft matter in liquids.

17:00 RESONANT MICRO-SENSOR PLATFORM FOR CONTACT-FREE CHARACTERIZATION OF LIQUID PROPERTIES 132

J.M. Gonzales and R. Abdolvand
Oklahoma State University, USA

This paper presents a novel resonant microsensor platform which maintains high quality factors(Q) when measuring ultrasonic properties of liquid samples such as blood. By avoiding the direct contact of the liquid with the resonator, significant losses due to liquid loading are mitigated and the physical properties of various fluids, including viscous samples, can be determined without adversely affecting the resonator performance. Devices have been fabricated and tested, achieving quality factors up to 6000 in air and the results show that the output signals measured from the device are sensitive to the properties of the liquid under test.

17:15 NOVEL IN-PLANE GAP CLOSING CMOS-MEMS MICROPHONE WITH NO BACK-PLATE.....136

C.-I. Chang[1], S.-C. Lo[1], C. Wang[2], Y.-C. Sun[1], and W. Fang[1,2]
[1]*National Tsing Hua University (NTHU), TAIWAN and*
[2]*MotionsTek Inc., TAIWAN*

The stacking of metal/tungsten layers as the sensing electrodes for CMOS-MEMS microphone without the back-plate has been proposed and demonstrated for the first time (Fig.1a). The acoustic pressure will deform the spring-diaphragm structure and further cause the in-plane gap-closing between sensing electrodes (Fig.1b). Thus, acoustic pressure and dynamic response of spring-suspension can be determined by the sensing capacitance changes. Such design has the following merits: (1) no back-plate is required, (2) bias voltage to pull diaphragm close to back-plate is not required, (3) in-use pull-in and process stiction between diaphragm and back-plate is also prevented, (4) easy integration with sensing circuits [1]. The design was implemented using the standard TSMC CMOS process. Typical microphone with 200μm-diameter diaphragm and 48-pairs sensing electrodes has been realized. Measurements show the sensitivity of microphone is -67.17dBV/Pa at 1KHz.

17:30 Adjourn for the day

WEDNESDAY, January 29

08:00 **ANNOUNCEMENTS**

PLENARY III

Session Chairs:

J. Brugger, *Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND*
W. van der Wijngaart, *KTH – Royal Institute of Technology, SWEDEN*

08:05 **CAVITY QUANTUM OPTOMECHANICS: COUPLING LIGHT AND MICROMECHANICAL OSCILLATORS.....140**
E. Verhagen, S. Deléglise, S. Weis, A. Schliesser, and **Tobias J. Kippenberg**
Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND

SESSION VIII – NANODEVICES

Session Chairs:

L. Lin, *University of California, Berkeley, USA*
Y.-J. Yang, *National Taiwan University, TAIWAN*

08:45 **AMORPHOUS CARBON ACTIVE CONTACT LAYER FOR RELIABLE NANOELECTROMECHANICAL SWITCHES.....143**
D. Grogg[1], C.L. Ayala[1], U. Drechsler[1], A. Sebastian[1], W.W. Koelmans[1], S.J. Bleiker[2], M. Fernandez-Bolanos[1], C. Hagleitner[1], M. Despont[1], and U.T. Duerig[1]
[1]*IBM Research – Zurich, SWITZERLAND and*
[2]*KTH Royal Institute of Technology, SWEDEN*

This paper reports an amorphous carbon (a-C) contact coating for ultra-low-power curved nanoelectromechanical (NEM) switches. a-C addresses important problems in miniaturization and low-power operation of mechanical relays: i) the surface energy is lower than that of metals, ii) active formation of highly localized a-C conducting filaments offers a way to form nano-scale contacts, and iii) high reliability is achieved through the excellent wear properties of a-C, demonstrated in this paper with more than 100 million hot switching cycles.

09:00 **NEAR INFRARED PHOTO-DETECTOR USING SELF-ASSEMBLED FORMATION OF ORGANIC CRYSTALLINE NANOPILLAR ARRAYS.....147**
Y. Ajiki[1,4], T. Kan[2], M. Yahiro[3], A. Hamada[3], J. Adachi[3], C. Adachi[3], K. Matsumoto[2], and I. Shimoyama[2]
[1]*Olympus Corporation, JAPAN,* [2]*University of Tokyo, JAPAN,*
[3]*Kyushu University, JAPAN, and*
[4]*NMEMS Technology Research Organization, JAPAN*

We proposed a near infrared photo-detector (NIR-PD) using self-assembled formation of organic crystalline arrays, which were formed on an n-type silicon (n-Si) substrate and covered with an Au film. These structures act as antennas for near infrared (NIR) light, resulted in an enhancement of the light absorption on the Au film. In this paper, the fabrication process of the NIR-PDs and the estimation results of photo-responsivity are described. The maximum value of the responsivity to NIR light (wavelength = 1.2 μm) was 1.79 mA/W without applying forward bias. This value is 10 times larger than that of a conventional Au/n-Si typed Schottky diode, which is fabricated as a reference.

SESSION VIII (con't.)

09:15 **ULTRASENSITIVE SI NANOWIRE PROBE FOR MAGNETIC RESONANCE DETECTION.....151**
Y.J. Seo, M. Toda, Y. Kawai, and T. Ono
Tohoku University, JAPAN

We have fabricated and evaluated an atto-newton-sensitive Si nanowire probe with a Nd-Fe-B magnet for magnetic resonance force microscopy. The width, thickness and length of the nanowire are 210 nm, 200 nm and 32 μm, respectively. The nanowire probe has a resonance frequency f0 of 11.256 kHz and a Q factor of order 12000. Then, we have demonstrated the measurement of force mapping based on electron spin resonance for three-dimensional imaging of radicals.

09:30 **A VERTICALLY INTEGRATED NANOSCALE TIPPED MICROPROBE INTRACELLULAR ELECTRODE ARRAY.....155**
Y. Kubota, H. Oi, H. Sawahata, A. Goryu, Y. Ando, R. Numano, M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

Here we report an integration of vertical 120-μm-long nanoscale tipped microprobe electrode (NTE) array and the intracellular recordings using a gastrocnemius muscle of a mouse. The tip diameter of the NTE was < 200 nm, with the height of 4 μm exposed from the parylene-shell. The impedance of the NTE exhibited 3.1 MΩ at 1 kHz in saline, with the output/input signal amplitude ratio of 50% for intracellular recordings. The penetrated NTE into the muscle of a mouse detected the residual potentials with the amplitude of ~ -200 mV, confirming the intracellular recording capability of the NTE.

09:45 **Break & Exhibit Inspection**

SESSION IX – ENERGY HARVESTING & POWER

Session Chairs:
Z. Li, *Peking University, CHINA*
J. Judy, *University of Florida, USA*

10:30 **ENERGY HARVESTING USING UNIAXIALLY ALIGNED CARDIOMYOCYTES 159**
X. Liu[1,2], X. Wang[1], S. Li[2], and L. Lin[2]
[1] *Tsinghua University, CHINA and* [2] *University of California, Berkeley, USA*

This study presents the concept of energy harvesting from uniaxially-aligned cardiomyocytes on a flexible substrate for the first time. Experimentally, synchronously contracting neonatal rat ventricular cardiomyocytes (NRVCs) at 0.5Hz have been found to cause the mechanical straining of a piezoelectric energy harvester to produce 87.5nA and 92.3mV of peak current and voltage, respectively. This work presents a successful step toward mechanical energy harvesting via living biological cells and tissues.

SESSION IX (con't.)

10:45 DIFFUSION REFUELING BIOFUEL CELL MOUNTABLE ON INSECT 163

K. Shoji[1], Y. Akiyama[1], M. Suzuki[2], N. Nakamura[2], H. Ohno[2], and K. Morishima[1]
[1] *Osaka University, JAPAN and*
[2] *Tokyo University of Agriculture and Technology, JAPAN*

This paper reports an insect-mountable biofuel cell (imBFC) using trehalose, main sugar of insect hemolymph. The imBFC is refueled trehalose by diffusion from insect hemolymph automatically and generates electric power by oxidizing glucose which is obtained by hydrolyzing trehalose enzymatically. We fabricated the imBFC consisted of a connector, two chambers separated by a dialysis membrane and electrodes and succeeded in driving a light-emitting diode by the imBFC. The results have shown a potentially to be applied for a battery of novel ubiquitous robots such as insect cyborgs.

11:00 ALD RUTHENIUM OXIDE-CARBON NANOTUBE ELECTRODES FOR SUPERCAPACITOR APPLICATIONS 167

R. Warren[1], F. Sammoura[1,2], A. Kozinda[1], and L. Lin[1]
[1] *University of California, Berkeley, USA and*
[2] *Masdar Institute of Science and Technology, UAE*

This work presents the first demonstration of atomic layer deposition (ALD) ruthenium oxide (RuO_2) and its conformal coating onto vertically aligned carbon nanotube (CNT) forest as supercapacitor electrodes. The ALD method allows precise control over the RuO_2 layer thickness and composition without the use of binder molecules. The ALD RuO_2 coated CNTs achieve a specific capacitance of 100 mF/cm^2 and retain their high-performance over repeated cycling.

11:15 SUB 3-MICRON GAP MICROPLASMA FET WITH 50 V TURN-ON VOLTAGE 171

P. Pai and M. Tabib-Azar
University of Utah, USA

We report the smallest microplasma transistor reported till date that operates with a low turn-on voltage of 50V dc. The device achieves more than 3x reduction in the turn-on voltage and 100x reduction in size compared to devices reported by other groups in the past. Earlier work reported by our group used plasma from an external source to operate the transistor. Our recent work successfully generated direct current plasma within the device with a turn-on voltage of 180V. This paper reports gate field-effect characterization results performed under dc and rf excitation and draws a comparison.

11:30 Lunch on Own & Exhibit Inspection

13:00 Poster/Oral Session III *see page 48 for listing of presentations*

SESSION X– MICRODEVICES FOR CELL MANIPULATION

Session Chairs:

I. Park, *Korea Advanced Institute of Science and Technology (KAIST), SOUTH KOREA*
Y. Sun, *University of Toronto, CANADA*

15:00 **FORMATION OF CROSS-SHAPED ESCHERICHIA COLI.....175**
K. Hirayama, Y.J. Heo, and S. Takeuchi
University of Tokyo, JAPAN

We develop a method to regulate the shapes of bacteria by confining a single cell of bacteria into micro chamber. Escherichia coli has a cell wall structure which determines the rod-shape. We removed the cell wall of E. coli and then confined the spheroplasts into cross-shaped microchambers. If the bacteria re-synthesize its cell wall within the microchamber, we could obtain the cross-shaped bacteria. By analyzing the behavior of proteins and the cross-shaped bacteria, we believe that we could contribute to the comprehensive understanding of the shape regulation mechanism of E. coli.

15:15 **SINGLE-CELL 3D BIO-MEMS ENVIRONMENT WITH ENGINEERED GEOMETRY AND PHYSIOLOGICALLY RELEVANT STIFFNESSES 177**
M. Marelli[1], N. Gadhari[2], G. Boero[1], M. Chiquet[2], and J. Brugger[1]
[1]*Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND and* [2]*University of Bern, SWITZERLAND*

We present a 3D microenvionment for on-chip cell culture, made of stress-bent cantilevers and designed to mimic essential physical properties of the in vivo environment, at the single-cell scale and with a high degree of parallelization. In particular, we report on a combinatorial fabrication approach bringing to the realization of a palette of devices with constant sizes (fitting a single-cell), but with stiffnesses spanning two orders of magnitude and matching physiologically relevant values.

15:30 **INTEGRATED MICRO CULTURE DEVICE FOR FULLY AUTOMATED CLOSED CULTURE EXPERIMENT OF EMBRYONIC BODY 181**
A. Yasukawa[1], T. Nishijima[2], M. Ikeuchi[1], and K. Ikuta[1]
[1]*University of Tokyo, JAPAN and* [2]*Nagoya University, JAPAN*

This paper reports formation, differentiation and analysis of embryonic bodies (EBs) from human iPS cells in a palm-size device "PASMA (Pressure Actuated Shapable Microwell Array)". By incorporating a transparent heat film and CO2 concentration adjusting system, PASMA realized miniaturization of the whole process of EB experiment in one chip. Moreover, the fully automated closed culture system can eliminate the risks of contamination due to manual operation. EBs from human iPS cells were successfully fabricated using this system.

SESSION X (con't.)

15:45 **MECHANICAL CELL PAIRING SYSTEM BY SLIDING PARYLENE RAILS 185**

Y. Abe[1,2], K. Kamiya[1,3], T. Osaki[1,4], R. Kawano[1], N. Miki[1,2], and S. Takeuchi[1,4]

[1]*Kanagawa Academy of Science and Technology, JAPAN,* [2]*Keio University, JAPAN,* [3]*Japan Science and Technology Agency (JST), JAPAN, and* [4]*University of Tokyo, JAPAN*

This paper proposes a cell pairing system that is capable of defining the number and the position of trapped cells by mechanically sliding the parylene rail films (PRF). This system allows us to control the number as well as the order of lined-up cells. We successfully demonstrated lining up of three different cells in a designated order. The proposed system is readily applicable to study the cell-cell interactions using the single cell pairing.

16:00 **Break & Exhibit Inspection**

SESSION XI– BIO-INSPIRED MICROACTUATORS

Session Chairs:

Y. Yamanishi, *Shibaura Institute of Technology, JAPAN*

T.-H. Wang, *The Johns Hopkins University, USA*

16:30 **TWO-DIMENSIONALLY STEERING MICROSWIMMER PROPELLED BY OSCILLATING BUBBLES.....188**

J. Feng and S.K. Cho

University of Pittsburgh, USA

An acoustically excited and oscillated bubble can generate a propelling force in micro scale. We develop a simple and efficient method that allows a bubble-propelled micro swimmer to propel and steer two dimensionally as wirelessly and remotely commanded.

16:45 **A MICROFABRICATED, BIOHYBRID, SOFT ROBOTICS FLAGELLUM 192**

B.J. Williams[1], S.V. Anand[1], J. Rajagopalan[2], and M.T.A. Saif[1]

[1]*University of Illinois, Urbana-Champaign, USA and*

[2]*Arizona State University, USA*

We develop a microfabricated soft robotics biohybrid swimmer utilizing the contractions of one to several cardiomyocytes to provide on-board actuation to a thin, deformable, polydimethylsiloxane (PDMS) filament. The actuated filament deforms passively in response to fluid drag, producing a time-irreversible deformation pattern and net propulsive force at low Reynolds number. We utilize an elastohydrodynamic model to determine appropriate filament parameters and realize a functional swimmer.

SESSION XI (con't.)

17:00 **EVALUATION AND OPTICAL CONTROL OF SOMATIC MUSCLE MICRO BIOACTUATOR OF CHANNELRHODOPSIN TRANSGENIC DROSOPHILA MELANOGASTER.....196**

M. Hirooka[1], S.P. Beh[1], T. Asano[1], Y. Akiyama[1], T. Hoshino[2], K. Hoshino[3], H. Tsujimura[3], K. Iwabuchi[3], and K. Morishima[1]
[1] *Osaka University, JAPAN,* [2] *University of Tokyo, JAPAN, and* [3] *Tokyo University of Agriculture and Technology, JAPAN*

In this research, we first developed light-activated somatic muscle of transgenic Drosophila melanogaster expressing a blue light sensitive cation channel, channelrhodopsin-2, and incorporated into a micro device. We successfully demonstrated that optogonetic stimulation using light pulses was able to control the contractile activity with a given temporal pattern. The contractile force was evaluated with varying light intensities and pulse widths. These results have shown that mechanical systems powered by muscles will be controlled more accurately under our strategy.

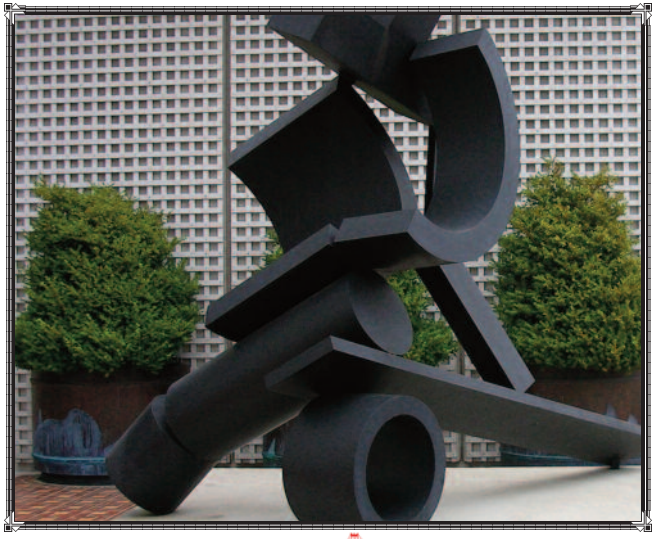
17:15 **FERROFLUID-ASSISTED MICRO ROTARY MOTOR FOR MINIMALLY INVASIVE ENDOSCOPY APPLICATIONS.....200**

B. Assadsangabi, M.H. Tee, S. Wu, and K. Takahata
University of British Columbia, CANADA

Micro-scale rotary motors have a vast range of potential applications in broad areas. One promising area is medical applications. Minimally-invasive endoscopic catheters are an excellent example. The micromotors used in these catheters, however, generally have large axial lengths (e.g., >1 cm). This paper presents the first rotary micromotor enabled by ferrofluid bearing that drastically shortens the axial length of micromotors, suitable for medical catheter applications, owing to the extremely simple and reliable bearing mechanism.

17:30 **Adjourn for the day**

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



THURSDAY, JANUARY 30

08:00 **ANNOUNCEMENTS**

PLENARY IV

Session Chairs:
F. Ayazi, *Georgia Institute of Technology, USA*
CJ Kim, *University of California, Los Angeles, USA*

08:05 **COMMERCIALIZATION OF WORLD'S FIRST PIEZOMEMS RESONATORS FOR HIGH PERFORMANCE TIMING APPLICATIONS** **204**
Harmeet Bhugra, S. Lee, W. Pan, M. Pai, and D. Lei
Integrated Device Technology, Inc. (IDT), USA

SESSION XII – RESONATORS & RF MEMS

Session Chairs:
A. Seshia, *Cambridge University, UK*
K. Böhringer, *University of Washington, USA*

08:45 **MEMS-RECONFIGURABLE WAVEGUIDE IRIS FOR SWITCHABLE V-BAND CAVITY RESONATORS** **206**
Z. Baghchehsaraei and J. Oberhammer
KTH Royal Institute of Technology, SWEDEN

We present, for the first time, a reconfigurable waveguide iris based on a MEMS-reconfigurable surface integrated into a WR-12 rectangular waveguide (60–90 GHz, 3.099 mm × 1.549 mm). The reconfigurable surface is only 30 µm thick and incorporates 252 simultaneously switched contact points for activating or deactivating an inductive iris. The switchable irises can be utilized to implement components such as reconfigurable filters and cavity resonators. We also present for the first time a reconfigurable cavity resonator based on the novel MEMS reconfigurable iris.

09:00 **A MICROMECHANICAL PARAMETRIC OSCILLATOR FOR FREQUENCY DIVISION AND PHASE NOISE REDUCTION** **210**
T.O. Rocheleau, R. Liu, J. Naghsh Nilchi, T.L. Naing, and C.T.-C. Nguyen
University of California, Berkeley, USA

A capacitive-gap RF MEMS resonator array demonstrates a first on-chip MEMS frequency divider with 61-MHz output generated from a 121-MHz electrical drive through use of a parametric oscillation effect. This provides not only the expected 6dB reduction in close-to-carrier phase noise, but also a remarkable 23dB reduction in far-from-carrier noise due to filtering by the high-Q mechanical resonator. In contrast with traditional frequency division, the parametric oscillator here requires no active devices, adds no noise to the signal and has essentially zero power consumption, limited in principle only by MEMS resonator loss.

SESSION XII (con't.)

09:15 **TEMPERATURE-COMPENSATED PIEZOELECTRICALLY ACTUATED LAMÉ-MODE RESONATORS 214**
V.A. Thakar and M. Rais-Zadeh
University of Michigan, USA

In this work, we present a passive compensation strategy for Lamé-mode resonators using silicon dioxide refilled islands within the resonator body. With this technique we achieve compensation of the first-order TCF and further demonstrate that the turnover temperature (TOT) can be tuned across a wide range from -40°C to +120°C by optimizing the placement of oxide refilled islands.

09:30 **A MEMS AUTONOMOUS SWITCHED OSCILLATOR 218**
G.B. Torri[1,2], J. Bienstman[2], X. Rottenberg[1], H.A.C. Tilmans[2], C. Van Hoof[1,2], and R. Puers[1,2]
[1]*imec, BELGIUM and* [2]*KU Leuven, BELGIUM*

We design and measure an autonomous electrostatic MEMS oscillator that exhibits periodic and aperiodic behavior. The system consists of an electrostatic MEM, a dc voltage source, and a displacement dependent resistive circuit. The applied voltage above the pull-in and the position dependent circuit are responsible for sustaining the oscillations. Electronic and non-electronic information can be input or retrieved from the oscillator system. Applications for such device range from chaotic signals for communications, sensitive mass sensors, and signal processing.

10:00 **Poster/Oral Session IV** *see page 48 for listing of presentations*

Session XIII – Chemical Sensors & Systems

Session Chairs:
A. Llobera, *Centre Nacional de Microelectronica, SPAIN*
H. Moon, *University of Texas, Arlington, USA*

12:00 **SURFACE TENSION MONITORING IN A "SOFT" INTERFACE USING ELECTROWETTING ON DIELECTRIC 222**
S. Choi[1], Y. Kwon[2], E. Jeon[1], S. Kim[1], and J. Lee[1]
[1]*Seoul National University, SOUTH KOREA and*
[2]*Samsung Electronics Co., Ltd., SOUTH KOREA*

We report the first demonstration of interfacial tension monitoring across two immiscible liquids using electrowetting on dielectric (EWOD). Impedance measurement during EWOD reveals the variation of surfactant concentration at the liquid-liquid interface in real time. We also show such approach can be used for label-free monitoring of DNA hybridization. Our approach opens a new horizon of EWOD used as a molecular sensing mechanism across a "soft" interface between liquids.

12:15 **MICROFLUIDIC BUBBLE-BASED GAS SENSOR 226**
A. Bulbul, H.-C. Hsieh, and H. Kim
University of Utah, USA

We report a new class of a gas sensor that utilizes the variations in bubble sizes, when different gases are introduced into a liquid flow, to identify gas types and even quantify the amounts. To verify the feasibility of the concept, the sizes of discretely formed bubbles were optically monitored and analyzed through a custom-developed MATLAB software.

SESSION XII (con't.)

12:30 A FLEXIBLE GRAPHENE FET GAS SENSOR USING POLYMER GATE DIELECTRICS 230

Y. Liu, J. Chang, and L. Lin
University of California, Berkeley, USA

We have successfully demonstrated a Graphene FET (GFET) gas sensor on a flexible plastic substrate for the first time with a sensitivity of $0.00428ppm^{-1}$ ($\Delta R/R_0$) for ammonia detection. Compared with the state-of-art technologies, four distinctive advancements have been achieved: (1) first demonstration of a flexible graphene FET gas sensor; (2) a new fabrication process to achieve embedded-gate GFET on a flexible substrate; (3) proof of utilizing polymeric materials of parylene and polyethylenimine (PEI) as the gate dielectrics and channel dopant for graphene FET, respectively; and (4) validation of a real-time gas sensing mechanism utilizing n-type doping of graphene induced by ammonia exposure.

12:45 Awards Ceremony

13:00 Conference Adjourns

M - Monday	13:00 - 15:00	W - Wednesday	13:00 - 15:00
T - Tuesday	14:00 - 16:00	Th-Thursday	10:00 - 12:00

Bio MEMS (Bio)

M-001 **A CONTINUOUS OPTICALLY-INDUCED CELL ELECTROPORATION DEVICE WITH ON-CHIP MEDIUM EXCHANGE MECHANISMS 234**

C.-J. Chang, M.-Y. Lu, and G.-B. Lee

National Tsing Hua University (NTHU), TAIWAN

We present a novel design of continuously optically-induced electroporation (OIE) device capable of replacing culture medium and electroporation buffer in a seamless fashion. With this approach, the entire process for continuous cell electroporation could be performed automatically without human intervention. Furthermore, the survival rate of the cells could be greatly improved due to this fast, automatic procedure.

T-002 **A HIGH-THROUGHPUT PERMEABILITY ASSAY PLATFORM FOR SHEAR STRESS CHARACTERIZATION OF ENDOTHELIAL CELLS.....238**

R. Booth, S. Noh, and H. Kim

University of Utah, USA

Here we present the first permeability assay platform to enable rapid characterization of shear stress effects fully spanning the physiologically relevant spectrum (1-60dyn/cm2) for endothelial cells in vitro. The structure comprised 4 parallel channels to enable independent permeability assays, and generated 15x shear stress range indicated by simulation and an integrated micro-flow sensor array. Endothelial cells exhibited decreased permeability of fluorescent tracers with shear stress, as well as increased elongation and cell alignment with increases in shear stress.

W-003 **A MICROFLUIDIC DEVICE FOR ISOLATION OF CELL-TARGETING APTAMERS.....242**

J. Zhu[1], T. Olsen[1], R. Pei[2], M. Stojanovic[1], and Q. Lin[1]

[1] *Columbia University, USA and* [2] *Chinese Academy of Sciences, CHINA*

This paper presents a microfluidic device for synthetically isolating cell-targeting aptamers from a randomized single-strand DNA (ssDNA) library. The device integrates cell culturing with affinity selection of cell-binding ssDNA, which is then amplified by bead-based polymerase chain reaction (PCR). Coupling of the selection and amplification using pressure-driven flow realizes multi-round aptamer isolation on a single chip.

Th-004 **A NANOWIRE-INTEGRATED MICROFLUIDIC DEVICE FOR HYDRODYNAMIC TRAPPING AND ANCHORING OF BACTERIAL CELLS 246**

D. Kwon, J. Kim, S. Chung, and I. Park

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

We develop nanowire-integrated microfluidic devices for hydrodynamic trapping and anchoring of bacterial cells and demonstrate that the mesh-like cages formed by integrating ZnO nanowires are effective in trapping and anchoring of Escherichia coli as a model bacterium. We present two anchoring modes, impaling and wedging, followed by irreversible damage or reversible deformation of the cell wall, respectively.

M-005 **AN INTEGRATED MICROFLUIDIC SYSTEM USING FIELD-EFFECT TRANSISTORS FOR CRP DETECTION 250**

C.L. Lin, Y.W. Kang, K.W. Chang, W.H. Chang, Y.L. Wang, and G.B. Lee
National Tsing Hua University (NTHU), TAIWAN

Cardiovascular diseases are responsible for 25-million deaths worldwide on a yearly basis. Timely diagnosis of the disease is therefore an important research area. Toward this end, C-reactive protein (CRP) is a general biomarker for inflammation and infection, and has become a good marker for evaluating risks of cardiovascular diseases. Previously, a CRP-specific aptamer (nucleic acid-based antibody, in a nutshell) with high sensitivity and specificity was used to detect CRP in microfluidic system, which was capable of performing the detection in an automated fashion while consuming tiny volumes of reagents and samples. In parallel, field-effect transistors (FET) have emerged as sensors to detect small molecules, proteins and even viruses, and have demonstrated rapid and highly sensitive detection in a compact system. In this work, an integrated device that combined the advantages of microfluidics, aptamers and FET-based sensors was developed to achieve rapid, sensitive and specific CRP detection. The developed integrated microfluidic system with FET sensor and CRP-specific aptamer can be promising for fast, sensitive and specific CRP detection.

T-006 **ASSEMBLY OF NEURAL CELL-LADEN MICROPLATES ON A MICROFABRICATED BREADBOARD.....254**

S. Yoshida[1], K. Sato[1,2], and S. Takeuchi[1,2]
[1]University of Tokyo, JAPAN and
[2]Japan Science and Technology Agency (JST), JAPAN

We developed a method to form an arbitrary network of neural cell-laden microplates using a breadboard-like microelectrode array (MEA). We cultured single neural cells on perforated microplates with control of their morphologies, then mounted the plates on the micro-sockets attached on the breadboard. Through a pore punched in the center of the microplate, the electrical activities of cells would be accessible with gold electrodes patterned on the MEA.

W-007 **CD4 CELL ISOLATION FROM BLOOD USING FINGER-ACTUATED ON-CHIP MAGNETOPHORESIS FOR RAPID HIV/AIDS DIAGNOSTICS.....256**

M. Glynn, D.J. Kinahan, D. Chung, and J. Ducrée
Dublin City University, IRELAND

We have developed a microfluidic based disposable device, actuated solely by finger pressure from the operator, to repeatedly pass micro quantities of blood past a magnetic based cell capture structure to allow CD4 cell based HIV diagnostics in less than 1 minute following sample application. This is aimed for deployment in resource-poor regions where HIV is endemic but diagnostics is a challenge.

Th-008 **CENTRIFUGALLY AUTOMATED SOLID-PHASE PURIFICATION OF RNA.....260**

N. Dimov, J. Gaughran, D. McAuley, D. Boyle, D.J. Kinahan, and J. Ducrée
Dublin City University, IRELAND

We report for the first time on a fully centrifugally automated solid-phase purification of RNA on an integrated microfluidic disc with sequential release of on-board reagents.

M-009 **FABRICATION METHOD TO A HIGH RESOLUTION CONTROL IN THE SPACE OF CELL CULTURING ENVIRONMENT WITH MICROFLUIDIC SYSTEM.....264**

T. Hiraiwa[1], T. Kimura[1], Y. Takenaka[1], R. Tanamoto[1], H. Ota[3], H. Kimura[2], Y. Taguchi[1], N. Miki[1], Y. Matsumoto[1], K. Oka[1], A. Funahashi[1], and N. Hiroi[1]

[1]*Keio University, JAPAN,* [2]*Tokai University, JAPAN, and* [3]*University of California, Berkeley, USA*

We develop a reusable Cell Culturing Device, designed for single cells and cellular network analysis. This is the first success of combination of Microcontact Printing (μCP) and Vacuum Device. This device has following advantages: (1) cells stay within the micropatterns more than 12hrs, (2) cell culture environment is regulated precisely using laminar flow, (3) this device is reusable for further experiments.

T-010 **INDIVIDUALLY ADDRESSABLE MULTI-CHAMBER ELECTROPORATION PLATFORM WITH DIELECTROPHORESIS-ASSISTED CELL POSITIONING.....268**

S. Park and G. Yossifon

Technion–Israel Institute of Technology, ISRAEL

We developed a novel, multifunctional platform with an array for high throughput screening which integrates DEP trapping/positioning and electroporation mechanisms in a multi-chamber array where each chamber may be individually activated. As a proof of concept, platforms with an array of 40 × 2 cell microchambers were fabricated and tested to demonstrate the feasibility of integrating the two functionalities: 1) the manipulation of the particles/cells using DEP, and 2) gradient electroporation using by producing a spatial gradient of electroporation parameters to optimize electroporation efficiency.

W-011 **INTEGRATION OF HEAT-TRANSFER RESISTANCE MEASUREMENTS ONTO A DIGITAL MICROFLUIDIC PLATFORM TOWARDS THE MINIATURIZED AND AUTOMATED LABEL-FREE DETECTION OF BIOMOLECULAR INTERACTIONS 272**

E. Perez-Ruiz[1], T. Vandenryt[2], D. Witters[1], D. Decrop[1], B. van Grinsven[2], D. Spasic[1], P. Wagner[2], and J. Lammertyn[1]

[1]*KU Leuven, BELGIUM and* [2]*University of Hasselt, BELGIUM*

In this work the successful integration of heat-transfer resistance measurements with a digital microfluidic chip is shown. The integrated miniaturized platform allows the automated label-free detection of biomolecular interactions. To immobilize biomolecules on the hydrophobic chip surface, hydrophilic gold sensing patches are created by means of a novel dry lift-off technique that leaves the chip surface unaffected. In order to validate the integrated device, DNA melting analysis was performed in the set-up.

Th-012 **NANOFLUIDIC SENSING AT NORMAL PHYSIOLOGICAL CONDITION BY COUPLING ION CONCENTRATION POLARIZATION WITH A LIMIT OF DETECTION OF ONE FEMTOMOLE.....276**

W. Ouyang[1], W. Wang[1,2], H. Zhang[1], W. Wu[1,2], and Z. Li[1,2]
[1]*Peking University, CHINA and* [2]*National Key Laboratory of Science and Technology on Micro/Nano Fabrication, CHINA*

Traditional nanofluidic sensing devices lose function at normal physiological condition (e.g. 0.1 M). This work enables nanofluidic sensing of Biotin at normal physiological condition by coupling ion concentration polarization (ICP) in a nanofluidic crystal (NFC) device. The enrichment effect of ICP was utilized for target molecule preconcentration for lower limit of detection, while the depletion effect of ICP was utilized for creating a nanofluidic regime in high ionic concentration buffer. A limit of detection of 1 fM was realized in our work.

M-013 **MASS-PRODUCTION AND PROLONGED UNDIFFERENTIATED STATE OF EMBRYONIC BODIES BY USING A SEMI-PERMEABLE TAPERED MICROWELL ARRAY.....280**

M. Ikeuchi[1], S. Hayashi[2], M. Osonoi[2], and K. Ikuta[1]
[1]*University of Tokyo, JAPAN and*
[2]*The Foundation for Promotion of State of the Art in Medicine and Health Care, JAPAN*

We have demonstrated embryonic body (EB) formation and prolongation of undifferentiated state by using an improved tapered microwell array equipped with semipermeable bottom. The array had hydrophilic surface to prevent cell adhesion, and thus, the cells seeded onto the array aggregated into EBs in each microwell. The semipermeable bottom only permitted liquid to go through, and promoted exchange of culture medium in each microwell, resulting in prolonged term of undifferentiated state of EBs.

T-014 **ON CHIP PRODUCT PURIFICATION FOR COMPLETE MICROFLUIDIC RADIOTRACER SYNTHESIS.....284**

S. Chen, A.A. Dooraghi, M. Lazari, R.M. van Dam, A.F. Chatziioannou, and C.J. Kim
University of California, Los Angeles, USA

We developed on-chip removal of excess radioactive fluoride to follow the radiolabeling of a neurotransmitter with an electrowetting-on-dielectric (EWOD) device. Solid phase extraction of fluoride was achieved by adding alumina particles in the radiolabeled droplet and filtering them out by passing the droplet through pillars in the device. Purification was analyzed both on chip with Cerenkov radiation imaging and off chip with radio-thin layer chromatography.

W-015 **RECONSTITUTION OF FUNCTIONAL MEMBRANE PROTEINS INTO ASYMMETRIC GIANT LIPOSOMES BY USING A PULSED JET FLOW.....288**

K. Kamiya[1], R. Kawano[1], T. Osaki[1,2], and S. Takeuchi[1,2]
[1]*Kanagawa Academy of Science and Technology, JAPAN and*
[2]*University of Tokyo, JAPAN*

We develop the reconstitution of functional membrane proteins (flippases) into asymmetric lipid giant liposomes that were prepared by deforming a planar asymmetric bilayer using a microfluidic pulsed jet flow. we observed the translocation of phosphatidylserine from the extracellular leaflet to the cytoplasmic leaflet which was catalyzed by flippases.

This paper reports on the traction force of smooth muscle cell during cell growth on the rigid substrate, specially designed for measuring the x and z axis forces. The proposed piezoresistive force sensor is characterized by three points: 1) a rigid substrate, 2) high force sensitivity (10 nN force resolution), 3) small gaps between sensor pads. We measured the traction force of the smooth muscle cells during culture at 37°C.

Chemical Sensors and Systems (CSS)

We report a micro gas chromatography (μGC) system that comprises a Knudsen pump with bi-directional flow capability (KP2), a two-stage preconcentrator-focuser (PCF2) and a separation column. In this valveless system, the bi-directionality of the pump allows flow reversal in the multi-stage preconcentrator. The KP2, PCF2, and separation column are arranged in a 4.3 cm3 stack, and used with a commercial flame ionization detector. In preliminary experiments, the μGC system demonstrated quantitative separations of benzene, toluene, and xylene (BTX) with concentrations of 43-328 mg/m3. The separations were completed in 80 sec using room air as the carrier gas.

We present a micro trace heavy metal sensor based on bismuth-modified mesoporous carbon electrodes that are direct prototyped on silicon wafer. The proposed device features a great electrochemical sensing platform for voltammetric analysis because of the thicker mesoporous carbon electrode has high surface area, high electric conductivity, and can be integrated into microsystems. The novel sensor achieves excellent sensing performance, the limits of detection are an order of magnitude lower than other reported and the peak current also exhibits well linear response.

The study aims to build a novel quantitative adsorbing/sensing model for chemical gas sensing-materials, with which various key sensing-parameters can be comprehensively evaluated and optimally designed. Gravimetric resonant-cantilevers are used in experiment to real-time record sensing curves at different temperatures, which are further used to extract adsorbing/sensing performance of the specific materials for quantitative evaluation and optimal sensor design. The model is well validated by choosing the best trimethylamine (TMA) sensing-material among three similar mesoporous-silica nano-particles (MSNs).

Th-020 **A POLYMER-BASED MEMS DIFFERENTIAL SCANNING CALORIMETER 306**

Y. Jia, B. Wang, J. Zhu, and Q. Lin

Columbia University, USA

We present a new MEMS differential scanning calorimeter (DSC). The device, using polymer calorimetric microstructures inexpensively fabricated on a polymer substrate, is mechanically flexible and highly robust, and well suited to disposable use for measurement of biomolecular energetics. We demonstrate this polymer MEMS DSC device with the characterization of lysozyme unfolding in a 1 micro liter volume at low concentrations of practically useful levels.

M-021 **DESIGN AND MOTION CONTROL OF SELF-PROPELLED DROPLETS 310**

A. Suzuki[1], S. Maeda[2], Y. Hara[3], and S. Hashimoto[1]

[1] *Waseda University, JAPAN,*

[2] *Shibaura Institute of Technology, JAPAN, and*

[3] *National Institute of Advanced Industrial Science and Technology (AIST), JAPAN*

We report a new oil droplet system that is autonomously driven by the energy of oil-water interactions and its motion control. This droplet moves by ejecting polymers in alkaline water and displays large driving force. The oil droplet can move along a flow channel by deforming in an amoeboid motion on the micro- to milli- scale, so we specifically demonstrated its motion in a micro fluidic channel. Such droplets offer considerable potential for the application as a transportable actuator.

T-022 **DETECTION OF MUTATIONS IN THE BINDING DOMAIN OF TAU PROTEIN BY KINESIN– MICROTUBULE GLIDING ASSAY 314**

S.P. Subramaniyan[1], M.C. Tarhan[2], S.L. Karsten[3], H. Fujita[2], H. Shintaku[1], H. Kotera[1], and R.Yokokawa[1]

[1] *Kyoto University, JAPAN,* [2] *Tokyo University, JAPAN, and*

[3] *NeuroInDx Inc., USA*

We have studied the kinesin- microtubule (MTs) based gliding assay for its application as a diagnostic tool indetecting neuronal marker - tau protein. In this paper we report our findings; that the landing rate and density of MTs have depicted the type of tau protein decorated on them, we have discussed five major tau mutants located in thebinding domain of tau protein in addition to its isoforms, and we have also demonstrated a micro device to detect MTsby their landing rate and gliding density.

W-023 **FROG EGG-ARRAY DEVICE INTEGRATED WITH FLUIDIC CHANNEL AND MICROELECTRODES FOR CHEMICAL SENSING 318**

M. Tomida, Y. Murakami, and N. Misawa

Toyohashi University of Technology, JAPAN

This study describes a membrane-protein based chemical sensor device consisting of microfluidic channels and Xenopus laevis oocytes. The fluidic device has Si-based microfabricated electrodes to measure of the oocyte's response to each chemical by two-electrode voltage clamping method. After cell trapping, the fluidic device can be separated to each fluidic channel that can measure an individual oocyte membrane potential change. We successfully placed each oocyte into the device and detected individual Xenopus oocyte responses to chemical stimulus.

Th-024 **INTEGRATION OF DIAMOND MICROELECTRODES ON CMOS-BASED AMPEROMETRIC BIOSENSOR ARRAY BY FILM TRANSFER TECHNOLOGY** **322**

T. Hayasaka, S. Yoshida, K.Y. Inoue, M. Nakano, T. Ishikawa, T. Matsue, M. Esashi, and S. Tanaka
Tohoku University, JAPAN

This study reports on integration of boron-doped diamond (BDD) microelectrodes on CMOS-based 20×20 amperometric biosensor array. The BDD electrodes are once formed on a Si wafer at 800°C, and then transferred to a 0.18 µm CMOS wafer with a benzocyclobutene (BCB) bonding interlayer. The fully-integrated device successfully detects biomolecules such as histamine owing to a wide potential window of the BDD electrode, and offers 2-dimensional real-time imaging of histamine diffusion in a solution. This type biosensor promises sensing and imaging applications of various biological materials which cannot be detected by conventional sensors.

M-025 **IONIC LIQUID-GATED GRAPHENE FET ARRAY WITH ENHANCED SELECTIVITY FOR ELECTRONIC NOSE** **326**

A. Inaba, Y. Takei, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

Graphene has high sensitivity to gases, but has poor selectivity. Therefore, graphene is hard to apply to electronic nose. Because the gas absorbability of ionic liquid (IL) depends on its type, graphene FETs (GFETs) gated by different ILs have different gas responses. The response pattern of the IL-gated GFETs (ILGFETs) enables gas species detection, i.e. ILs provide gas selectivity to graphene. We assembled three ILGFETs with three kinds of ILs into an ILGFET array. The response patterns to several gases were measured to demonstrate the feasibility of graphene electronic nose.

T-026 **LoC SENSOR ARRAY PLATFORM FOR REAL-TIME COAGULATION MEASUREMENTS** **330**

O. Cakmak[1], N. Kilinc[1,2], E. Ermek[1], A. Mostafazadeh[1], C. Elbuken[1], G.G. Yaralioglu[3], and H. Urey[1]
[1]*Koc University, TURKEY,* [2]*Gebze Institute of Technology, TURKEY, and* [3]*Ozyegin University, TURKEY*

We report the first demonstration of MEMS-based sensor array enabling multiple tests in one disposable microfluidic cartridge using plasma. The LoC (Lab-on-Chip) platform technology is versatile and demonstrated here for real-time coagulation and clot-time tests (activated Partial Thrompoblastin Time (aPTT) and Prothrombin Time (PT)). The start and the end of fibrin generation during coagulation can be clearly seen in real-time for both of the tests. Magnetic actuation and optical read-out is used. Hence no electrical connection to the MEMS chip is required. This makes the system convenient for point-of-care tests.

W-027 **PARALLELIZATION OF FISSION AND FUSION+OPERATIONS FOR HIGH THROUGHPUT GENERATION OF COMBINATORIAL DROPLETS** **334**

H.C. Zec, T.D. Rane, P. Ma, and T.H. Wang
Johns Hopkins University, USA

In this paper, we present a parallelized droplet-based platform for on-demand, combinatorial generation of nanoliter droplets. By parallelizing fission and fusion modules, throughput is increased by two orders ofmagnitude. With 32 Hz droplet generation, the projected throughput of this parallelized design is nearly 3 million sample-probe droplets per day on a single device (with 4 replicates of 750 thousand different mixtures). This translates to 240 unique sample-probe mixtures with 4 replicates per minute each.

Th-028 **TOWARDS ON-CHIP CHEMICAL REACTION MONITORING BY EWOD IMPEDANCE MEASUREMENT.....338**

X. Ma, S. Chen, C.J. Kim, and R.M. van Dam
University of California, Los Angeles, USA

We develop an EWOD impedance measurement system for in situ chemical reaction monitoring to maximize the advantage of microscale chemical synthesis. As a demonstration, we measure the droplet impedance on EWOD at various stages of an acid-base titration, showing its capability of detecting the equivalence point of neutralization.

Energy Harvesting and Power MEMS (EHPM)

M-029 **3D SOLID-STATE SUPERCAPACITORS OBTAINED BY ALD COATING OF HIGH-DENSITY CARBON NANOTUBES BUNDLES.....342**

G. Fiorentino, S. Vollebregt, F.D. Tichelaar, R. Ishihara, and P.M. Sarro
Delft University of Technology, THE NETHERLANDS

A three-dimensional solid-state miniaturized supercapacitor based on double conformal coating of Multiwalled Carbon Nanotubes (MWCNTs) bundles is presented. Atomic Layer Deposition (ALD) is used to deposit Al_2O_3 as dielectric layer and TiN as high aspect-ratio conformal counter-electrode on 2µm long MWCNTs bundles. The devices are realized using an IC wafer-scale manufacturing process and show a remarkable volumetric capacitance density value of 12mF/cm^3 with high reproducibility (≤0.3E-12F deviation). The small footprint (100µm^2 to 625µm^2), a thickness of only 2µm, the extremely high capacitance density and the novel and easy-to-integrate fabrication process make it possible to realize high performance energy storage micro-devices.

T-030 **A HIGH PERFORMANCE TRIBOELECTRIC GENERATOR FOR HARVESTING LOW FREQUENCY AMBIENT VIBRATION ENERGY.....346**

B. Meng, W. Tang, X.S. Zhang, M.D. Han, X.M. Sun, W. Liu, and H.X. Zhang
Peking University, CHINA

We present a novel triboelectric generator for vibration energy harvesting based on the mass production manufacture of flexible printed circuit (FPC). An elastic zigzag-shaped structure was employed as a natural spring, making the generator simple and easy to be stimulated. The use of FPC manufacture makes the fabrication efficient and low-cost. Low resonant frequency of 16 Hz and wide bandwidth of 37 Hz was achieved. The maximum effective output power of 77.3 µW was obtained at 16 Hz.

W-031 **A GAP-VARYING ELECTROSTATIC TRANSDUCER UTILIZING FERROFLUID-BASED ACTUATION FOR MOTION HARVESTING.....350**

T. Galchev, D. Barutçu, and O. Paul
University of Freiburg – IMTEK, GERMANY

This paper provides electrical characterization of the gap-varying electrostatic springless proximity inertial harvester (SPIH). This is a new type of harvester for converting multi-dimensional motion from low-frequency sources such as humans or other environment. Each 2-mm-diameter transducer is capable of producing between 0.05-4.2 nJ of energy per actuation cycle at bias voltages of 10-100 V under controlled experiments.

Th-032 **A HYBRID SUPERCAPACITOR USING VERTICALLY ALINGED CNT-POLYPYRROLE NANOCOMPOSITE 354**

F. Sammoura[1,3], K.S. Teh[2], A. Kozinda[3], X. Zang[3], and L. Lin[3]
[1]*Masdar Institute of Science and Technology, UAE,*
[2]*San Francisco State University, USA, and*
[3]*University of California, Berkeley, USA*

We have successfully demonstrated, for the first time, the fabrication of vertically aligned carbon nanotube (VACNT)-polypyrrole (PPY) nanocomposites as a "hybrid supercapacitor material directly integrated on silicon-based electrodes. In contrast to previous works, three distinctive achievements are accomplished: (1) a "hybrid supercapacitor" using VACNT forest with electroplated PPY and dodecylbenzenesulfonate (DBS) as a dopant in acetonitrile, (2) realizing 500% higher capacitance as compared to the capacitance of electrodes made of VACNT or DBS-doped PPY alone, and (3) highly reversible cycling between -1 V and +1 V with improved knee frequency at 797Hz. As such, this hybrid nanocomposite could become a new class of material for future supercapacitors.

M-033 **A MEMS-ENABLED BIODEGRADABLE BATTERY FOR POWERING TRANSIENT IMPLANTABLE DEVICES 358**

M. Tsang[1], A. Armutlulu[1], A. Martinez[1], F. Herrault[1],
S.A. Bidstrup[1], and M.G. Allen[1,2]
[1]*Georgia Institute of Technology, USA and* [2]*University of Pennsylvania, USA*

A series of MEMS-enabled biodegradable batteries, composed of a Mg anode and Fe cathode in a 0.1M MgCl2 electrolyte, were developed to power transient implantable medical devices (IMD). Biodegradable energy sources would enable active devices for the monitoring and treatment of transient disease states, such as bone fracture healing and drug delivery. The anode was fabricated by electroplating Mg from a non-aqueous solution and passivated with either polycaprolactone or polyglycerol sebacate. The batteries demonstrated a capacity and power of up to 1.1mAh and 22uW, respectively, which are sufficient for a typical IMD.

T-034 **A MICRO-SCALE MICROBIAL SUPERCAPACITOR 362**

H. Ren[1], H. Tian[2], T.L. Ren[2], and J. Chae[1]
[1]*Arizona State University, USA and* [2]*Tsinghua University, CHINA*

We report, for the first time, a micro-scale microbial supercapacitor to substantially enhance the current and power density, aiming for a carbon-neutral renewable miniaturized electrochemical power converter. Current and power density of 501.5A/m2, and 251.4W/m2 are achieved, which is more than 18 and 32 folds of the previous records, yielding the supercapacitor an attractive alternative to existing energy conversion and storage device.

W-035 **A THREE-DIMENSIONAL ELECTROSTATIC/ELECTRET MICRO POWER GENERATOR FOR LOW ACCELERATION AND LOW FREQUENCY VIBRATION ENERGY HARVESTING 366**

K. Tao, S.W. Liu, J.M. Miao, and S.W. Lye
Nanyang Technological University, SINGAPORE

In this work, a three-dimensional (3D) multimodal electret-based micro power generator is developed for scavenging energy from low acceleration (<0.05g) and low frequency (<100Hz) vibrations, which are ubiquitous existence and readily available in our daily life.

Th-036 **A WEARABLE SYSTEM OF MICROMACHINED PIEZOELECTRIC CANTILEVERS COUPLED TO A ROTATIONAL OSCILLATING MASS FOR ON-BODY ENERGY HARVESTING 370**

R. Lockhart, P. Janphuang, D. Briand, and N.F. de Rooij

École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

We present a compact, wearable piezoelectric on-body harvesting system that uses a small eccentric mass from a common watch movement to mechanically deflect a set of micromachined piezoelectric cantilevers when excited by the low frequency movements of the human body. The piezoelectric cantilevers are directly coupled to the rotating mass via a set of pins located near its rotational center. The energy produced by each pluck of a single cantilever is 545 nJ, corresponding to a maximum output power of 11 μW for continuous plucking. This concept could be used to power on-body electronics.

M-037 **ALL-POLYMER PIEZOELECTRET ENERGY HARVESTER WITH EMBEDDED PEDOT ELECTRODE 374**

Y. Feng and Y. Suzuki

University of Tokyo, JAPAN

We develop a novel all-polymer high-aspect-ratio (HAR) piezoelectret energy harvester with embedded PEDOT electrode, and demonstrate its performance for low-resonant-frequency in-plane vibration energy harvesting. Butterfly-shaped stop valves is devised to control the PEDOT capillary flow inside the parylene channels. With the present early prototype, 5.2 V open circuit voltage and 53 nW output power have been obtained at the low resonant frequency of 205 Hz with 3 g acceleration.

T-038 **ELECTROMAGNETIC ENERGY HARVESTER WITH HIGH EFFICIENCY USING MICRO-MACHINING SI SPRINGS 378**

T. Shirai, Y. Wakasa, T. Nakagawa, K. Nomura, and H. Yagyu

Panasonic Corporation, JAPAN

We developed electromagnetic vibration energy harvester with quite high generating efficiency over 40%. This high efficiency was realized by using the 1mm-thick uniquely-structured Si springs in the harvester, which was created using micromachining process.

W-039 **ELECTROMAGNETIC ENERGY HARVESTER WITH AN IN-PHASE VIBRATION BANDWIDTH BROADENING TECHNIQUE.....382**

S.J. Chen, J.Y. Wu, and S.Y. Liu

National Central University, TAIWAN

This paper develops a duo-mode vibration structure for increasing usable bandwidth in a micromachined electromagnetic energy harvester. Compared to a pure cantilever harvester, the proposed cantilever-spiral coupled energy harvester has lower resonant frequencies and larger bandwidth.

Th-040 ELECTROSTATIC GENERATOR WITH FREE MICRO-BALL AND ELASTIC STOPPERS FOR LOW-FREQUENCY VIBRATION HARVESTING 385

F. Cottone[1], P. Basset[2], F. Marty[2], D. Galayko[3], L. Gammaitoni[1], and T. Bourouina[2]

[1]*University of Perugia, ITALY,* [2]*Université Paris-Est, FRANCE, and* [3]*UPMC-Sorbonne Universités, FRANCE*

We present a novel MEMS electrostatic vibration harvester based on frequency amplification through multiple-mass impacts in combination with elastic stoppers. The harvester proof mass hosts a tungsten micro-ball free to travel along the vibration direction. At low frequencies (10-60 Hz) the micro-ball impacts with the oscillating mass of the generator transferring kinetic energy to the gap-closing comb transducer which in turn resonates at 92 Hz. In addition, the elastic stoppers amplify the proof mass and ball velocity by collision with the rigid frame. Output power between 0.25 and 0.45 μW is achieved at 0.3-g amplitude and only 15 V bias in the range of 10-60 Hz with a -3db bandwidth of 50 Hz.

M-041 FLEXIBLE MICRO-SUPERCAPACITORS FROM PHOTORESIST-DERIVED CARBON ELECTRODES ON FLEXIBLE SUBSTRATES 389

M.-S. Kim, B. Hsia, C. Carraro, and R. Maboudian

University of California, Berkeley, USA

We demonstrate a simple and scalable technique for the fabrication of flexible micro-supercapacitors. The flexible high surface area electrodes are fabricated via a photoresist pyrolysis process followed by transfer for the electrodes to a flexible substrate. An energy density of 1 mWh/cm^3 is measured and the mechanical stability of the device is demonstrated through mechanical cycling tests.

T-042 GRAPHENE ELECTRODES ENHANCE PERFORMANCE FOR MICROLITER-SCALE MICROBIAL FUEL CELLS 393

V. Jayaprakash, R.D. Sochol, R. Warren, K. Iwai, and L. Lin

University of California, Berkeley, USA

In this work, graphene electrodes are employed to increase the power output of a microliter-scale microbial fuel cell (μMFC) for the first time. Previously, researchers have predominantly used Au/Cr electrodes in μMFCs, and have operated these fuel cells under controlled anodic conditions to attain high current densities and columbic efficiencies. At present, relatively low power outputs and open circuit potentials have limited such fuel cells from implementation in practical applications. To improve such performance, here we introduce a graphene-based μMFC (G-MFC) that utilizes graphene electrodes.

W-043 HIGH PERFORMANCE NONLINEAR MICRO ENERGY HARVESTER INTEGRATED WITH (K,Na) NbO_3/Si COMPOSITE QUAD-CANTILEVER 397

L.V. Minh, M. Hara, and H. Kuwano

Tohoku University, JAPAN

We developed a lead-free (K,Na)NbO_3 (KNN) nonlinear microenergy harvester. The harvester was densely integrated with a quatrefoil-shaped proof mass and quad cantilevers using bulk micromachining. The KNN/Si composite cantilever with two-separated KNN capacitors was to effectively collect charge. Clamped-clamped beam design was also adopted for wide band operation. The experimental results showed that the wide bandwidth of 253 Hz and the highest power density of 1623 uW/cm3 among the developed piezoelectric nonlinear MEMS harvesters were achieved at the low acceleration of 6 m/s2.

Th-044 HIGH-ENERGY-DENSITY ON-CHIP LI-ION CAPACITORS.....401

S. Li[1] and X. Wang[1,2]
[1] *Tsinghua University, CHINA and* [2] *Chinese Academy of Sciences, CHINA*

This paper presents a new on-chip Li-ion capacitor featured by higher energy density than that of supercapacitor under the same level of charge/discharge rate. Activated carbon (AC), a supercapacitor material, is used as positive electrode, while graphite, an anode material of Li-ion battery, is used as negative electrode and the electrolyte ued in Li-ion battery serves as electrolyte. The prototype with 100-μm-thick electrodes shows a capacity of 175μAh/cm^2 and an energy density of about 1500m/J/cm^2 under a charge/discharge current of 0.5mA/cm^2, and a cell voltage of 3.4V.

M-045 HIGH-ENERGY-DENSITY ON-CHIP SUPERCAPACITORS USING MANGANESE DIOXIDE-DECORATED DIRECT-PROTOTYPED POROUS CARBON ELECTRODES 405

S. Li[1], X. Wang[1,2], and C. Shen[1]
[1]Tsinghua University, CHINA and
[2]Chinese Academy of Sciences, CHINA

This paper presents the high performance on-chip micro supercapacitors using manganese dioxide (MnO_2) decorated into direct-prototyped porous carbon electrodes. By a new method of incorporating MnO_2 into carbon framework, both electric double layer capacitance (EDLC) and pseudocapacitance contribute to total capacity. Therefore, about 4-time increase in volumetric capacitance (0.8mF/(cm^2 μm) vs. 2.9mF/(cm^2 μm) under the scan rate of 50mV/s) is achieved. The procedure makes such devices potentially to be integrated into multi-function microsystems.

T-046 MEMS VIBRATION ELECTRET ENERGY HARVESTER WITH COMBINED ELECTRODES.....409

Q.Y. Fu and Y. Suzuki
University of Tokyo, JAPAN

We have developed a novel in-plane MEMS electret energy harvester with overlapping-area change and gap-closing electrodes that provides large output power both at low and high vibration accelerations. An early prototype has been successfully microfabricated with the single layer silicon-on-insulator process. Soft X-ray charging is employed to establish uniform surface potential around 60 V on vertical electrets on the sidewall of the comb fingers. Up to 1.6 μW output power has been obtained, which corresponds to the effective as high as 57%.

W-047 MICRO PATTERN OF CHARGE IN PTFE ELECTRET FOR ENERGY HARVESTERS 413

W. Bian, X. Wu, and X. Wang
Tsinghua University, CHINA

This paper presents a novel fabrication process to pattern the charge in electret film for vibration energy harvester (VEH) Applications. Compared with previously reported techniques, PTFE electret material, which is inexpensive and has highSurface potential, is used. The line width of the charge pattern is determined by photolithography process. Experiment results show that the surface potential on the patterned charge zone of PTFE is higher than -200V when line width reaches 20um. A demoed VEH is built by using the pattern technique and tested.

Th-048 **NANO-POROUS SiO_2 ELECTRET WITH HIGH SURFACE POTENTIAL AND HIGH THERMAL RESISTANCE 417**

M. Suzuki[1], T. Wada[1], T. Takahashi[1], T. Nishida[2], Y. Yoshikawa[2], and S. Aoyagi[1]

[1]*Kansai University, JAPAN and* [2]*ROHM Co., Ltd., JAPAN*

This study proposes a new electret with high surface potential and high thermal resistance, which is made of nano-porous SiO_2. Electrical charge density in the nano-porous SiO_2 is higher than that in a normal SiO_2 because the interfaces between void and SiO_2 trap electrical charges. Thermal stability of the nano-porous SiO_2 electret is better than that of a polymer electret. Output power generated by vibration energy harvesting using the nano-porous SiO_2 electret is also larger than that using the normal SiO_2 or CYTOP electret.

M-049 **NANOFLUIDIC REVERSE ELECTRODIALYSIS PLATFORM USING CONTROLLED ASSEMBLY OF NANOPARTICLES FOR HIGH POWER ENERGY GENERATION 421**

E. Choi, K. Kwon, D. Kim, and J. Park

Sogang University, SOUTH KOREA

This paper presents a novel microplatform for high power energy generation based on reverse electrodialysis. The ideal cation-selective membrane for power generations is realized using geometrically controlled in-situ self-assembled nanoparticles and it can be constructed with simple and cost effective process using microdroplet control containing nanoparticles in microchannel. Another advantage in our system is that maximum powers and the energy conversion efficiency can be improved by changing the geometry of microchannel and proper selection of size and materials in nanoparticles

T-050 **SPRINGLESS CUBIC HARVESTER FOR CONVERTING THREE DIMENSIONAL VIBRATION ENERGY 425**

M.D. Han, W. Liu, B. Meng, X.S. Zhang, X.M. Sun, and H.X. Zhang

Peking University, CHINA

This paper reports the design, fabrication and measurement of a springless cubic energy harvester. Coils are fabricated onto polyimide substrate and folded to form a cubic box. Output performance of the device is theoretically and experimentally investigated. Vibration in all dimensions can be effectively harvested and the maximum output is achieved at low frequencies with a wide bandwidth. Moreover, the device can be placed on a backpack or wrist to harvest vibration energy from daily life.

W-051 **ON THE OPTIMIZATION AND PERFORMANCES OF A COMPACT PIEZOELECTRIC IMPACT MEMS ENERGY HARVESTER.....429**

P. Janphuang, R. Lockhart, D. Briand, and N.F. de Rooij

École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This paper presents the development of a compact energy harvesting configuration to convert low frequency, mechanical oscillations into usable electrical energy using AFM-like MEMS piezoelectric cantilevers coupled to a rotating gear. The harvester, with an active device volume of 3.5 mm3 (3×5×0.23 mm3), is able to produce an average output power of 12 μW measured across an optimal resistive load of 4.7 kΩ at a rotational speed of 19 rps, demonstrating the potential of the compact MEMS piezoelectric micro-power generator.

Fabrication Technologies (FAB)

Th-052 **"ASSIST-FREE" ASSEMBLY TECHNIQUE OF STANDING OPTICAL DEVICES ON SOFT SPRING ACTUATOR STAGES 433**

Y. Oka, R. Shinozaki, K. Terao, T. Suzuki, F. Shimokawa, F. Oohira, and H. Takao
Kagawa University, JAPAN

In this study, a new assembly technique of independently fabricated optical devices on fragile MEMS actuator stages has been developed to realize novel functional optical-MEMS devices. This technique realizes the “assist-free" alignment and fixing of vertically mounted optical devices by combination of “micro spring slider” and “trapezoidal alignment slit”. In the experiments, micro mirrors were attached on electrostatic linear actuators and rotational actuators using this assembly technique, and a small average value of relative-angle error around 4/100° was successfully obtained."

M-053 **3D NANOFABRICATION ON COMPLEX SEED SHAPES USING GLANCING ANGLE DEPOSITION 437**

H.-H. Jeong[1], A.G. Mark[1], J.G. Gibbs[1], T. Reindl[2], U. Waizmann[2], J. Weis[2], and P. Fischer[1,3]
[1]*Max Planck Institute for Intelligent Systems, GERMANY,*
[2]*Max Planck Institute for Solid State Research, GERMANY, and*
[3]*University of Stuttgart, GERMANY*

We report a 3D fabrication scheme that combines two existing techniques, electron beam lithography (EBL) and glancing angle deposition (GLAD), to fabricate nanostructures with complex 3D shapes both parallel and perpendicular to the growth direction. GLAD is a physical vapor deposition (PVD) technique where evaporant is delivered to a substrate at a high angle of incidence. Local shadowing and azimuthal manipulation of the substrate allows a rich variety of complex 3D structures to be grown down to the nanoscale. Herein, we use EBL to write custom seed layers with complex shapes, and do so at the resolution limit for the GLAD technique.

T-054 **A FLEXIBLE TACTILE AND SHEAR SENSING ARRAY FABRICATED BY A NOVEL BUCKYPAPER PATTERNING TECHNIQUE 441**

C.-W. Ma, L.-S. Hsu, J.-C. Kuo, and Y.-J. Yang
National Taiwan University, TAIWAN

In this work, we present a flexible tactile and shear sensing array utilizing patterned buckypaper as the sensing elements. A novel fabrication process for realizing patterned buckypaper with high aspect ratio was proposed. The fabricated sensing device possesses the advantages such as anisotropic sensing capability, flexibility, simple fabrication process, and low cost. Measured results show excellent sensitivity and repeatability. In addition, the anisotropic sensing capability, which can be employed for better shear sensing, was also observed and discussed.

W-055 **A TECHNOLOGY FOR MONOLITHIC MEMS-CMOS INTEGRATION AND ITS APPLICATION TO THE REALIZATION OF AN ACTIVE-MATRIX TACTILE SENSOR** **445**

F. Zeng and M. Wong

Hong Kong University of Science and Technology, HONG KONG

A scheme of MEMS-CMOS integration based on the surface-migration of silicon is presently described. A cavity sealed with a cover-diaphragm is first formed, the electronic devices are next fabricated, and the suspended mechanical components are finally realized using the cover-diaphragm, without a sacrificial layer etch. With this scheme, the material and process incompatibility issues inherent in the existing integration techniques are largely eliminated. As a demonstration, a 16x16 active-matrix tactile sensor integrating a total of 256 force-sensing diaphragms, 512 transistors and 512 piezoresistors was designed, realized and characterized.

Th-056 **ALD HONEYCOMB PLATES ENABLING ROBUST ULTRATHIN MEMS** **449**

K. Davami, L. Zhao, and I. Bargatin

University of Pennsylvania, USA

We report rigid MEMS structures made of ALD films, with a thickness of the order of 10 nanometers and patterned in the shape of a 3D honeycomb. Unlike planar ALD films, the 3D honeycomb plates do not warp due to fabrication stress gradients and are promising for a number of applications. For example, honeycombs made from refractive metals, such as ALD tungsten can be used to create thermionic energy converters with a well-controlled gap. Honeycomb cantilevers or beams can be used as resonant gas sensors, thanks to their low thickness and high stiffness, which lead to high resonance frequencies and high sensitivity to surface adsorbates. The transparency of the alumina ALD films may even enable their use as support films in electron microscopy.

M-057 **ARRAYS OF MICRO PENNING-MALMBERG TRAPS: AN APPROACH TO FABRICATE VERY HIGH ASPECT RATIOS** **453**

A. Narimannezhad, J. Jennings, M.H. Weber, and K.G. Lynn

Washington State University, USA

This paper reports on the progress of fabrication of very high aspect ratio (1000:1) micro-Penning-Malmberg trap arrays designed to store antimatter. The structure consists of thousands of 100μm diameter tubes etched by deep reactive ion etching through Si wafers. Cycles of thermal oxidation and wet etching in buffered oxide etch (BOE) minimized the sidewalls roughness and ensured a complete coating gold sputtering. The wafers were then aligned and stacked in order to create the microtubes. Uniform plating with mean roughness of Ra=600nm was achieved by tuning the electroplating parameters.

T-058 **BATCH RELEASE OF MONODISPERSE LIPOSOMES TRIGGERED BY PULSED VOLTAGE STIMULATION** **457**

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[1]*Kanagawa Academy of Science and Technology, JAPAN and*

[2]*University of Tokyo, JAPAN*

We present a batch release technique for monodisperse liposomes immobilized on a substrate. A single pulsed voltage to the substrate induced detachment of the arrayed liposomes previously developed. Simultaneous release was observed shortly after the electrical stimulation. The release technique produced monodisperse and solvent-free liposomes freely suspended on the substrate, and allowed manipulation of the liposomes.

W-059 **CLARITAS™ – A UNIQUE AND ROBUST ENDPOINT TECHNOLOGY FOR SILICON DRIE PROCESSES WITH OPEN AREA DOWN TO 0.05%.....459**

O. Ansell[1], R. Barnett[1], T. Haase[2], L. Xie[3], S. Vargo[1], and D. Thomas[1]
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[2] *Fraunhofer Institute for Photonic Microsystems (IPMS,) GERMANY, and*
[3] *Harvard University, USA*

SPTS' Claritas is an enhanced method of OES endpoint detection for the Bosch process. It will be shown that Claritas has the capability to endpoint very low open area patterns (<1%), Bosch process recipes with high process pressures and show potential use of Claritas with other process solutions, including vapour phase etching.

Th-060 **CONCURRENT REACTIVE ION ETCHING EMPLOYING MICROMACHINED IONIC LIQUID ION SOURCE ARRAY.....463**

R. Yoshida, M. Hara, H. Oguchi, T. Suzuki, and H. Kuwano
Tohoku University, JAPAN

This paper describes concurrent reactive ion etching using micro ionic liquid ion source (ILIS) array. The ILIS array was fabricated using bulk micromachining and consists of micro needle emitters and a reservoir for the ionic liquid (IL) of 1-ethyl-3-methylimidazolium tetrafluoroborate. The ion beam etching of a (100) silicon substrate using the fabricated ILIS array was demonstrated. Monitoring mass spectra during the etching, the peaks of SiF+, SiF2+, and SiF3+ could be observed. These peaks indicate the chemical reaction between the silicon and fluorine based ions from the IL.

M-061 **DEVELOPMENT OF MEMS PIERCE-TYPE NANOCRYSTALLINE SI ELECTRON-EMITTER ARRAY FOR MASSIVELY PARALLEL ELECTRON BEAM DIRECT WRITING.....467**

H. Nishino[1], S. Yoshida[1], A. Kojima[2], N. Ikegami[3], N. Koshida[3], S. Tanaka[1], and M. Esashi[1]
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[3] *Tokyo University of Agriculture and Technology, JAPAN*

This study reports on development of the fabrication process for 100×100 Pierce-type nanocrystalline Si electron-emitter array for massively-parallel electron-beam (EB) direct writing system based on active-matrix operation of large-scaled-integrated circuit (LSI). The 100-μm-pitch emitter array with each diameter of ~40 μm is prototyped and successfully demonstrates EB resist patterning by 1:1 projection exposure at CMOS-compatible operation voltages. This study also successfully establishes the integration process of the emitter array on a CMOS-LSI wafer. This achievement is a giant step for realizing the novel EB lithography system.

T-062 **DIRECT LASER WRITING OF 3D PROTEIN STRUCTURES WITH NANOSCALE FEATURE SIZES.....471**

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[1] *University of Tokyo, JAPAN,* [2] *CIRMM-IIS, JAPAN, and*
[3] *Japan Science and Technology Agency (JST), JAPAN*

We report the fabrication of three-dimensional (3D) protein structures with nanoscale feature sizes by two-photon direct laser writing (DLW). For this fabrication technology, we combine the established DLW technology with previously reported 3D protein structure fabrication by photosensitized crosslinking. We demonstrate the fabrication of 2D and 3D protein structures with nm-sized features.

W-063 **FABRICATION OF ANISOTROPIC AND HIERARCHICAL UNDULATIONS BY BENCHTOP SURFACE WRINKLING.....474**

K. Wei and Y. Zhao
Ohio State University, USA

This paper describes a benchtop wrinkling process where highly ordered sinusoidal wrinkles with tailored wavelength and amplitude are created atop a PDMS foundation by atmospheric electric discharge. The method is used to fabricate hierarchical and anisotropic wrinkle-on-wrinkle and wrinkle-on-microstructure surface patterns. Its accessibility in general wet lab environments and simplicity to create multi-scale roughness are believed to facilitate applications in optical gratings, topography guidance for cell alignment, and micro/nanofluidics.

Th-064 **FABRICATION OF THIN STENCIL WITH BUFFER RESERVOIR UTILIZING THE COMBINATION OF AZ4620 AND SU-8 ELECTROPLATING MOLDS 478**

P.H. Chen[1], C.W. Huang[2], and C.H. Lin[1]
[1]*National Sun Yat-sen University, TAIWAN and*
[2]*Metal Industries Research and Development Center, TAIWAN*

This work develops a novel process for fabricating ultra-thin stencil with buffer reservoir utilizing the combination of AZ4620 positive photoresist (PR) and SU-8 negative PR as the electroplating molds. A 5 um thick AZ4620 layer is used to precisely define the printing patterns while a 3 um thick of nickel layer is electroplated. A SU-8 layer of the thickness 50 um is patterned as the second electroplating mold. The high transparency of SU-8 PR makes it easy to align the two PR plating molds. A 30 um thick nickel layer is then electroplated onto the first nickel layer. The developed stencil can be used to printing ultra fine line and thin film pattern.

M-065 **FREE-STANDING SUBWAVELENGTH GRID INFRARED REJECTION FILTER OF 90 MM DIAMETER FOR LPP EUV LIGHT SOURCE.....482**

Y. Suzuki, K. Totsu, M. Moriyama, M. Esashi, and S. Tanaka
Tohoku University, JAPAN

A subwavelength grid infrared filter as large as 90 mm in diameter was fabricated and tested on a 6 inch Si wafer for a laser-produced plasma extreme ultraviolet (EUV) light source used in the next generation lithography tools. The IR filter has a free-standing Mo-coated Si honeycomb grid structure with a thickness of 5 μm, a wire width of only 0.35 μm and a pitch of 4.5 μm, showing 99.7% rejection for 10.6 μm IR light. Such a large-size free-standing microstructure was successfully fabricated by carefully balancing film stress at each process step.

T-066 **GRAPHENE SYNTHESIS VIA DROPLET CVD AND ITS PHOTONIC APPLICATIONS 486**

X.N. Zang and L. Lin
University of California, Berkeley, USA

The process of "droplet CVD" for the synthesis of graphene sheets and its photonic applications have been demonstrated for the first time. Metal (Cu or Ni) droplets are naturally transformed from thin films in a high temperature furnace and utilized to grow graphene sheets via the chemical vapor deposition (CVD) process. As such, this new class of fabrication process could open up various graphene-based device/system applications, including photonic sensors."

W-067 **HIGH ASPECT RATIO, LARGE AREA SILICON-BASED GRATINGS FOR X-RAY PHASE CONTRAST IMAGING 490**

J.J. Baborowski, V. Revol, C. Kotler, R. Kaufman, P. Niedermann, F. Cardot, A. Dommann, A. Neels, and M. Despont
CSEM SA, SWITZERLAND

The presented work reports on the latest developments in the manufacturing of high aspect ratio silicon-based gratings used for X-ray phase contrast imaging (XPCI). XPCI reveals subtle changes in the microstructure of the samples, such as micro-cracks in composite materials or micro-calcifications in breast tissues. In fields as diverse as medicine, non-destructive testing or security, the gained information of this technique allows early diagnostic or detection of defects, tumors or explosives. The range of opportunities offered by depends highly on the achievable gratings parameters, such as periodicity, depth, duty cycle and aspect ratio. We have developed large (100x100mm2) Au-Si-Au-Air gratings with a periodicity of down to 2 µm and a depth of up to 100 µm with extremely low defect density (<1 defect/cm2). The fabricated gratings have been implemented on a XPCI set-up and used to demonstrate unprecedented imaging quality in material quality control.

Th-068 **HIGH RESOLUTION MICRO ULTRASONIC MACHINING (HR-µUSM) FOR POST-FABRICATION TRIMMING OF FUSED SILICA 3-D MICROSTRUCTURES 494**

A. Viswanath, T. Li, and Y.B. Gianchandani
University of Michigan, USA

Post-fabrication trimming is interesting for devices such as inertial sensors, timing references, and mass-balance resonators to adjust stiffness, mass, and potentially damping. The trimming process should be capable of micro machining brittle materials, without inducing stress or subsurface cracks. We have developed and evaluated a subtractive trimming technique based on micro ultrasonic machining (µUSM), for high-resolution trimming of complex 3D microstructures made from fused silica. Machining rates as low as 10 nm/sec and surface roughness as low as 30 nm have been achieved.

M-069 **FABRICATION OF CARBON NANOFIBROUS MICROELECTRODE ARRAY (CNF-MEA) USING NANOFIBER IMMERSION PHOTOLITHOGRAPHY.....498**

P.F. Jao[1], E. Franca[1], S.P. Fang[1], J. Yoon[1], K. Cho[1,3], D.E. Senior[2], G.J. Kim[1], B. Wheeler[1], and Y.K. Yoon[1]
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[2]*Universidad Tecnologica de Bolivar, COLOMBIA, and*
[3]*Korea Basic Science Institute, SOUTH KOREA*

Microelectrode arrays are used for stimulating and receiving neural electrical signals in vitro neural study. This work demonstrates the fabrication process of nanofibrous 3D microelectrodes using immersion lithography. Oil immersion negates the diffraction effects intrinsic in the photopatterning of electrospun nanofibers to give higher aspect ratio. Nanofiber electrode resistivity is characterized and its performance compared to that of carbon thin film. In vitro testing of electrodes are performed using E18 cortical neurons and cell density and cell viability analyzed.

T-070 **INDUCTIVELY COUPLED PLASMA ETCHING OF BULK TUNGSTEN FOR MEMS APPLICATIONS.....502**

L. Song, N. Li, S. Zhang, J. Luo, J. Hu, Y. Zhang, S. Chen, and J. Chen
Peking University, CHINA

Tungsten based MEMS devices have the potential to be used for many applications, such as tools for micro electrical discharge machining and ultrasonic machining, or mold for inject molding. For the first time, bulk tungsten ICP etching was developed and characterized, which is capable of producing high aspect ratio (>13) structures with feature size below 3μm. Etching depth of 230μm has been achieved at an etch rate up-to 2.2μm/min. This technology offers big opportunities for MEMS applications.

W-071 **LARGE ARRAYS OF INKJET-PRINTED MEMS MICROBRIDGES ON FOIL 506**

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This works describes the fabrication of an array of printed MEMS microbridges on polymeric foil in only four easy steps.Each functional material was deposited exclusively by inkjet-printing technique, compatible with large-area fabrication. Thearray consists of 60 to 80 individual microbridges, occupying an area of 2 mm x 2 mm, and displaying a total capacitancevalue of 1 - 1.7 pF when connected in parallel.

Th-072 **LIGHTWEIGHT MICRO LATTICES WITH NANOSCALE FEATURES FABRICATED FROM PROJECTION MICROSTEREOLITHOGRAPHY 510**

X. Zheng[1], J. Deotte[1], J. Vericella[1], M. Shusteff[1], T. Weisgraber[1], H. Lee[2], N. Fang[2], and C.M. Spadaccini[1]
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[2] *Massachusetts Institute of Technology, USA*

We demonstrate the utility of three-dimensional Projection Microstereolithography manufacturing system by producing a variety of microstructures with complex geometries and explored the potential of using the system to build meso-scale structures with micro-scale architecture and nano-scale features. These achievements pave the way for large scale micro- and nano- manufacturing that extends the current state-of-the-art of three-dimensional fabrication technologies.

M-073 **FABRICATION OF MICRO-HEATERS EMBEDDED IN PDMS USING A DRY PEEL-OFF PROCESS.....514**

I. Byun, R. Ueno, and B.J. Kim
University of Tokyo, JAPAN

We show a reliable fabrication method of micro-heaters embedded in polydimethylsiloxane (PDMS), and shows characterization of the micro-heaters. Metallization of PDMS is achieved using a dry peel-off process which involves modifying the surface properties of the substrate and metal patterns through self-assembled monolayer and manually peeling off the PDMS with embedded metal layers. Thus, micro-heaters can be fabricated by a simpler and easier way compared to conventional methods.

T-074 **MICROPATTERNING OF BACTERIAL CELLULOSE AS DEGRADABLE SUBSTRATE FOR CELL CULTURE 518**

Y. Karita, K. Hirayama, H. Onoe, and S. Takeuchi
University of Tokyo, JAPAN

This paper describes microfabrication of bacterial cellulose membrane, which is a nanofibrous cellulosic material produced by a bacterium, Acetobacter xylinum. We successfully micropatterned bacterial cellulose membrane by applying MEMS process and this patterned bacterial cellulose was confirmed to work as a scaffold for mouse embryonic fibroblast cells. Moreover, formation of cell cluster was observed by the treatment of cellulose degrading enzyme. We believe that this micropatterned cellulose plate would be useful in degradable microscaffolds for cell culture.

W-075 **MICROSCALE MAGNETIC PATTERNING OF HARD MAGNETIC FILMS USING MICROFABRICATED MAGNETIZING MASKS 520**

A. Garraud[1], O.D. Oniku[1], W.C. Patterson[1], E. Shorman[1], D. Le Roy[2], N.M. Dempsey[2], and D.P. Arnold[1]
[1]*University of Florida, USA and* [2]*University of Grenoble-Alpes, FRANCE*

We present a batch-fabrication process to imprint microscale magnetic pole patterns (perpendicular north/south poles) into hard magnetic films using field-shaping, soft magnetic "magnetizing masks". Using 7-µm-thick, electroplated Fe–Co magnetizing masks, magnetic stripes with widths down to 50 µm have been imprinted into both 15-µm-thick Co–Pt films and 5-µm-thick Nd–Fe–B films. These patterned films exhibit a sinusoidal stray magnetic field pattern with ~4 and ~7 mTpk-pk variations and corresponding field gradients of 80 and 140 T/m, respectively. We also demonstrate the ability to transfer more complex patterns by showing magnetization of various geometric shapes.

Th-076 **MONOLITHIC PIEZOELECTRIC IN-PLANE MOTION STAGE LOW-CROSS-AXIS-COUPLING 524**

S. Nadig, S. Ardanuc, and A. Lal
Cornell University, USA

In this work we present a rotary dither stage which can provide rotation stimulus with high dynamic range of 1800-deg/s, and parts-per-thousand cross axis actuation, and is planar compatible with in-package inertial sensor calibration. We use bulk PZT-4 beams, laser cut out from plates, to achieve monolithic integration of lateral actuators and flexures. This process enables high-aspect ratio beams (500um thick x150um wide) resulting in parts-per-thousand in-plane to out-of-plane motion coupling

M-077 **POLYMER MICROMACHINING BASED ON CU ON POLYIMIDE SUBSTRATE AND ITS APPLICATION TO FLEXIBLE MEMS SENSOR.....528**

Y. Niimi, S. Shibata, and M. Shikida
Nagoya University, JAPAN

MEMS technologies have produced various types of MEMS sensors on a Si or Silicone On Insulator (SOI) wafers. To realize MEMS sensors in the flexible fashion, we newly proposed to apply a Cu On Polyimide (COP) substrate as a starting material, and introduced a sacrificial etching for producing a cavity and an electrical feed through structures on the COP substrate. Finally, a flexible thermal MEMS sensor was fabricated on COP substrate.

T-078 **PRINTING AND ENCAPSULATION OF ELECTRICAL CONDUCTORS ON POLYLACTIC ACID (PLA) FOR SENSING APPLICATIONS.....532**

A. Vásquez Quintero, N. Frolet, D. Märki, G. Mattana, A. Marette, D. Briand, and N.F. de Rooij
Ecole Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This paper presents the printing of resistive and capacitive devices for temperature and humidity sensing applications, respectively, on biodegradable polylactic acid (PLA) substrates. Inkjet and gravure printing were assessed as direct silver-based nanoparticles inks transfer methods. Flash photonic ink sintering methodologies were optimized due to the low PLA glass transition temperature (58 °C) and maintain its mechanical integrity. An encapsulation method for electrical conductive structures is proposed by means of laminating PLA sheets at relatively low temperatures (< 60 °C). These fabricated structures are now exposed for long periods (months) in compost and high humidity environments to evaluate their degradation.

W-079 **RAPID PROTOTYPING OF RESISTIVE MEMS SENSING DEVICES ON PAPER SUBSTRATES 536**

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[2] *University of British Columbia, CANADA*

We have developed an inexpensive inkjet printing process to rapidly fabricate resistive sensor devices on paper substrates. Since we use a commercial inexpensive inkjet printer and the design can be modified and tested within minutes, the process is especially useful to easily develop and test MEMS sensor models. Additional applications encompass disposable medical sensors, sensors for paper packaging, as well as very low cost strain sensing.

Th-080 **REAL-TIME DYNAMICALLY RECONFIGURABLE LIQUID METAL BASED PHOTOLITHOGRAPHY.....540**

D. Kim[1], J.H. Yoo[1], W. Choi[1], K. Yoo[2], and J.B. Lee[1]
[1] *University of Texas at Dallas, USA and*
[2] *Hanbat National University, SOUTH KOREA*

We report real-time dynamically reconfigurable photolithography technique using liquid metal Galinstan as UV opaque material and PDMS as UV transparent material. We demonstrated dynamically reconfigured on-demand patterning of single digit numbers in positive photoresists along with various patterns with minimum feature size of 10 μm. To the best of our knowledge, this is the first demonstration of true real-time reconfigurable photolithography in UV wavelengths.

M-081 **RELEASE AND TRANSFER OF LARGE-AREA ULTRA-THIN PDMS 544**

J. Gao, D. Guo, S. Santhanam, Y.J. Yu, A.J.H. McGaughey, S.C. Yao, and G.K. Fedder
Carnegie Mellon University, USA

This paper reports on a successful fabrication of ultra-thin 10μm PDMS films with embedded Au electrodes, as well as the releasing and transferring of large area films. The motivation for this work is in development of a miniature pump actuator for moving working fluid in an electrocaloric microcooler. It opens a promising route for fabricating ultra-thin and compliant MEMS and electronic devices.

T-082 **SOLID STATE MEMS DEVICES ON FLEXIBLE AND SEMI-TRANSPARENT SILICON (100) PLATFORM.....548**

S.M. Ahmed, A.M. Hussain, J.P. Rojas, and M.M. Hussain
King Abdullah University of Science and Technology, SAUDI ARABIA

We report fabrication of MEMS thermal actuators on flexible and semi-transparent bulk silicon <100> substrate. The fabricated thermal actuators exhibit similar performance before and after bending. We fabricate the devices first and then release the top portion of the silicon (≈ 19 μm) which is flexible and semi-transparent. Then we perform chemical mechanical polishing to reuse the remaining wafer. Prior demonstrations on flexible MEMS devices had limited thermal budget (<150 °C) compatibility and they did not have cost-saving wafer recycling process.

W-083 **WAFER-SCALE FABRICATION OF HIGHLY INTEGRATED RUBIDIUM VAPOR CELLS.....552**

T. Overstolz, J. Haesler, G. Bergonzi. A. Pezous, P.-A. Clerc, S. Ischer, J. Kaufmann, and M. Despont
CSEM SA, SWITZERLAND

CSEM is developing a highly integrated chip scale atomic clock based on coherent population trapping (CPT) of 87-Rb atoms which are confined in a vapor cell. The vapor cells are batch fabricated, based on pipetting dissolved RbN3 into cell cavities etched into a silicon wafer, closing the cavities by anodic bonding, and UV decomposition of recrystallized RbN3 deposits into Rb and N2. The vapour cells are equipped with resistive heaters, temperature sensors, and Helmholtz coils integrated on both sides of the cell windows.

Th-084 **WAFER-SCALE FLEXIBLE GRAPHENE LOUDSPEAKERS.....556**

H. Tian, Y.L. Cui, Y. Yang, D. Xie, and T.L. Ren
Tsinghua University, CHINA

Wafer-scale flexible graphene loudspeakers are fabricated in one-step laser scribing technology. Current fabrication process for graphene devices is mainly based on CVD graphene, which needs several hours' graphene growth, transfer and patterning. By using this new laser scribing technology, wafer-scale graphene patterns can be obtained in 25 minutes. The loudspeaker is demonstrated to be high performance with wide-band sound generation from 1~50 kHz. Our results show that the laser scribed graphene could be widely used in integrating wafer-scale graphene-based electroacoustic devices.

Industry

M-085 **A POLYMER MEMS MIRROR FOR ON-DEMAND LIGHT DISTRIBUTION FABRICATED BY INJECTION MOLDING AND TRANSFER OF PRINTED LAYERS 560**

K. Kurihara[1], O. Nagumo[2], H. Takagi[1], and R. Maeda[1]
[1]*National Institute of Advanced Industrial Science and Technology (AIST), JAPAN and* [2]*Designtech Co., Ltd, JAPAN*

A low-cost and wide mirror area polymer MEMS scanner for on-demand light distribution was fabricated by combined process of the injection molding and layer transfer of screen-printed patterns on a film. This fabrication process realizes low cost polymer MEMS. It is expected that the low-cost MEMS can be a killer application for new industry field.

T-086 **BI-CHAMBER ELECTROMAGNETIC FLUIDIC PUMP.....564**

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We describe the design, fabrication and performance of a MEMS pump that is actuated electromagnetically and is capable of pumping very high viscosity liquids. Valve motion relative to that of the pumping piston is described in detail.

W-087 **IMPROVED MECHANICAL RELIABILITY OF MEMS PIEZOELECTRIC VIBRATION ENERGY HARVESTERS FOR AUTOMOTIVE APPLICATIONS 568**

M. Renaud, Z. Wang, M. Jambunathan, S. Matova, R. Elfrink, M. Rovers, M. Goedbloed, C. de Nooijer, R.J.M. Vullers, and R. van Schaijk
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We present a comprehensive approach to address the issue of the mechanical reliability of MEMS piezoelectric vibration harvesters. These harvesters generate sufficient electrical power for powering a tire pressure monitoring system. However, their reliability, particularly in terms of shock resilience, has to be optimized for in-tire applications. This paper showcases experimentally verified improvements of the mechanical reliability, which is achieved by optimizing both the package design and the wafer processing.

Th-088 **LOW-COST MICROBOLOMETER WITH NANO-SCALED PLASMONIC ABSORBERS FOR FAR INFRARED THERMAL IMAGING APPLICATIONS.....572**

F. Utermöhlen[1], D. Etter[2], D. Borowsky[1], I. Herrmann[1], C. Schelling[1], F. Hutter[2], S.H. Sun[2], and J. Burtghartz[2]
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[2]Institut für Mikroelektronik Stuttgart (IMS CHIPS), GERMANY

We have developed a scalable low-cost microbolometer which can be used for automotive nightvision as well as consumer applications with a broad variety of requirements regarding image resolution and sensitivity. In contrast to state-of-the-art microbolometers which are based on a standard CMOS ASIC process with CMOS-compatible MEMS post-processing on the same wafer, we use a MEMS wafer with the microbolometer pixels and a standard CMOS wafer with the read-out ASIC which are mechanically, electrically and hermetically connected. This concept allows for significant cost reduction since the two dedicated technologies for the MEMS and the ASIC can be optimized and fabricated independently and because the ASIC chip can serve as a hermetic package for the MEMS.

Materials and Device Characterization (MDC)

M-089 **2D PHOTONIC-CRYSTALS FOR HIGH SPECTRAL CONVERSION EFFICIENCY IN SOLAR THERMOPHOTOVOLTAICS.....576**

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[2]*Kyung Hee University, SOUTH KOREA*

We present a high-efficiency 2D photonic crystal based solar thermophotovoltaic (STPV) device operating at high temperatures (~1300 K) under moderate solar concentration (~100 Suns). These results were only possible by tailoring the spectral properties of the absorber-emitter through surface nanostructuring of tantalum and minimizing parasitic thermal losses through an innovative vacuum-enclosed experimental setup.

T-090 **AN OPTICAL IN-PLANE DISPLACEMENT MEASUREMENT TECHNIQUE WITH SUB-NANOMETER ACCURACY BASED ON CURVE FITTING.....580**

J. Kokorian[1], F. Buja[1], U. Staufer[1], and W.M. van Spengen[1,2]
[1]*Delft University of Technology, THE NETHERLANDS and*
[2]*Falco Systems BV, THE NETHERLANDS*

We will show a technique, based on plain optical microscopy and curve fitting, for measuring in-plane displacements in MEMS applications. We modeled and experimentally verified how the measurement accuracy is influenced by quantization noise, photon shot noise, optical magnification, camera resolution and pixel binning. We found that when the noise figure was dominated by shot noise, the measurement error was lowered into the deep-subnanometer range.

W-091 **CHARACTERIZATION OF IMPROVED CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS (CMUTS) USING ALD HIGH-K DIELECTRIC ISOLATION 584**

T. Xu, C. Tekes, and F.L. Degertekin
Georgia Institute of Technology, USA

We show the advantages of high-k dielectric, ALD HfO2 over traditional PECVD silicon nitride isolation for Capacitive Micromachined Ultrasonic Transducers (CMUTs) fabricated by a low temperature, CMOS compatible, sacrificial release method. ALD HfO2 dielectric properties are characterized to optimize CMUT design in transmit and receive mode. Performances of the two different dielectric isolation devices are evaluated through parallel plate modeling and experimentally measured pressure outputs and receive sensitivities.

Th-092 **CHARACTERIZATION OF STICTION FORCES IN ULTRA-CLEAN ENCAPSULATED MEMS DEVICES.....588**

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

We show that stiction in contact between encapsulated MEMS devices and the surrounding sidewalls generally results in a reversible adhesion with a consistent adhesion force. This force is small enough (25 μN) to be overcome by the restoring force of the springs in inertial sensors with resonant frequency above 4 kHz. Therefore, it should be possible to design and build stiction-free inertial sensors in this process – a significant advantage over approaches that rely on deposition, tuning and maintenance of chemical coatings for inertial sensors.

M-093 **COMPOSITE OF THERMALLY RESPONSIVE SOLUTION AND LUBRICATING MICRO BEADS AS SEALING MATERIAL FOR PISTON-CYLINDER ACTUATOR 592**

T. Chishiro, S. Honda, and S. Konishi
Ritsumeikan University, JAPAN

This paper proposes a novel sealing technique for miniaturized piston-cylinder actuator. The sliding part of a piston actuator requires both high sealing and excellent lubrication. This paper will show a smart sealing material composed of thermally responsive solution and lubricating micro beads. Micro beads are expected to contribute to provide lubricant between a sliding part and an inner wall when thermally responsive solution gels by heating. We will present the concept, design, and characterization of proposed sealing technique for a piston actuator.

T-094 **CONTINUOUS DYNAMIC TIMING MEASUREMENTS TO MONITOR SPRING AND SURFACE FORCES IN MEMS SWITCH RELIABILITY.....596**

C. Kosla[1], P. Fitzgerald[2], and M. Hill[1]
[1]*Cork Institute of Technology, IRELAND and* [2]*Analog Devices, IRELAND*

We demonstrate an automatic reliability detection/prediction system for industry manufactured MEMS switches based on dynamic time measurements, allowing for non-invasive and continuous device monitoring. The developed method highlights the influence of both restoring and surface forces evolution on switch reliability and for the first time allows identification of an imminent device failure due to its continuous monitoring. Additionally we present the scalability of this approach by testing it on different switch types and on a large number of samples.

W-095 **DIRECT MEASUREMENT OF SHEAR PIEZORESISTANCE COEFFICIENT ON SINGLE CRYSTAL SILICON NANOWIRE BY ASYMMETRICAL FOUR-POINT BENDING TEST.....600**

T. Kimura, N. Saito, T. Takeshita, K. Sugano, and Y. Isono
Kobe University, JAPAN

This research evaluated the shear piezoresistance property of p-type single crystal silicon nanowire (SiNW) by the asymmetrical four-point bending (AFPB) testing proposed by the authors. We fabricated the p-type SiNW on the AFPB specimen with "V" shaped notches made of single crystal silicon. Bending the specimen by the asymmetrical four point-supports, simple shear stress can be produced at the center of the specimen. Consequently, we have succeeded in evaluating the shear piezoresistance coefficient of SiNW directly."

Th-096 **DISSOLVABLE MATERIAL FOR HIGH-ASPECT-RATIO FLEXIBLE SILICON-MICROWIRE PENETRATIONS.....604**

S. Yagi, S. Yamagiwa, T. Imashioya, H. Oi, Y. Kubota,
M. Ishida, and T. Kawano
Toyohashi University of Technology, JAPAN

For realization of low invasive electrode penetrations into biological tissue, here we improved the penetration capability of high-aspect-ratio flexible silicon-micorwires by coating a dissolving material of silk fibroin. The silk fibroin was coated over vertically vapor-liquid-solid (VLS) grown silicon-microwires. The 420-μm-long silicon-wire with a ~200-μm-thick silk film exited the stiffness of 4.03 N/m, which is 72% improved value compared to that of the silicon-wires without silk (2.34 N/m). The effects of the silk support on the wire penetration were observed by demonstrating the gelatin penetrations. These results suggest that the numerous high-aspect-ratio flexible bioprobes can be penetrated by using the silk support.

M-097 **DOME-DISC: DIFFRACTIVE OPTICS METROLOGY ENABLED DITHERING INERTIAL SENSOR CALIBRATION.....608**

S. Nadig[1], S. Ardanuç[1], B. Clark[2], and A. Lal[1]
[1]*Cornell University, USA and* [2]*Analog Devices Inc., USA*

We demonstrate ~100-ppm accurate scale-factor and bias calibration of a commercial gyroscope, in which the typical un-calibrated scale factor variations are 100,000-ppm. In this paper, we present a Diffractive Optical Metrology Enabled Dithering Inertial Sensor Calibration consisting of a novel piezoelectric dither stage, the motion of which is measured by imaging the diffraction pattern off the stage of a long-term stable wavelength laser. The architecture presented here illustrates how atomically stable lasers and CMOS imagers can be combined to form a miniature atomically stable self-calibrated inertial sensor platform.

T-098 **ELECTRICAL CHARACTERIZATION OF ALD COATED SILICON DIOXIDE MICRO-HEMISPHERICAL SHELL RESONATORS.....612**

P. Shao, V. Tavassoli, C.-S. Liu, L.D. Sorenson, and F. Ayazi
Georgia Institute of Technology, USA

A micro-hemispherical shell resonator (μHSR) is the beating heart of a micro-scale hemispherical resonator gyroscope (μHRG). Small damping and high symmetry are two essential requirements for μHRGs. Damping can be quantified bymechanical quality factor (Q) of the resonance, and structural symmetry can be quantified by the frequency split between two degenerate resonance modes. This paper reports on important electrical characterizations of Q and frequency split of ALD coated thermally-grown silicon-dioxide μHSRs, and analysis on how the performance will change with fabrication and measurement parameters.

W-099 **FABRICATION AND DEGRADATION CHARACTERISTIC OF SPUTTERED IRIDIUM OXIDE NEURAL MICROELECTRODES FOR FES APPLICATION.....616**

X.-Y. Kang, J.-Q. Liu, H.-C. Tian, J.-C. Du, B. Yang, H.-Y. Zhu, Y. NuLi, and C.-S. Yang
Shanghai Jiao Tong University, CHINA

We have fabricated reactively sputtered iridium oxide film (SIROF) microelectrodes under different oxygen flows and the stimulus-evoked degradation properties are also tested. The SIROF microelectrodes prepared under 25 sccm oxygen flow shows the least degradation from continuous electrical stimulation. That the charge storage capacity (CSC) is only 9.6 % lost and the 1 kHz impedance is only 4.23% increase. Hence, the 25 sccm one can be an ideal microelectrode modification material for electrical stimulation with the least degradation.

Th-100 **FABRICATION AND TESTING OF PIEZOELECTRIC HYBRID PAPER FOR MEMS APPLICATIONS.....620**

S.K. Mahadeva, K. Walus, and B. Stoeber
University of British Columbia, CANADA

We have developed a new inexpensive functional paper based material that can be used as a piezoelectric substrate for sensing applications. In our simple method, nanostructured BaTiO3 is embedded onto the fibers prior to forming paper sheet, which involves immersion of wood fibers in aqueous solution of poly (diallyldimethylammonium chloride) PDDA and poly(sodium 4-styrenesulfonate) and once again in PDDA, and results in the creation of a positively charged surface on wood fiber. The treated wood fibers are then immersed in a BaTiO3 suspension, leading to the electrostatic binding of BaTiO3. The hybrid paper showed the highest d33 of 4.8±0.4 pC/N.

M-101 **GRAPHENE WOVEN FABRIC AS HIGH-RESOLUTION SENSING ELEMENT OF CONTACT-LENS TONOMETER.....624**

Y. Zhang[1], T. Man[1], X. Li[2], H. Zhu[2], and Z. Li[1]
[1]*Peking University, CHINA and* [2]*Tsinghua University, CHINA*

In our work, the graphene woven fabrics (GWFs), the combination of highly sensitive strain sensing and transparency, is investigated as the sensing element of the contact-lens tonometer, which enables precisely monitor IOP. The relationship between the current changes when keeping the voltage constant and effective IOP increasing has been obtained.

T-102 **INCREASED THERMAL CONDUCTIVITY POLYCRYSTALLINE DIAMOND FOR LOW-DISSIPATION MICROMECHANICAL RESONATORS** **628**

H. Najar[1], A. Thron[1], C. Yang[2], S. Fung[1], K. van Benthem[1], L. Lin[2], and D.A. Horsley[1]
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[2] *University of California, Berkeley, USA*

We report an investigation of microcrystalline diamond (MCD) films deposited under different conditions to increase thermal conductivity and therefore mechanical Q in MEMS resonators. Here, through a study of different deposition conditions, we demonstrate a three-fold increase in thermal conductivity (i.e. k = 100W/mK) and therefore Q-TED. We further present a study of the unique microstructure of hot filament CVD diamond films and relate growth conditions to observed microstructural defects.

W-103 **INTERFACE LOSSES IN MULTIMATERIAL RESONATORS** **632**

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[1] *Denmark Technical University, DENMARK and*
[2] *Ecole Polytechnique Federale de Lausanne (EPFL), SWITZERLAND*

We present an extensive study shedding light on the role of surface and bulk losses in micromechanical resonators. We fabricate a set of Si3N4 square membranes with different lateral dimensions, thickness and thickness of metal on top andcharacterize the 81 lowest flexural modes, obtaining more than 3000 experimental points to eventually quantify the importance of interface losses in multimaterial resonators.

Th-104 **INVESTIGATION OF DOMINANT FACTORS TO CONTROL C-AXIS TILT ANGLE OF ALN THIN FILMS FOR EFFICIENT ENERGY HARVESTING** **636**

Q. Wang, H. Oguchi, M. Hara, and H. Kuwano
Tohoku University, JAPAN

We investigated growth conditions to enhance the c-axis inclination of aluminum nitride (AlN) thin films grown on silicon substrates using the electron cyclotron sputtering. Higher substrate tilt angles, lower substrate temperature, and rougher buffer layer surface resulted in higher c-axis tilt angle, mainly due to decrease in ad-atom mobility on the surface. This study deepens the understanding of how to control c-axis inclination of AlN thin film to control the electro-mechanical coupling coefficient for larger output power of the AlN-based energy harvesters.

M-105 **INVESTIGATION OF THE FATIGUE ORIGIN AND PROPAGATION IN SUBMICROMETRIC SILICON PIEZORESISTIVE LAYERS** **640**

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We present the study performed on structures designed and tested for the analysis of long-term reliability and fatigue of 250-nm-thick crystalline Silicon that can be used as piezoresistive sensing layer in low-power 10-axis inertial measurement units. With a specimen surface-to-volume ratio 100 times smaller than previous literature, this work extends to the nanometric domain the debate data previously published about the origin and propagation of fatigue in Silicon at the micro scale.

T-106 **NANOFIBER FORESTS WITH HIGH INFRARED ABSORPTANCE.....644**

H.Y. Mao[1,3], C. Lei[1,4], Y.J. Chen[1,4], Z.J. Chen[2], W. Ou[1,3], W.G. Wu[2], A.J. Ming[1,3], and D.P. Chen[1,3]
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Nanofiber forests with high infrared(IR) absorptance are reported in this work. In wavelength range from 1.5 to 5 μm, the absorptance of the nanofiber forests reaches a minimum of 96%, which is much higher than that of Si3N4-based IR absorbers and the polymer coatings from which the nanofibers are obtained. Such nanofiber forests are fabricated by using a plasma-stripping-of-polymer technique, which is fast, high-yield, and compatible with micro-fabrication. By introducing the nanofiber forests in MEMS IR devices, improved performance of the devices is expected to be acquired.

W-107 **NANOSTRUCTURED SILICON FLAPPING WING WITH HIGHER STRENGTH AND LOW REFLECTIVITY FOR SOLAR POWERED MEMS AIRCRAFT 648**

K. Kashyap[1], A. Kumar[1], C.-N. Chen[1], M.T. Hou[2], and J.A. Yeh[1,3]
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[2]*National United University, TAIWAN, and*
[3]*National Applied Research Laboratories, TAIWAN*

We develop a novel way of higher strength silicon flapping wings design for MEMS aircraft achieved by silicon nanostructures, which breaks the limitation of silicon as a fragile material. Silicon flapping wings were designed for MEMS aircraft which increases the bending strength of wings by 6 times and reduces the reflectance to 2%. Both the benefits simultaneously were achieved from nanostructure surface texturing by low cost wet chemical etching.

Th-108 **POSSIBILITY OF CEMENTED CARBIDE AS STRUCTURAL MATERIAL FOR MEMS 652**

T. Morikaku[1], T. Fujii[1], K. Kuroda[2], Y. Takami[2], S. Inoue[1], and T. Namazu[1,3]
[1]*University of Hyogo, JAPAN,* [2]*Silveralloy Co., Ltd. JAPAN, and* [3]*Japan Science and Technology Agency (JST), JAPAN*

We present the possibility of WC-Co cemented carbide as mechanical elements in MEMS. The cemented carbide is typically used as material for working tool because it has superior characteristics, such as very high Young's modulus, excellent rigidity, good chemical inertness, and good thermal stability. These are also very attractive as structural material in MEMS. We investigated the influences of specimen size and WC-Co composition ratio on mechanical properties of FIB-fabricated WC-Co cemented carbide nanowires by means of on-chip uniaxial tensile testing.

M-109 **THIN-FILM MAGNESIUM AS A SACRIFICIAL AND BIODEGRADABLE MATERIAL 656**

Y. Liu, J. Park, J.H.-C. Chang, and Y.-C. Tai
California Institute of Technology, USA

Magnesium (Mg) and magnesium alloys have drawn great attention as biodegradable materials. It means that magnesium could be an interesting dual "sacrificial and biodegradable MEMS material". This work then reports the first etching tests of the dual properties of ebeam-deposited thin-film Mg (i.e., 0.3 and 1.0 micron thick). Here we have tested etchants including diluted hydrochloric acid, saline, and culture medium. Data are fitted by ''First-and-Second order'' model. The initial results do show that thin-film Mg indeed is a promising dual sacrificial and biodegradable material."

T-110 **THREE-DIMENSIONAL (3-D) RESHAPING TECHNIQUE IN MEMS DEVICES BY SOLELY ELECTRICAL CONTROL WITH ULTRAFINE TUNING RESOLUTION.....660**

Y.H. Yoon, C.H. Han, and J.-B. Yoon
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We propose an innovative and simple three-dimensional (3-D) reshaping (plastic deformation) technique in MEMS devices by solely electrical control with ultrafine tuning resolution. While voltage input induces stress on the device, Joule heating is applied to make plastic deformation in the device, where the tuning resolution was demonstrated at a sub-100nm level. The proposed technique is expected to be favorably used in many integrated MEMS devices where reshaping feature is required avoiding any external instruments.

W-111 **TUNABLE THZ FILTER BASED ON RANDOM ACCESS METAMATERIAL WITH LIQUID METAL DROPLETS.....664**

Q.H. Song[1], W.M. Zhu[2], W. Zhang[2], E.M. Chia[2], M. Ren[2], and A.Q. Liu[1]
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[2]*Nanyang Technological University, SINGAPORE*

We report a tunable THz filter based on random access metamaterial with liquid metal droplet, which is tuned by controlled electrowetting effects. The random access metamaterial consists of micro droplets formed by lotus effect. In experiment, it measures a near 0.01-THz frequency shift of the dipole resonance spectrum induced by changing of the droplets shape via electrowetting effect. The random access metamaterial is flexible in tuning and easy in fabrication, which has potential application on tunable filters, controllable beam steering and flat lens.

Th-112 **WETTING DYNAMICS STUDY OF UNDERWATER SUPERHYDROPHOBIC SURFACES THROUGH DIRECT MENISCUS VISUALIZATION.....668**

M. Xu, G. Sun, and C.J. Kim
University of California, Los Angeles, USA

We report the study of underwater wetting transition of superhydrophobic (SHPo) surfaces from dewetted (Cassie) to wetted (Wenzel) state through direct and continuous meniscus visualization. The result confirmed two meniscus states of pinning and wetting, the latter leading to the Wenzel state. Furthermore, the result revealed that the Cassie state can (or cannot) be indefinite if (or unless) the water is saturated with air and the hydrostatic pressure is low enough.

Mechanical Sensors and Systems (MECH)

M-113 **3-D HEMISPHERICAL MICRO GLASS-SHELL RESONATOR WITH INTEGRATED ELECTROSTATIC EXCITATION AND CAPACITIVE DETECTION TRANSDUCERS.....672**

M.M. Rahman, Y. Xie, C. Mastrangelo, and H. Kim
University of Utah, USA

This paper reports the development and performance of a 3D hemispherical micro glass-shell resonator with integrated electrostatic excitation and capacitive detection transducers. This paper presents the first performance results of the 3D shell resonator with integrated micro fabricated excitation and sensing units that produced the first vibration mode of resonance at 5.843 kHz with a quality factor of 730 at atmosphere with the time decay constant of 39.78ms.

T-114 **A CMOS MEMS PIRANI VACUUM GAUGE WITH COMPLEMENTARY BUMP HEAT SINK AND CAVITY HEATER 676**

Y.-C. Sun[1], K.-C. Liang[1,2], C.-L. Cheng[1], and W. Fang[1]
[1]*National Tsing Hua University (NTHU), TAIWAN and*
[2]*Taiwan Semiconductor Manufactury Company Ltd., TAIWAN*

We design and manufacturing a new CMOS-MEMS Pirani vacuum gauge with complementary bump heat-sink and cavity heater. By using the bump heat-sink and cavity heater design, the active area of heat-sink and heater can be increased without changing device footprint size. In addition, the cavity in heater reduces the thermal mass for low power operation. The proposed design have larger dynamic range, higher sensitivity and lower power consumption as compare to the typical type.

W-115 **A LARGE RANGE MULTI-AXIS CAPACITIVE FORCE/TORQUE SENSOR REALIZED IN A SINGLE SOI WAFER.....680**

D. Alveringh, R.A. Brookhuis, R.J. Wiegerink, and G.J.M. Krijnen
University of Twente, THE NETHERLANDS

A miniature silicon capacitive force/torque sensor is designed and realized to be used for biomechanical applications. The sensor is capable of measuring 5 degrees of freedom with a force range of 2 N in shear and normal direction and a torque range of 6 Nmm. The fabrication of the sensor requires only two masks, making the sensor cost-effective to fabricate. This is the first 5 degrees of freedom force/torque sensor in this force range made in a single SOI wafer.

Th-116 **A NOVEL ELECTRET ROTATIONAL SPEED SENSOR.....684**

W. Bian, X. Wu, and X. Wang
Tsinghua University, CHINA

In this paper, a novel rotational speed sensor based on electrostatic variation is presented, which is fabricated by typical micro fabrication processes. Compared to the other rotational sensors, the merits of the presented sensor are its simple configuration, small size, and low cost.

M-117 **ALN-BASED PIEZOELECTRIC RESONATOR FOR INFRARED SENSING APPLICATION 688**

W.C. Ang[1,2], P. Kropelnicki[1], H. Campanella[1], Y. Zhu[1,2],
A.B. Randles[1], H. Cai[1], Y.A. Gu[1], K.C. Leong[3], and C.S. Tan[2]
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[2]*Nanyang Technological University, SINGAPORE, and*
[3]*GLOBALFOUNDRIES Singapore Pte Ltd, SINGAPORE*

We develop a highly sensitive AlN-based resonant uncooled infrared (IR) detector utilizing the photoresponse and piezoelectric properties of polycrystalline AlN. The design, fabrication, and IR sensing characterization of the device are presented. Different from other reported works, photoresponse mechanism was proposed in this paper instead of thermal effect. Without the need of vacuum, AlN-based IR detector brings the great advantage in device packaging and thus further reduces the manufacturing and operation cost.

T-118 **AN ALL OPTICAL SHOCK SENSOR BASED ON BUCKLED DOUBLY-CLAMPED SILICON BEAM.....692**

B. Dong[1], J.G. Huang[3], H. Cai[2], P. Kropelnicki[2], A.B. Randles[2], Y.D. Gu[2], and A.Q. Liu[1]

[1]*Nanyang Technological University, SINGAPORE,* [2]*Agency for Science, Technology and Research (A*STAR), SINGAPORE, and* [3]*Xi'an Jiao Tong University, SINGAPORE*

An all optical shock sensor is designed, fabricated and experimentally demonstrated. Fabricated with CMOS compatible process, this optical shock sensor can be easily integrated with other photonic devices. The opto-mechanical shock sensor can be potentially used at hash environment like in oil industry, or military usage in a complex electromagnetic environment. It also has potential applications such as inertial sensor, optical switch and other optomechanical devices.

W-119 **AN ANGULAR ACCELERATION SENSOR INSPIRED BY THE VESTIBULAR SYSTEM WITH A FULLY CIRCULAR FLUID-CHANNEL AND THERMAL READ-OUT 696**

J. Groenesteijn, H. Droogendijk, M.J. de Boer, R.G.P. Sanders, R.J. Wiegerink, and G.J.M. Krijnen

University of Twente, THE NETHERLANDS

We report on an angular accelerometer based on the semicircular channels of the vestibular system. The accelerometer consists of a water-filled circular tube, wherein the fluid flow velocity is measured thermally as a representative for the external angular acceleration. Measurements show a linear response for angular acceleration amplitudes up to 2×10^5 °s^{-2}.

Th-120 **AN EFFICIENT EARTH MAGNETIC FIELD MEMS SENSOR: MODELLING AND EXPERIMENTAL RESULTS.....700**

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We present the experimental results and performance indexes of a new z-axis Lorentz force MEMS magnetometer with reduced dimensions and high efficiency and exploit an ad-hoc formulated multi-physics approach and its solutions to model the sensor dynamics. The obtained sensor has a good resolution for earth magnetic field detection and navigation, and is very efficient in terms of exciting current, surface area and bandwidth.

M-121 **AN ELECTRET-BIASED RESONANT RADIATION SENSOR 704**

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Purdue University, USA

In this work, an electret-biased resonant radiation sensor capable of measuring accumulated radiation dosage is presented. The sensor consists of a positive corona-charged Teflon electret placed underneath a ZnO piezoelectric cantilever. As ionizing radiation passes through the ambient air surrounding the electret, ions are generated in the air and drift toward the Teflon substrate. These ions neutralize the electret's surface charges and thus reduce the electrostatic force. The force reductions result in the cantilever's resonant frequency back to its natural frequency.

T-122 **AN SOI TACTILE SENSOR WITH A QUAD SEESAW ELECTRODE FOR 3-AXIS COMPLETE DIFFERENTIAL DETECTION.....709**

Y. Hata[1], Y. Nonomura[1], H. Funabashi[1], T. Akashi[1], M. Fujiyoshi[1], Y. Omura[1], T. Nakayama[2], U. Yamaguchi[2], H. Yamada[2], S. Tanaka[3], H. Fukushi[3], M. Muroyama[3], M. Makihata[3], and M. Esashi[3]
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This paper presents an SOI capacitive tactile sensor with a quad-seesaw electrode for 3-axis differential detection. For differentially detecting 3-axis forces, we propose a novel seesaw-electrode structure composed of four rotating plates individually suspended by torsion beams. We successfully fabricated the test device that integrates an SOI with seesaw electrodes and an LTCC with fixed electrodes. The test results demonstrated that the proposed sensor differentially detects 3-axis forces.

W-123 **DIELECTRICAL LIQUID-BASED TACTILE SENSING ARRAY WITH ADJUSTABLE SENSING RANGES AND SENSITIVITY 713**

K.W. Liao[1], M.T. Hou[2], H. Fujita[3], and J.A. Yeh[1]
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[2] *National United University, TAIWAN, and* [3] *University of Tokyo, JAPAN*

We present a novel tactile sensing array with adjustable sensing ranges. Each sensing element contains a low dielectric constant droplet covered with high liquid. We controlled the contact angle of the droplet by controlling the electric flux passing through the element. Then, the sensing ranges and sensitivity were also adjusted due to the variation of the droplet shape. The results show the sensor's the sensing range is easily adjusted from 0.04N ~ 0.60N to 0.33N ~ 1.05N. The sensitivity increases 1.9 times in at small force range from 1.47pF/N to 2.90.pF/N.

Th-124 **ELECTRET-BASED LOW POWER RESONATOR FOR ROBUST PRESSURE SENSOR.....717**

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[1] *Saginomiya Seisakusho, Inc., JAPAN,* [2] *Shizuoka University, JAPAN, and* [3] *University of Tokyo, JAPAN*

We have developed a membrane-less pressure sensor based on squeeze-film damping in a 2-μm driving gap of a silicon ring-shape resonator. Its sensing range is from sub-atmospheric to over 1MPa; very wide-range pressure measurement is possible with one sensor element. An electret film having the 200-V-bias voltage was incorporated to the resonator; this allows the excitation of the resonator at very low AC voltage. This membrane-less pressure sensor has robust and low power consumption (nW-range) characteristics.

M-125 **ELECTRIC GRADIENT FORCE DRIVE MECHANISM FOR NOVEL MICRO-SCALE ALL DIELECTRIC GYROSCOPE 721**

R. Perahia, J.J. Lake, S.S. Iyer, D.J. Kirby, H.D. Nguyen, T.J. Boden, R.J. Joyce, L.X. Huang, L.D. Sorenson, and D.T. Chang
HRL Laboratories, USA

This paper reports a novel drive mechanism used to excite a cylindrical, all-dielectric micro-shell gyroscope structure. The drive mechanism operates by generating a gradient electric-field force from a set of interdigitated electrodes placed adjacent to the gyroscope structure. This novel transduction mechanism enables mechanical actuation of a pristine dielectric structure without the need for direct metallization which could otherwise degrade mechanical performance. Design, fabrication, and experimental demonstration are presented.

T-126 **ELECTROMECHANICAL DAMPING IN MEMS ACCELEROMETERS: A WAY TOWARDS SINGLE-CHIP GYROMETER-ACCELEROMETER CO INTEGRATION.....725**

Y. Deimerly[1], P. Rey[1], P. Robert[1], T. Bourouina[2], and G. Jourdan[1]
[1]*CEA - LETI – Minatec, FRANCE and* [2]*Université Paris-Est, FRANCE*

This work proposes a method for controlling mechanical damping in MEMS devices. By capacitively coupling a micro mechanical sensor to an electrical resistance, mechanical energy is dissipated by an additional damping sink. In this study, the damping rate of a MEMS accelerometer has been tuned under vacuum, in compliance with a simple electromechanical model that will be further detailed. Using this phenomenon, this presentation will discuss the possibility of co integrating accelerometers with gyrometers on a single chip inside a same cavity to form compact System In Package.

W-127 **EXPERIMENTALLY VALIDATED ALUMINUM NITRIDE BASED PRESSURE, TEMPERATURE AND 3-AXIS ACCELERATION SENSORS INTEGRATED ON A SINGLE CHIP 729**

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[1]*University of California, Berkeley, USA,*
[2]*Murata Manufacturing Co., Ltd, JAPAN, and*
[3]*University of California, San Diego, USA*

This paper reports a unified fabrication process used to build multiple aluminum nitride (AlN) based micro-electromechanical system (MEMS) sensors on a single chip. A fully functional AlN-based sensor cluster has been demonstrated and is presented in this paper. This sensor cluster is a “five degree-of-freedom" cluster; it measures 3-axis acceleration, temperature and pressure fabricated on a 1 cm x 1 cm die. In addition to utilizing AlN as both the structural and active layer of the sensors, this work is novel because all sensors are fabricated in the same fabrication run.

Th-128 **FABRICATION AND CHARACTERIZATION OF ALL HYDROGEL CANTILEVERS FOR ATOMIC FORCE MICROSCOPY APPLICATIONS 733**

I. Lee and J. Lee
Sogang University, SOUTH KOREA

We develop a novel method for fast and simple fabrication of hydrogel microcantilevers for atomic force microscopy applications. Fabricated hydrogel microcantilevers exhibit imaging performance comparable to that of commercial silicon microcantilevers in case of non-contact mode operation.

M-129 **FULLY PRINTED, LARGE-SCALE, HIGH SENSITIVE STRAIN SENSOR ARRAY FOR STRESS MONITORING OF INFRASTRUCTURE 737**

S. Harada, W. Honda, T. Arie, S. Akita, and K. Takei
Osaka Prefecture University, JAPAN

We demonstrated a macroscale sensor sheet by fabricating the fully printed, large-scale, and high sensitive strain sensor array on flexible substrates, which can cover any surfaces, for the application of real-time secure infrastructure maintenance as a proof-of-concept. Printed strain sensor array exhibits that the impressively high gauge factor ~106 and successfully detects the small deformation <20μm distributions.

T-130 **HARBOR SEAL INSPIRED MEMS ARTIFICIAL MICRO-WHISKER SENSOR**.....741

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[1]Nanyang Technological University, SINGAPORE and [2]Massachusetts Institute of Technology, USA

Harbor seal whiskers possess a unique geometry along the length of the whisker which is believed to perform vortex induced vibrations (VIV) in frontal flows. The geometry of the whisker appears to be well-tuned to offer maximum allowable sensitivity for sensing by minimizing the self-induced vibrations until an upstream stimulus is encountered. In this work we develop artificial MEMS versions of seal whiskers using stereolithography. These artificial sensors demonstrate a threshold velocity detection limit as low as 193μm/s which rivals the abilities of the Harbor seal's real whisker. Experiments conducted in water tunnel reveal VIV suppression by the whisker structure.

W-131 **HIGH FREQUENCY PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER ARRAY FOR INTRAVASCULAR ULTRASOUND IMAGING**.....745

Y. Lu, A. Heidari, S. Shelton, A. Guedes, and D.A. Horsley
University of California, Davis, USA

This paper presents a 1.2 mm diameter high fill-factor array of 1,261 piezoelectric micromachined ultrasonic transducers (PMUTs) operating at 18.6MHz for medical imaging applications. This process incorporates a sacrificial polysilicon release pit that precisely defines the PMUT diameter, thereby enabling 10× smaller device spacing and eliminating the need for through-wafer etching. Measurements show a large voltage response of 2.5nm/V and good frequency matching in air, a high center frequency 18.6MHz and wide bandwidth 4.9MHz when immersed in fluid, and phased array simulations based on measured PMUT parameters show high output pressure of the focused acoustic beam.

Th-132 **IMPACT OF GYROSCOPE OPERATION ABOVE THE CRITICAL BIFURCATION THRESHOLD ON SCALE FACTOR AND BIAS INSTABILITY**.....749

S.H. Nitzan[1], T.-H. Su[1], C.H. Ahn[2], E.J. Ng[2], V.A. Hong[2], Y. Yang[2], T.W. Kenny[2], and D.A. Horsley[1]
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We investigate the impact of operating a vibratory rate gyro (VRG) at large oscillation amplitude where the VRG's driven becomes nonlinear. Nonlinearities arising at large amplitudes cause the resonator's amplitude-frequency response to become multi-valued above a level known as the critical bifurcation threshold, xc. Open-loop resonators operating at amplitudes above xc are subject to large amplitude instabilities. We demonstrate using closed-loop operation, that scale-factor and bias instability are not affected by operation above xc and angle random walk is reduced.

M-133 **IMPROVED ACOUSTIC COUPLING OF AIR-COUPLED MICROMACHINED ULTRASONIC TRANSDUCERS** **753**

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[2]University of California, Berkeley, USA

A micromachined ultrasonic transducer (MUT) achieves maximum acoustic coupling when its radius approaches the acoustic wavelength. Previously, this fact posed a critical limitation on size for MUTs operating in air. We present a new approach to increase the acoustic coupling and bandwidth of MUTs using a resonant cavity etched beneath the MUT. The result is a 4x increase in sound pressure level for MUTs having radius equal to one-eighth the acoustic wavelength and an 8x improvement in the bandwidth, thereby enabling much smaller transducers.

T-134 **MECHANICAL FORCE-DISPLACEMENT TRANSDUCTION STRUCTURE FOR PERFORMANCE ENHANCEMENT OF CMOS-MEMS PRESSURE SENSOR** **757**

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[1]National Tsing Hua University (NTHU), TAIWAN and
[2]National Nano Device Laboratories, TAIWAN

This study implements a mechanical force-displacement transduction structure using the TSMC 0.18um 1P6M CMOS process to improve CMOS-MEMS capacitive pressure sensor. The membrane will be deformed by pressure and cause the sensing-gap change between undeformed movable-electrode and fixed-electrode. Feature of this study is CMOS-MEMS deformed membrane and undeformed movable-electrode to enable the parallel-plate gap-closing pressure detection. Thus, the performance of pressure sensor can be improved and stabilized.

W-135 **LOW NOISE VACUUM MEMS CLOSED-LOOP ACCELEROMETER USING SIXTH-ORDER MULTI-FEEDBACK LOOPS AND LOCAL RESONATOR SIGMA DELTA MODULATOR** **761**

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[2]University of Southampton, UK, and
[3]University of Duisburg-Essen, GERMANY

We report a novel sixth-order sigma-delta modulator MEMS closed-loop accelerometer with extended bandwidth operating in a vacuum environment, which can coexist on a single die with other sensors requiring vacuum packaging. The sensing element was fabricated on a common SOI substrate, four electronic integrators with local resonators are cascaded with the sensing element form high-order noise shaping and notch to suppress the total in-band quantization noise. The feedback voltage signal was applied to the proof-mass to artificially damp the system, which guarantees stable operation in vacuum.

Th-136 **MICRO LIQUID-BASED THERMO-ACOUSTIC TRANSMITTER FOR EMITTING ULTRASOUND IN LIQUID MEDIUM** **765**

D. Hoang-Giang[1], N. Thanh-Vinh[1], K. Noda[1], P. Hoang-Phuong[2], N. Binh-Khiem[1], T. Takahata[1], K. Matsumoto[1], and I. Shimoyama[1]
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We proposed a thermo-acoustic transmitter using a nanometer thickness metal layer encapsulated with a micrometer thickness liquid layer on thermal-insulator substrate for emitting ultrasound in liquid medium. To improve energy efficiency we take advantage of low specific heat capacity liquid which is encapsulated physically and thermally in small volume by a thin parylene film to fabricate the device. The experiment results demonstrated that by using silicone oil (HIVAC-F5) encapsulated on glass composite, we can obtain ultrasound with sound pressure 3Pa in water medium.

M-137 MULTI-AXIS FORCE SENSOR WITH DYNAMIC RANGE UP TO ULTRASONIC 769

P. Quang-Khang[1], N. Minh-Dung[1], N. Binh-Khiem[1], H.P. Phan[2], K. Matsumoto[1], and I. Shimoyama[1]

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We proposed a multi-axis force sensor that has a dynamic range up to ultrasonic. The sensor utilizes multilayer structure of elastomer/polymer/viscous liquid to conduct forces and acoustic vibrations to four piezoresistive cantilevers. Experiment results showed that the sensor was capable of measuring normal and lateral forces with high linearity in the range up to 40kPa. Moreover, the dynamic range of the sensor covers ultrasonic frequencies, with the first resonant frequency located at 170kHz.

T-138 MULTIFUNCTIONAL INTEGRATED SENSOR IN A 2X2 MM EPITAXIAL SEALED CHIP OPERATING IN A WIRELESS SENSOR NODE.....773

C.L. Roozeboom[1], V.A. Hong[1], C.H. Ahn[1], E.J. Ng[1], Y. Yang[1], B.E. Hill[1], M.A. Hopcroft[2], and B.L. Pruitt[1]

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We present multifunctional integrated sensors that combine temperature, humidity, pressure, air speed, chemical gas, magnetic, and acceleration sensing on a single 2x2 mm chip. We fabricate the multi-sensor in a wafer scale encapsulation process to hermetically seal the sensor functions with moving parts at low vacuum, and then surface micromachine the environmental sensors on top of the sealed layer. We demonstrate the multi-sensor in a wireless sensor node that combines energy harvesting, power management, and low power electronics to transmit data using a cloud-based service.

W-139 OUT-OF-PLANE MICRO TRIPLE-HOT-WIRE ANEMOMETER BASED ON PYREX BUBBLE FOR AIRFLOW SENSING.....777

S.W. Liu[1], S.S. Pan[1], F. Xue[1], N. Lin[1], H.B. Liu[1], J.M. Miao[1], L.K. Norford[2], and H.B. Lim[1]

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We report novel design and fabrication of out-of-pane micro airflow sensors based on the hot-wire sensing principle, i.e. gas cooling of electrically-heated hot-wires. With three micro Cr/Au/Cu hot-wire components fabricated on a Pyrex bubble, the anemometer has demonstrated the ability to detect velocity (<10m/s) and to determine flow direction with an error less than ±8° when the velocity is 10m/s.

Th-140 A PAPER-BASED PIEZOELECTRIC TOUCH PADS INTEGRATING ZINC OXIDE NANOWIRES 781

Y.H. Wang, X. Li, C. Zhao, and X.Y. Liu

McGill University, CANADA

We report a new type of paper-based piezoelectric touch pads integrating zinc-oxide nanowires (ZnO-NWs) as the sensing component. We directly grew ZnO-NWs on cellulose paper using a simple hydrothermal approach, and fabricated single-layer piezoelectric touch pads from ZnO-NW-coated paper. The presented piezoelectric touch pads are inexpensive, easy-to-fabricate, ultra-thin, lightweight and disposable, and will further enrich the tool set of paper electronics.

M-141 PIEZORESISTIVITY OF AG NWS-PDMS NANOCOMPOSITE.....785

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In this work, we developed a conductive silver nanowire (AgNW)-PDMS composite thin film for a flexible strain sensing application. The piezoresistivity of Ag NWs-PDMS nanocomposite thin film was experimentally investigated and analyzed by a computational model. Finally, a finger motion detection device was developed by using Ag NWs-PDMS nanocomposite thin film as a highly stretchable, flexible and sensitive strain sensor.

T-142 SINGLE-CHIP ATOMIC FORCE MICROSCOPE WITH INTEGRATED Q-ENHANCEMENT AND ISOTHERMAL SCANNING 789

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We report on the design, fabrication, and imaging performance of a single-chip Atomic Force Microscope (AFM) that does not require any off-chip scanning or sensing hardware. The first AM-AFM images obtained with such a device reveal that 90nm vertical features (on an AFM calibration standard) can be resolved. The design comprises improved lateral and vertical actuators, an isothermal electrothermal scanner design that maintains constant tip-temperature while traversing a 50um x 10um area, and a Q-enhancement mechanism that improves the force resolution of the instrument.

W-143 SMART-CUT 6H-SILICON CARBIDE (SIC) MICRODISK TORSIONAL RESONATORS WITH SENSITIVE PHOTON RADIATION DETECTION.....793

R. Yang[1], K. Ladhane[2], Z. Wang[1], J. Lee[1], D. Young[2], and P.X.-L. Feng[1]
[1] *Case Western Reserve University, USA and* [2] *University of Utah, USA*

We report on experimental demonstration of a new type of microdisk torsional resonators based on a smart-cut 6H-silicon carbide (6H-SiC) technology. We carefully calibrate these torsional mode resonances by employing highly sensitive multi-wavelength laser interferometric techniques. To utilize these first 6H-SiC torsional resonators, we further demonstrate sensitive detection of radiations from both blue and infrared (IR) photons. Toward force detection applications which are well suited for torsional resonators, our calibration measurements demonstrate impressive intrinsic force resolutions in these SiC torsional resonators.

Th-144 SUB-0.05° PRECISION OPTOFLUIDIC DUAL-AXIS INCLINOMETER 797

S. Wahl, F. Marty, N. Pavy, B. Mercier, and D.E. Angelescu
Université Paris-Est, FRANCE

We present a low-power bi-axial miniaturized inclinometer based on a mobile mass (spherical ball or fluidic droplet) positioned on a precision curved surface that is generated using a novel MEMS process. The detection of the mobile mass was implemented through an external optical system, using a quadrant photodetector. Nanotopography and chemical treatment of the curved surface have been implemented to increase accuracy when using a fluidic mobile mass, by tailoring wetting properties and minimizing contact angle hysteresis. Fluidic damping was also implemented to render the sensor less sensitive to vibrations.

M-145 **TUNING OF NONLINEARITIES AND QUALITY FACTOR IN A MODE-MATCHED GYROSCOPE.....801**
E. Tatar, T. Mukherjee, and G.K. Fedder
Carnegie Mellon University, USA

This paper examines methods to electrically tune cubic nonlinearity and quality factor (Q) of a mode-matched MEMS gyroscope by changing the DC voltages across specially shaped combs. The gyroscope includes traditional combs for drive-sense and dedicated shaped combs for cubic nonlinearity and frequency tuning. In addition to nonlinearity, Q can be tuned by understanding the nature of the losses with the appropriate model. The electrical loss components are added to the electromechanical resonator model to account for the electrical losses which depend on the applied voltages.

Medical Microsystems (MEDM)

T-146 **2D RESONANT MICROSCANNER FOR DUAL AXES CONFOCAL FLUORESCENCE ENDOMICROSCOPE 805**
H. Li, Z. Qiu, X. Duan, K. Oldham, K. Kurabayashi, and T.D. Wang
University of Michigan, USA

We demonstrate a parametrically-excited 2D microscanner for a miniature dual axes confocal fluorescence endomicroscope. The scanner has a compact and robust gimbal structure which can perform resonant scanning with large tilting angle at high speed. A single-wafer based SOI process has been developed for improving the quality and the yield of the device. Ex vivo imaging on mouse colon is performed using the fabricated endomicroscope, and the near infrared fluorescence en-face image of dysplasia crypts over a large field-of-view of 800μm×400μm with subcellular resolution is obtained.

W-147 **A CAPACITIVE IMMUNOSENSOR USING ON-CHIP ELECTROLYTIC PUMPING AND MAGNETIC WASHING TECHNIQUES FOR POINT-OF-CARE APPLICATIONS 809**
J.-C. Kuo, P.-H. Kuo, H.-T. Hsueh, C.-W. Ma, C.-T. Lin, S.-S. Lu, and Y.-J. Yang
National Taiwan University, TAIWAN

This work presents a capacitive immunosensor using on-chip electrolytic pumping and magnetic washing techniques. The proposed device possesses the advantages such as simple operation, low power consumption, and portability. The proposed device was fabricated using typical micromachining process, and is suitable for mass-production. We also demonstrated the detection of N-Terminal pro-brain-Type natriuretic peptide (NT-proBNP) using the fabricated device integrated with a CMOS capacitance sensing chip. The proposed device potentially can be used as a portable system for point-of-care applications.

Th-148 **A WIRELESS SLANTED OPTRODE ARRAY WITH INTEGRATED MICRO LEDS FOR OPTOGENETICS 813**
K. Kwon[1], H. Lee[2], M. Ghovanloo[2], A. Weber[1], and W. Li[1]
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[2]*Georgia Institute of Technology, USA*

We develop a wireless-enabled, flexible optrode array with multichannel micro-LEDs for selective optical stimulation of cortical neurons and simultaneous recording of light-evoked neural activity. The array integrates wirelessly addressable micro-LED chips with slanted polymer waveguides for precise light delivery to multiple cortical layers simultaneously. A droplet backside exposure (DBE) method was developed to monolithically fabricate varying-length optrodes on a single polymer platform.

M-149 **AN ELECTROPORATION CHIP BASED ON FLEXIBLE MICRONEEDLE ARRAY FOR IN VIVO NUCLEIC ACID DELIVERY.....817**

Z. Wei[1], R. Wang[2], S. Zheng[3], Z. Liang[3], and Z. Li[3]
[1]*National Center for Nanoscience and Technology, CHINA,*
[2]*North University of China, CHINA, and* [3]*Peking University, CHINA*

We reports a flexible microneedle array electroporation chip for in vivo nucleic acid delivery. Silicon MNA is proposed to penetrate the high-resistant stratum corneum, while flexible parylene substrate is used to fit the natural shape of electroporated objects. Using the proposed chip, we successfully achieved plasmid DNA expression and siRNA delivery in living tissue with low voltage (30-40V), neither physical nor biological harm to skin was observed.

T-150 **AN INTEGRATED MICROFLUIDIC SYSTEM FOR DIAGNOSIS OF UINOLONES RESISTANCE OF *HELICOBACTER PYLORI*.....821**

C.Y. Chao[1], C.H. Wang[1], Y.J. Che[1], C.Y. Kao[2], J.J. Wu[2], and G.B. Lee[1]
[1]*National Tsing Hua University (NTHU), TAIWAN and*
[2]*National Cheng Kung University, TAIWAN*

Helicobacter pylori play a crucial role in gastric diseases. The incidence rate of duodenal ulcer and gastric ulcer from H. pylori infected patients were found to be about 90-100% and 60-100%.Recently, some point mutations were found in gyrase genes against Quinolones. In this study a new method was therefore developed to perform molecular diagnostic techniques of SNP-PCR on an integrated microfluidic system to detect the Quinolones resistance of H. pylori.

W-151 **ANNEALING EFFECTS ON FLEXIBLE MULTI-LAYERED PARYLENE-BASED SENSORS.....825**

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The mechanical and electrochemical properties and sensing performance of untreated and annealed Parylene-platinum electrochemical impedance-based force sensors were compared. Annealing reduced the height and increased the stiffness of the Parylene structure, and smoothed electrode surfaces, affecting sensor performance. Our results indicate that annealing effects cannot be ignored for Parylene-metal device systems and that mechanical and electrochemical properties and performance must be determined after heat treatment, such as annealing and sterilization.

Th-152 **AUTOMATED VITRIFICATION OF MAMMALIAN EMBRYOS ON A DIGITAL MICROFLUIDIC DEVICE 829**

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We present, for the first time, the development of a digital microfluidic device to achieve automated vitrification of mammalian embryos for clinical in vitro fertilization (IVF) applications. Micro drops are used as vessels to move an embryo and subject it to a series of cyroprotectants of different concentrations, as required by the IVF vitrification protocols.

M-153 **CHARACTERIZATION OF RED BLOOD CELL DEFORMABILITY CHANGE DURING BLOOD STORAGE 833**

Y. Zheng[1], J. Chen[1], T. Cui[2], N. Shehata[3], C. Wang[3], and Y. Sun[1]
[1] *University of Toronto, CANADA,* [2] *University of Minnesota, USA, and* [3] *Mount Sinai Hospital, CANADA*

Deformability change of stored red blood cells over an 8 weeks' storage period was measured using a microfluidic device and high-speed imaging. Multiple parameters including deformation index (DI), time constant, and RBC circularity were quantified. Compared to previous RBC deformability studies, our results include a significantly higher number of cells (>1,000 cells/sample vs. a few to tens of cells/sample) and, for the first time, reveal deformation changes of stored RBCs when traveling through human-capillary-like microchannels.

T-154 **DETERMINATION OF MULTIDRUG RESISTANCE LEVEL IN K562 LEUKEMIA CELLS BY 3D-ELECTRODE CONTACTLESS DIELECTROPHORESIS 837**

Y. Demircan, M. Erdem, E. Özgür, U. Gündüz, and H. Külah
Middle East Technical University, TURKEY

We designed, fabricated and tested a MEMS based cell identification 3D-electrode contactless dielectrophoresis system. As an application for this system, the determination of multidrug resistance degree of K562 cells was presented in this study.

W-155 **FLEXIBLE MEA FOR ADULT ZEBRAFISH ECG RECORDING COVERING BOTH VENTRICLE AND ATRIUM 841**

X. Zhang[1], J. Tai[2], J. Park[1], and Y.C. Tai[1]
[1] *California Institute of Technology, USA and* [2] *Tufts University, USA*

We develop a parylene based MEA to monitor adult zebrafish ECG, for the first time, in both ventricle and atrium viewing angles, during its heart regeneration post injury. It is a novel tool to allow the discovery of fine bio-electrical activities in the entire heart.

Th-156 **MEASUREMENT OF MECHANOMYOGRAM 845**

T. Kaneko, N. Minh-Dung, R. Aoki, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We proposed an approach for measuring mechanomyogram (MMG) by taking advantage of the acoustic impedance matching between liquid and human skin to convey the pressure signal of MMG to a piezo-resistive cantilever.In experiments, the sensor was placed on the skin surface above bicepcs brachii. The MMG signal, the frequency of which was 10-15 Hz, was able to be detected using silicone oil as the propagating medium, while it was not using air as the medium.Experiment results also indicated that the proposed sensor was able to detect the vascular oscillations.

M-157 **MEASURING FLOW VELOCITY OF SWALLOWED LIQUID IN THE HUMAN PHARYNX BY TONGUE PRESSURE SENSOR AND SWALLOWING SOUND SENSOR** **849**

Y. Takei, T. Kaneko, K. Noda, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We measured flow velocity of swallowed liquid passing through pharynx. We put pressure sensor on palate and two acoustic sensors on the neck skin. From the output of these three sensors, we can know the timing of the liquid passing through each sensor points and can calculate the flow velocity of the swallowed liquid at the pharynx. In this paper, we compare the flow velocity between two swallowing positions, “sit straight position" and “look upward position.” As a result, we found that the flow speed of the “look upward position” was 2.5 times faster than that of “sit straight position.”

T-158 **MEMS NEURAL PROBE ARRAY FOR MULTIPLE-SITE OPTICAL STIMULATION WITH LOW-LOSS OPTICAL WAVEGUIDE BY USING THICK GLASS CLADDING LAYER**..... **853**

Y. Son[1,2], H.J. Lee[1], D. Kim[1], Y.K. Kim[1], E.-S. Yoon[1], J.Y. Kang[1], N. Choi[1], T.G. Kim[2], and I.-J. Cho[1]
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We present a MEMS neural probe array for multiple-site optical stimulation with low-loss SU-8 optical waveguides. The 20-μm-thick cladding layer was formed by glass reflow process and no additional thickness was required due to embedded structure. Furthermore, the low-loss optical waveguide enables multiple-site stimulation with the two-step optical splitter. We also demonstrate a successful in-vivo optical stimulation and recording of neural signals of a transgenic ChR2-YFP mouse. Recorded neural signals are synchronized with light pulses which confirm that neurons were successfully stimulated and recorded.

W-159 **MICRO-ELECTRODE ARRAYS FOR MULTI-CHANNEL MOTOR UNIT EMG RECORDING**..... **857**

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

We report an array of micro-electrodes, which can record motor unit (MU) electromyogram (EMG) signals. As a basic structure of the electrode, we prepared 200-μm-square Si-pyramids with the height of 200 μm by Tetramethylammonium hydroxide (TMAH), resulting in robust MU-EMG recordings without conductive gel. Platinum (Pt) was used as an electrode material and parylene-C was deposited as an insulator. Fabricated μEMG electrodes connected to a recording system clearly detected MU-EMG action potentials from a human forearm. In addition, different MU-EMG signals between μEMG electrodes were detected by crooking fingers. These results indicate that the μEMG array device becomes a powerful tool for medical applications including myoelectric prosthetic technologies.

Th-160 **MICRO-WING AND PORE DESIGN IN AN IMPLANTABLE FPC-BASED NEURAL STIMULATION PROBE FOR MINIMALLY INVASIVE SURGERY.....861**

Y.-H. Wang[1], D. Tsai[1,2], B.-A. Chen[1], Y.-Y. Chen[1], C.-C. Huang[1], P.-C. Huang[1], C.-Y. Lin[1], J. Yu[1], W.-P. Shih[1], C.-W. Lin[1], and H.-J. Sheen[1]
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[2]*University of California, San Diego, CA*

A bipolar porous probe for an implantable nerve stimulation treatment utilizing minimally invasive surgery is presented. The flexible printed circuit (FPC) probe features micro-wings, which can increase fixation after implantation, and contains porous structures for cell growth to promote permanence in the body. Two recording pairs detect whether or not cells grow into the pores, and one pair of stimulating pads stimulates the target nerve. This probe is composed of two SU-8 layers and one FPC layer, to form a 3-D porous structure.

M-161 **NANOELECTROPORATION AND CONTROLLABLE INTRACELLULAR DELIVERY INTO LOCALIZED SINGLE CELL WITH HIGH TRANSFECTION AND CELL VIABILITY.....865**

T.S. Santra, J. Borana, P.-C. Wang and F.-G. Tseng
National Tsing Hua University (NTHU), TAIWAN

Here we demonstrate controllable nano-electroporation platform for HeLa and human Caucasian Gastric Adenocarcinoma (AGS) cell to achieve high efficient bimolecular delivery with high cell viability.

T-162 **OPTO-MECHANICAL MICROBRIDLES FOR THE DETERMINATION OF STRUCTURAL AND FUNCTIONAL PROPERTIES OF SMALL RESISTANCE ARTERIES.....869**

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[3]University of Aarhus, DENMARK, and
[4]Technische Universität Braunschweig, GERMANY

We develop and optimize an opto-mechanical system for monitoring diameter of arterial segments in vitro.

W-163 **PDMS MICROCHANNEL SCAFFOLDS FOR NEURAL INTERFACES WITH THE PERIPHERAL NERVOUS SYSTEM 873**

Y. Choi[1], S. Park[2], Y. Chung[3], R.K. Gore[4], A.W. English[4], and R.V. Bellamkonda[2]
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[2]*Georgia Institute of Technology, USA,*
[3]*University of Rhode Island, USA, and* [4]*Emory University, USA*

Neural interfaces with the peripheral nervous system have been developed to provide a direct communication pathway between peripheral nerves and prosthetic limbs. This paper reports a regenerated peripheral nervous system which can control the reinnervated muscles and interpret neurological signals. The acquired bioelectrical signals can be used for the interpretation of mind which will be used to monitor prosthetic limbs. Transected nerves were regenerated through PDMS scaffolds and transferred signals through embedded microwires and acquisition systems.

Th-164 **SELECTIVE RF HEATING OF RESONANT STENT TOWARD WIRELESS ENDOHYPERTHERMIA FOR RESTENOSIS INHIBITION** **877**

Y. Luo, M. Dahmardeh, X. Chen, and K. Takahata
University of British Columbia, CANADA

Stents have served as a critical device for minimally invasive treatment of cardiovascular disease, the leading cause of death in North America. Artery renarrowing (known as restenosis) often occurs after stent implantation due to excess growth of vessel tissue, blood clot(thrombus) formation, and/or other factors. This paper presents, for the first time, a novel active stent that serves as a resonant heater with high frequency selectivity controlled using external RF fields, offering a new therapeutic path to wireless endohyperthermia for in-stent restenosis.

M-165 **TUNABLE MEMS FIBER SCANNER FOR CONFOCAL MICROSCOPY** **881**

N. Weber, T. Meinert, H. Zappe, and A. Seifert
University of Freiburg – IMTEK, GERMANY

We present an endoscopic probe with forward-looking piezoelectric fiber scanner for confocal optical imaging with a very short length of 13.1 mm. The system is based on Si bench technology with integrated fluidics for realizing tunable liquid-filled membrane-lenses. The tunability in focal length allows confocal depth scanning up to 100 µm without any movable optics or stages. The lateral and axial resolution were demonstrated to be 2 µm and 20 µm, respectively.

T-166 **ULTRASOUND-ASSISTED MICRO-KNIFE FOR CELLULAR SCALE SURGERY** **885**

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[1]Pohang University of Science and Technology (POSTECH), SOUTH KOREA and [2]University of Michigan, USA

We developed a microknife for cellular scalce surgery.The work includes modeling, fabrication, measurement and actual cell-cutting. The result showed that developed knife can cut cell monolayer successfully with 2 micro cut line width by utilizing the ultra-sharp edge and ultrasound assiat.

W-167 **WRINKLE CELLOMICS: SCREENING BLADDER CANCER CELLS USING AN ULTRA-THIN SILICONE MEMBRANE** **889**

J.H. Appel[1], L.Y. Sin[2], J.C. Liao[2], and J. Chae[1]
[1]*Arizona State University, USA and* [2]*Stanford University, USA*

We report a visualization platform comprised of an ultra-thin silicone membrane to differentiate between the biophysical properties of cancerous and healthy cells. Cancerous cells adhere to and spread on the membrane inducing deformation, termed 'membrane wrinkling', while healthy cells do not generate wrinkle patterns on the membrane. Quantitative measurement of wrinkling represents a powerful, non-invasive diagnostic tool for common cancers such as bladder cancer.

Th-168 **AN X-RAY DETECTABLE PRESSURE MICROSENSOR FOR MONITORING CORONARY IN-STENT RESTENOSIS** **893**

M.N. Gulari, M. Ghannad-Rezaie, P. Novelli, N. Chronis, and T.C. Marentis
University of Michigan, USA

We present a novel implantable X-ray-addressable MEMS Blood Pressure sensor, the X-BP, for the non-invasive and cost-effective surveillance of coronary in-stent restenosis. We successfully fabricated and tested the X-BP sensor and its pressure response curve. We placed the X-BP sensor in a coronary stent and prove adequate visibility in a clinically realistic scenario.

Micro-Actuators (ACT)

M-169 **A NOVEL ACTUATOR FOR ENERGY HARVESTING USING AN ACOUSTICALLY OSCILLATING LIQUID DROPLET.....897**

Y.R. Lee, J.H. Shin, I.S. Park, and S.K. Chung
Myongji University, SOUTH KOREA

This paper presents a novel actuator for energy harvesting from ambient acoustic noise using acoustically oscillating droplets. When a water droplet sitting on a piezocantilever is excited by an acoustic wave around its natural frequency, it oscillates and simultaneously bends the piezocantilever by the reaction of the droplet oscillation, resulting in electric power generation from the piezocantilever. The envisioned energy harvesting system can extract mechanical power from acoustic noise in a wide range of frequencies using liquid droplets in different sizes and natural frequencies and convert the mechanical power to electrical power for wireless electronic devices. This new type of actuation technique is a simple but useful tool not only for the energy harvesting system but also potential acoustic wave sensors and actuators.

T-170 **A NOVEL ON-CHIP MICROMANIPULATION METHOD USING A MICROBUBBLE FOR SINGLE CELL MANIPULATION AND CHARACTERIZATION.....901**

J.H. Shin, Y.R. Lee, I.S. Park, and S.K. Chung
Myongji University, SOUTH KOREA

This paper presents a novel on-chip micromanipulation method using a microbubble actuated by optical and acoustical excitation for single cell manipulation and characterization in a microfluidic chip, along with the experimental verification of bubble manipulation (generating and transporting operations) and micro-object manipulation (capturing, carrying, and releasing operations).

W-171 **A THERMOTROPIC LIQUID CRYSTAL ELASTOMER MICRO-ACTUATOR WITH INTEGRATED DEFORMABLE MICRO-HEATER.....905**

S. Petsch[1], R. Rix[2], P. Reith[1], B. Khatri[1], S. Schuhladen[1], D. Ruh[1], R. Zentel[2], and H. Zappe[1]
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We present a large-stroke thermal actuator with an integrated, MEMS fabricated, deformable heater based on the phase transition in a thermotropic liquid crystal elastomer (LCE) material. The transition from nematic to isotropic phase in the LCE causes a contraction of 28% (1.15mm) when the integrated system is heated to 120°C. With the heater buried in the LCE, full contraction is reached after 19.7s at 320mW when heated from room temperature. Complete back actuation is achieved in 5.6s.

Th-172 **A TUNABLE LIQUID LENS DRIVEN BY A CONCENTRIC ANNULAR ELECTROACTIVE ACTUATOR 909**

K. Wei, N. Domicone, and Y. Zhao
Ohio State University, USA

We present a membrane-enveloped fluidic lens hydrostatically coupled to a concentric annular electroactive elastomer. Electrical activation deforms the annular elastomer, which induces fluid transmission between the lens part and the actuation part. The lens changes the shape and thereby the focal length from 12.5 mm to 105.2 mm within 1.0 kV. Compared to existing fluidic lenses driven by electroactive polymer, this lens implements a larger focusing range at a lower voltage. It finds applications in miniaturized optical components where adaptive focalization is at a premium.

M-173 LONG STROKE OUT-OF-PLANE ACTUATOR USING COMBINATION OF ELECTROSTATIC AND PNEUMATIC FORCES 913

T.K. Kan, A.I. Isozaki, H.T. Takahashi, K.M. Matsumoto, and I.S. Shimoyama
University of Tokyo, JAPAN

We propose an out-of-plane MEMS actuator with a large stroke length comparable to the size of the actuator itself. The proposed device is actuated by the combined forces of the electrostatic and the pneumatic forces. This combination of two independent forces enlarges a stable area during the actuation, resulting in a large stroke which is difficult to be achieved with only either force. The 3D profiling by the laser scanning microscopy confirmed the largest stroke of 103 μm was obtained with the 150-μm-diameter actuator area with the electric field of 5.8×10^5 V/m (330V between the electrodes) and the air pressure of 2.0 kPa.

T-174 MECHANO-ACTIVE TISSUE SCAFFOLD SYSTEM BASED ON A MAGNETIC NANOPARTICLE EMBEDDED NANOFIBROUS MEMBRANE.....917

S.P. Fang[1], H. Shang[1], P.F. Jao[1], K.T. Kim[1], G.J. Kim[1], J.H. Yoon[1], K. Cho[1,2], A.J. Katz[1], and Y.K. Yoon[1]
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[2]*Korea Basic Science Institute, SOUTH KOREA*

A mechano-active nanofibrous scaffold system consisting of iron oxide nanoparticle embedded electrospun nanofibers, a membrane holder and an electro magnet, is designed and demonstrated. The scaffold provides mechanical stress on culturing cells by external AC magnetic fields. The mechanical properties of the nanoporous membrane including the density, the porosity, and the effective Young's modulus are characterized. Cell viability with and without magnetic nanoparticle embedded has been tested.

W-175 NANO-SCALE BIOMECHANICAL ANALYZER FOR STUDYING STIMULUS DEPENDENT SELF-ASSEMBLY OF ACTIN FILAMENT 921

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[2]*Japan Science and Technology Agency, JAPAN*

We have developed nano-scale mechanical analysis system by using "optically driven nano-beam" to measure elasticity of self-assembled actin filament under dynamic mechanical stimulus. In this report, we worked on developing a new nano-beam to specifically capture actin on its surface. By using the new nano-beam, we have successfully measured elasticity of self-assembled actin filament in water. The nano-mechanical analysis system unravels cell life phenomenon which can't be dealt with through conventional methodologies."

Th-176 PINCHING AND RELEASING OF CELLULAR AGGREGATE BY MICROFINGERS USING PDMS PNEUMATIC BALLOON ACTUATORS 925

S. Shimomura[1], Y. Teramachi[1], Y. Muramatsu[1], S. Tajima[2], Y. Tabata[2], and S. Konishi[1]
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This paper proposes microfingers for manipulation of spherical cellular aggregates (φ200μm). The microfinger is driven by pneumatic balloon actuator "PBA" to pinch and release a spherical cellular aggregate directly. The paper presents the design, operation principle, fabrication, and characterization. The pinching force of developed fingers was estimated with the aim of evaluating the damage to the cellular aggregate. A series of operation of a real cellular aggregate by developed microfingers will be successfully demonstrated.

To prevent the adhesion of particles at surfaces by transporting them along the surface this paper reports on a pneumatically actuated new type of biomimetic particle transporter. Rows of flaps are positioned asymmetrically on movable membranes. Each flap row can be deflected separately by an induced pneumatic force. This membrane movement converts to a large deflection of the flaps in x-direction (lateral). Due to the high aspect ratio of the flaps the angle rotation results in a fluid movement parallel to the surface which prevents the particle deposition.

This paper discusses characterization of the surface textures created by MEMS tactile display with a large displacement MEMS actuator array. The actuator consists of piezoelectric actuators and a hydraulic displacement amplification mechanism to achieve large enough displacement to stimulate human tactile receptors. In our prior work, we successfully displayed smooth and rough surfaces using MEMS tactile display by controlling the vibration frequency and the driving voltage of the actuators. In this paper, we propose “sample comparison method" to further characterize the virtually created surface textures, where microfabricated tactile samples are used. In this method, by requesting the subjects to select samples that they felt most similar to the displayed surfaces, the control parameters of the MEMS tactile display were successfully correlated with the surface properties of the samples.

Micro-Fluidic Components and Systems (μFLUIDIC)

Our work reports on a passive compact flow regulator designed to maintain a steady flow during breath diagnostics using a novel flow regulation principle. The fabricated prototype consists of two 3D-printed plastic parts with an integrated cantilever aligned in the direction of the flow, to control comparatively large air flows in the 50 ml/s regime suitable for asthma diagnostics.

We have developed and implemented a simple three-dimensional (3D) particle tracking method for use in particle focusing applications. Using conventional fluorescence microscopy and a multi-step image post-processing algorithm based on particle defocusing principles, this technique was experimentally verified with results comparable to theoretical predictions of (1) gravitational settling and (2) inertial focusing. Our technique determines particle positions to micron accuracy in microfluidic systems for Re < 100.

M-181 **CELL-NICHE-ON-CHIP: PAIRED SINGLE CELL CO-CULTURE PLATFORMS USING IMMISCIBLE LIQUID ISOLATION AND SEMI-PERMEABLE MEMBRANES** **943**

Y.-C. Chen, Y. Cheng, and E. Yoon
University of Michigan, USA

The fundamental difficulty in single cell co-culture is to provide a controlled microenvironment. The cell culture chamber must be isolated for secreted cytokines to be accumulated inside the chamber over time. However, in an isolated environment nutrition factors will deplete. It is important to find a way to continuously supply nutrition factors while isolating cells sectional view of the proposed co-culture chip and its operation. We placed a semi-permeable membrane between the cell culture chamber and the media exchange channel. Nutrition can be supplied to the cells through the membrane, but the secreted cytokines are accumulated inside the chamber because their molecule sizes are too large to escape. The preliminary result demonstrated the capability of studying interaction between two cells and its potential to investigate modeling of more complicated cell niches.

T-182 **DEVELOPMENT OF VACUUM ASSISTED MICROFLUIDIC CELL TRAPPING DEVICE FOR REPOSITIONING OF OOCYTE INTRACELLULAR CHROMOSOMES** **947**

J. Hong, P. Purwar, S. Lee, N. Verma, and J. Lee
Seoul National University, SOUTH KOREA

We report the design and fabrication of vacuum assisted microfluidic trapping device for the capture of single cell such as an oocyte. We also suggest an application of such device for an intracellular monitoring of a cell that has an interaction wit external environments. Real time monitoring is enabled through the fabrication on a silicon-on-glass substrate, offering excellent optical imaging window. We demonstrate the single cell capture event and monitoring of chromosome activity. This result will provide a powerful tool for investigating the physiological and pathological cellular functions.

W-183 **DIELECTROPHORETIC (DEP) SEPARATION OF LIVE/DEAD CELLS ON A GLASS SLIDE FUNCTIONALIZED WITH INTERDIGITATED 3D SILICON RING MICROELECTRODES** **951**

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Hong Kong University of Science and Technology, HONG KONG

An elegant device with 3D interdigitated silicon ring electrodes is developed here for DEP-activated cell sorting. The integration of transparent glass substrate makes the device cost-effective and aids the coupling of DIC microscopy. The self-aligned lateral rings form multiple flow lines thus enhancing the throughput of the whole device. A capture efficiency of live mammalian cancer cells approaching 100% is achieved in separating them from a dead group with high flow rate.

Th-184 **DROPLET DISPENSING AND SPLITTING BY ELECTROWETTING ON DIELECTRIC DIGITAL MICROFLUIDICS** **955**

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[2] *University of Texas at Dallas, USA*

This paper reports an experimental study of two essential capabilities of electrowetting-on-dielectric (EWOD) digital microfluidics (DMF) – 1) high precision and consistency in volume of unit nanodrop dispensed from a reservoir, and 2) reduction of time to dispense and split drops. These capabilities are sought in applications that need tiny but accurate volume of liquid delivery at high flow rate.

M-185 ENZYME-DOPED POLYESTER THREAD COATED WITH PVC MEMBRANE FOR ON-SITE UREA AND GLUCOSE DETECTION ON A THREAD-BASED MICROFLUIDIC SYSTEM.....959

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[2]*National Kaohsiung First University of Science and Technology, TAIWAN*

This study presents a novel enzyme-doped thread with PVC membrane coating for on-site urea and glucose detection on a thread-based microfluidic device. The enzyme can be directly applied on the thread without delicate pretreatment or surface modification process. The passing biomolecules are digested by the enzymes and then electrochemically detected downstream. With this approach, CE-EC detection with on-site bio-reaction can be simply achieved. A thin layer of PVC membrane is coated on the enzyme-doped thread to further fix the applied enzyme and to prevent from the rapid evaporation of the running buffer due to the Joule heating effect. In addition, the PVC coated thread can be operated at a higher separation electric field of 500 V/cm due to the reducing buffer evaporation. Successfully on-site enzyme digestion, CE separation and EC detection of urea and glucose samples in a single test run is demonstrated with the enzyme-doped microfluidic system. Results also indicate that the developed system exhibits good linear dynamic range for detecting urea and glucose sample in concentrations from 0.1 mM – 10.0 mM (R2=0.9850) and 0.1 mM – 13.0 mM (R2=0.9668), which is suitable for adoption in detecting the BUN concentration in serum (1.78~7.12 mM) and the standard glucose fasting measuring range (3.89~6.11 mM).

T-186 FABRICATION OF HIGH ASPECT RATIO INSULATING NOZZLE ARRAY USING GLASS REFLOW PROCESS AND ITS ELECTROHYDRODYNAMIC PRINTING CHARACTERISTICS.....963

K.I. Lee[1], B. Lim[1], S.W. Oh[1], S.H. Kim[1], C.S. Lee[1], J.W. Cho[1], and Y. Hong[2]
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[2]*Seoul National University, SOUTH KOREA*

We develop micromachining process including glass filling to fabricate high aspect ratio glass nozzles which is more appropriate for electrohydrodynamic inkjet printing head. With this nozzle array, we print very narrow lines of various materials which is not obtained by conventional piezoelectric or thermal inkjet printing systems.

W-187 GALLIUM-BASED LIQUID METAL INKJET PRINTING.....967

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[2]*Hanbat National University, SOUTH KOREA*

We report clog-free and oxide-free metal inkjet printing using gallium-based liquid metal. Unlike typical metal nanoparticles or metal alloys, gallium-based liquid metal alloys are in liquid-phase at room temperature. Therefore, there is no need for heating or dispersing in solvent for inkjet printing. Another distinctive benefit is it maintains liquid-phase after printing if the substrate stays at around room temperatures. This is extremely useful to create 3D freeform rapid prototyping of metallic patterns that can conform to virtually any dynamic deformation of substrates.

Th-188 **IN-PLANE CAPACITIVE MEMS FLOW SENSOR FOR LOW-COST METERING OF FLOW VELOCITY IN NATURAL GAS PIPELINES.....971**

S.D. Nguyen[1], I. Paprotny[2], P.K. Wright[1], and R.M. White[1]
[1]*University of California, Berkeley, USA and*
[2]*University of Illinois, Chicago, USA*

This paper presents the design, fabrication, and experimental results of an in-plane capacitive MEMS flow sensor that uses the displacement of a micro-fabricated paddle caused by dynamic pressure for measuring the velocity of the flow of surrounding gas. Simplicity of fabrication, combined with insensitivity to variations in ambient temperature makes this sensor ideal for widespread deployment in natural gas pipelines.

M-189 **INTEGRATED MULTI-PARAMETER FLOW MEASUREMENT SYSTEM.....975**

J.C. Lotters[1], E. van der Wouden[1], J. Groenesteijn[2], W. Sparreboom[1], T.S. Lammerink[2], and R.J. Wiegerink[2]
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[2]*MESA+ - University of Twente, THE NETHERLANDS*

We have designed and realised an integrated multi-parameter flow measurement system, consisting of an integrated Coriolis and thermal flow sensor and a pressure sensor. The integrated system enables on-chip measurement, analysis and determination of flow and several physical properties of both gases and liquids. With the system, we demonstrated the feasibility to measure the flow rate, density, viscosity and heat capacity of hydrogen, helium, nitrogen, air, argon and water.

T-190 **INTERACTION FORCES DURING THE SLIDING OF A WATER DROPLET ON A TEXTURED SURFACE 979**

N. Thanh-Vinh, H. Takahashi, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

Using a MEMS 2-axis force sensor array, we have directly measured the pressure and shear force during the sliding of a water droplet on a Su-10 micropillar array. The measurement results showed a fluctuation in the interaction forces when the micropillar was close to the trailing edge or leading edge of the droplet. Meanwhile, in the inner region of the contact line, both the normal and lateral interaction forces were relatively stable. These results indicate that the interaction forces at the edges of the droplet are important factors controlling the sliding motion of the droplet.

W-191 **LIQUID DROPLET MICRO-BEARINGS ON DIRECTIONAL CIRCULAR SURFACE RATCHETS 983**

C. Varel and K.F. Bohringer
University of Washington, USA

This paper presents de-ionized water droplets used as torque-generating micro-bearings between a glass plate and amicromachined Si substrate. The pattern on the micromachined Si substrate includes circular tracks, which allow droplet motion in a single direction.When vertical vibration is applied to the system, a rotation in the transverse plane is triggered. The system can be tailored to respond to a specific vibration frequency, from 36.5 to 83 Hz by droplet volumes from 13 to 1 µL.

Th-192 **LOW GAS PERMEABLE AND NON-ABSORBENT RUBBERY OSTE+ FOR PNEUMATIC MICROVALVES** **987**

J. Hansson, J.M. Karlsson, C.F. Carlborg, W. van der Wijngaart, and T. Haraldsson
KTH Royal Institute of Technology, SWEDEN

We present an elastomeric, low gas permeable off-stoichiometric thiol–ene-epoxy (OSTE+) polymer fully compatible with standard micro-molding manufacturing and demonstrate its use in pneumatic pinch microvalves for lab-on-chip. The polymer is shown to have rubbery properties (similar to PDMS), low permeability to gases, low absorption of molecules from liqud samples, and the ability to bond layers in room temperature without the need for adhesives or plasma treatment.

M-193 **FREE SURFACE PROPULSION BY ELECTROWETTING-ASSISTED 'CHEERIOS EFFECT'** **991**

J. Yuan and S.K. Cho
University of Pittsburgh, USA

We combine electrowetting principle with Cheerios effect in order to manipulate floating objects in centimeter and millimeter scales. By turning electrowetting on/off, we attract or repel floating objects. Using an array of electrowetting electrodes, we generates translationally and rotationally continuous motions on floating objects.

T-194 **MESOPOROUS-SILICA NANO-CHANNELS INTEGRATED IN MICRO-FLUIDIC CHIP FOR FAST LIQUID MICRO-EXTRACTION OF PESTICIDE RESIDUAL** **995**

P.C. Xu, C.Z. Chen, H. Yu, and X.X. Li
Shanghai Institute of Microsystem and Information Technology (SIMIT), CHINA

The paper reports a micro-chip with nano-channels integrated as extraction-reservoir for quickly extracting analyt from aqueous solution to water-soluble organic solvent. Using this novel technology, trace-level residual of organophosphorus pesticide in water-solution can be micro-extracted to a common organic-solvent (e.g. ethanol) and, thereafter, quantitatively detected by GC-MS (Gas Chromatography-Mass Spectrometry) analysis.

W-195 **MINIATURISED PRANDTL TUBE WITH INTEGRATED PRESSURE SENSORS FOR MICRO-THRUSTER PLUME CHARACTERISATION** **999**

M. Dijkstram, K. Ma, M.J. de Boer, J. Groenesteijn, J.C. Lötters, and R.J. Wiegerink
MESA+ - University of Twente, THE NETHERLANDS

Micro chemical propulsion systems (μCPS) have been identified by ESA as emerging compact propulsion system. Within the PRECISE project a MEMS-based monopropellant propulsion system applying catalytic decomposition of hydrazine is being developed. Investigation of the micro-thruster rarefied plume flow as well as direct simulation Monte Carlo (DSMC) validation is of great importance for nozzle design and performance evaluation. A novel 6 mm long 40 μm diameter micro Pitot tube with integrated pressure sensors for characterisation of rarefied plume flow during hot-firing test has therefor been developed.

Th-196 MICROFLUIDIC-BASED DROPLET MERGING DEVICE WITH A NON-CONTACT DROPLET PAIRING METHOD 1003

S. Lee, H. Kim, and J. Kim
Pohang University of Science and Technology (POSTECH), SOUTH KOREA

We developed a novel droplet merging method based on the deformability characteristic of a droplet in pressure-driven shear flow using only fluid flow control by a unique Laplace trap that performs a multi-step 'trapping–releasing–non-contact pairing–washing–and–merging' process. Using the unique Laplace trap array, parallel merging was successfully performed within a short time variation in non-contact pairing (SD ±4.3 s) compared with conventional contact pairing (SD ±136.4 s).

M-197 MINIATURE CIRCULATORY COLUMN SYSTEM FOR GAS CHROMATOGRAPHY.....1007

H.-C. Hsieh and H. Kim
University of Utah, USA

We develop the first micro-scale circulatory column system for functioning gas chromatography and the resultant highest separation capacity demonstrated by any commercial and non-commercial GC column systems beyond the current state-of-art, by enabling the extension of the effective column length through the circulatory loop without increasing the device volume.

T-198 MIRRORED ANODIZED DIELECTRICS FOR RELIABLE ELECTROWETTING 1011

S. Chen and C. Kim
University of California, Los Angeles, USA

Anodized metal oxides are an attractive dielectric material for electrowetting-on-dielectric (EWOD) devices because of their ability to limit current leakage, high dielectric constants and low cost fabrication. However, the reliability is for only one actuation polarity because of their rectifying effect. To overcome this limitation, we developed parallel-plate EWOD devices using anodized aluminum on both plates so that one is always under the correct bias to limit the leakage current. Lifetime and current leakage were tested across a range of actuation biases.

W-199 NANOPARTICLES SORTING AND ASSEMBLY BASED ON DOUBLE-AXICON IN AN OPTOFLUIDIC CHIP 1015

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We present a novel optofluidic system of sorting and assembly of nanoparticles by tunable interference patterns generated from injecting a Gaussian beam through a double-axicon. The tightly confined (several micrometers) Bessel beam is used to sort the 100-nm gold, 200-nm and 500-nm polystyrene nanoparticles massively and simultaneously by controlling the flow rate and the laser power (from 300 mW to 500 mW). In addition, the 500-nm polystyrene particles are assembled into a 2D array by the discrete interference pattern.

Th-200 NANOSLIT MEMBRANE INTEGRATED FLUIDIC CHIP FOR MICRO/NANO PARTICLE TRAPPING AND SEPARATION 1019

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[2]*Hanyang University, SOUTH KOREA*

We propose a nanoslit fluidic chip that has a large number of nanoslit array membrane (Nanoslit-Chip) for trapping and concentrating particles of a desired size. The proposed Nanoslit-Chip has several benefits such as low flow resistance and little non-specific nanoparticle clogging for the separation of nanoparticles.

M-201 **ON-CHIP CONTROL OF PNEUMATIC-BASED BISTABLE VALVE SWITCH 1023**

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University of California, Davis, USA

We present pneumatic-based, bistable valve (BSV) switches for immediate on-chip fluid-flow manipulation without the requirement of external microcontroller circuitries. The applicability of the on-chip controller is demonstrated in a 4-to-1 microfluidic multiplexor and its clinical relevance is further supported in a point-of-care ABO blood-typing diagnostic chip.

T-202 **RAPID MICROFLUIDIC PROTOTYPING OF SOPHISTICATED PROTEIN ANALYSIS PLATFORMS USING GRAYSCALE PHOTOPATTERNING.....1027**

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[2] *ETH Zurich, USA*

We introduce, characterize, and demonstrate a novel grayscale fabrication technique for rapid prototyping of complex spatially varied hydrogels as lab-on-a-chip devices optimized to address important protein measurement questions. Our technique utilizes hydrogel photopatterning via grayscale masks to define non-uniform pore-size distributions from a single UV exposure and precursor solution. Using this method we realize two workhorse analytical electrophoresis platforms: (1) a 24-plex electrophoresis screening assay and (2) a 96-plex gradient gel-based protein sizing assay.

W-203 **REALIZATION OF 240 NANOMETER RESOLUTION OF CELL POSITIONING BY A VIRTUAL FLOW REDUCTION MECHANISM 1031**

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[1] *Osaka University, JAPAN and* [2] *Nagoya University, JAPAN*

For cell manipulation in a microchannel, it is often required to control the cell as accurate as possible. However, the issue for using a syringe pump is that the flow rate is geometrically amplified in microchannel. Therefore, we propose a virtual flow reduction mechanism in this paper. By using elastic feature of the PDMS chip, we designed and developed the total system for cell manipulation. Through experiments, we confirmed that the cell positioning resolution is 240 nm with the frequency up to 20 Hz.

Th-204 **SINGLE CELL SEPARATION BY USING ACCESSIBLE MICROFLUIDIC CHIP 1035**

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In this paper, we proposed novel single cell separation method that used accessible microfluidic channel. Various single cell separation method by using microfluidic chip have been proposed. However, the biggest problem is that those microfluidic chip are closed and separated cells are tend to missed at interface of the chip to outer world. Therefore, we used cover opened microfluidic chip that can be accessible in order to collect the separated cell. And also, we proposed single cell pick-up tool to collect the separated single cell.

M-205 STUDY OF HOTSPOT COOLING USING ELECTROWETTING ON DIELECTRIC DIGITAL MICROFLUIDIC SYSTEM.....1039

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[2]*University of Texas at Dallas, USA*

This paper presents a novel digital microfluidic (DMF) cooling system using electrowetting on dielectric (EWOD) developed for demonstrating and studying hotspot cooling for applications in electronics thermal management. The merits of this cooling system lies in the fact that no mechanically moving parts such as valves, pumps and fans are required to achieve hotspot cooling, thus having smaller form factor than bulky heatpipes and other conventional cooling systems. This study reveals close profiles of temperature change during coolant drop motion over hotspot as well as importance of phase change in the proposed cooling system.

T-206 SURFACE-ACOUSTIC-WAVE DRIVEN POINT SOURCE ATOMIZER INTEGRATED WITH PICOLITER MICRO PUMPS FOR POLYMERIC NANOPARTICLES SYNTHESIS.....1043

S. Sugimoto, M. Hara, H. Oguchi, A. Yabe, and H. Kuwano
Tohoku University, JAPAN

We developed a surface acoustic wave (SAW) driven atomizer integrated with picoliter micro pumps for polymeric nanoparticles synthesis. The pumps consisted of the reservoir and a pair of interdigital transducer (IDT). The atomizer also consisted of arc-shaped IDT for focusing the SAW energy into the liquid. As an experimental result using water, when applying the burst signal to the IDT, discharge in which the rate was 0.3 pl a burst could be observed. Moreover, we succeeded in ejection of narrow mist spray from the atomizer.

W-207 TEFLON WETTING AND DEWETTING ON EWOD DEVICE FOR CHEMILUMINESCENCE DETECTOR 1047

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[1]*Fudan University, CHINA, and* [2]*National Taiwan University, TAIWAN*

We develop a hydrophobicity recoverable EWOD (electrowetting-on-dielectric) based chemiluminescence detector with an integrated signal and heater electrode. A series of experiments and X-ray photoelectron spectroscopic analysis are used to reveal the wetting and dewetting mechanism of Teflon in the EWOD device, and get the recovery relationships between the recovered contact angle, the recovery threshold time and heating temperature.

Th-208 TRANSIENT INERTIAL FLOWS: A NEW DEGREE OF FREEDOM FOR PARTICLE FOCUSING IN MICROFLUIDIC CHANNELS.....1051

M.H. Winer, A. Ahmadi, and K.C. Cheung
University of British Columbia, CANADA

We have investigated the unique effect of transient flow rate on inertial particle focusing in microfluidic systems. A comparative analysis was conducted using both constant and transient flow rates on polystyrene (PS) beads in various channel geometries. Results show that particle focusing equilibrium positions are affected by the use of a transient (changing) flow rate. Transient inertial flows provide a new degree of freedom for manipulation of particle positioning in microfluidic channels.

Nano-Electro-Mechanical Devices and Systems (NANO)

M-209 **BIAXIAL STRAIN IN SUSPENDED GRAPHENE MEMBRANES FOR PIEZORESISTIVE SENSING 1055**

A.D. Smith[1], F. Niklaus[1], S. Vaziri[1], A.C. Fischer[1], M. Sterner[1], F. Forsberg[1], S. Schröder[1], M. Östling[1], and M.C. Lemme[2]
[1]*KTH Royal Institute of Technology, SWEDEN and*
[2]*University of Siegen, GERMNAY*

This work compares through both theory and experiment the effect of cavity shape and size on the sensitivity of piezoresistive pressure sensors based on suspended graphene membranes. Further, the paper analyzes the effect of both biaxial and uniaxial strain on the membranes.

T-210 **FABRICATION OF GOLD NANOPARTICLE-EMBEDDED NANOCHANNELS FOR SURFACE-ENHANCED RAMAN SPECTROSCOPY.....1059**

K. Suekuni, T. Takeshita, K. Sugano, and Y. Isono
Kobe University, JAPAN

A micro/nanofluidic device including linearly-arranged gold nanoparticles embedded into nanochannels was developed for highly-sensitive Surface-Enhanced Raman Spectroscopy (SERS) analysis. The nanochannels array was fabricated by a “photo" lithography-based process without costly and time-consuming process such as EB lithography. Then particles with diameters of 100 nm are arranged into the nanochannels by a nanotrench-guided self-assembly process. The device was successfully fabricated and it was active for SERS analysis with 4,4’-bypiridine as a target molecule."

W-211 **FINFET WITH FULLY PH-RESPONSIVE HFO2 AS HIGHLY STABLE BIOCHEMICAL SENSOR.....1063**

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[2]*University of Basel, SWITZERLAND, and*
[3]*Paul Scherrer Institute, SWITZERLAND*

We present a sensing platform based on high-stability low-power n-channel fully depleted FinFETs on Si-bulk. Efficient chemical and biological label-free sensing has been demonstrated, paving the way towards non-invasive simultaneous monitoring of human physiological signals such as pH and proteins. In contrast to other SiNW-based sensors, the use of scalable high-k dielectric FinFETs for both applications is in accordance with the material constraints which come along Moore’s Law of scaling.

Th-212 **FREQUENCY DEPENDENT AC ELECTROOSMOTIC FLOW IN NANOCHANNELS.....1067**

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MESA+ - University of Twente, THE NETHERLANDS

We report frequency-dependent bidirectional AC electroosmotic flow (AC-EOF) in a nanochannel with double layer overlap. Simulations confirm the observed bidirectionality. By this frequency-dependent bidirectional pumping, nanochannel AC-EOF behaves in fundamentally different way than microchannel AC-EOF. The results are of importance for the understanding of ion and liquid transport in nanoconfinement.

M-213 **FULLY MONOLITHIC AND ULTRA-COMPACT NEMS-CMOS SELF-OSCILLATOR BASED ON SINGLE-CRYSTAL SILICON RESONATORS AND LOW-COST CMOS CIRCUITRY.....1071**

J. Philippe, G. Arndt, E. Colinet, M. Savoye, T. Ernst, E. Ollier, and J. Arcamone
CEA - LETI – Minatec, FRANCE

This work reports on the first experimental demonstration of a self-oscillator based on a single crystal silicon NEMS resonator monolithically co-integrated with a simple electronic circuitry manufactured with a very low-cost 0.35µm CMOS technology. This NEMS-CMOS self-oscillator pixel is as small as 50x70 µm^2 (pads excluded).

T-214 **A GRAPHENE NANOSENSOR FOR DETECTION OF SMALL MOLECULES.....1075**

C. Wang[1,2], J. Kim[1], J. Zhu[1], R. Pei[3], G. Liu[2], J. Hone[1], M. Stojanovic[1], and Q. Lin[1]
[1]Columbia University, USA, [2]Nankai University, CHINA, and [3]Chinese Academy of Sciences, CHINA

We developed a graphene field effect transistor (GFET) biosensor for detection of an important small molecular hormone DHEA-S. In view of the low charged small biomolecules can't excite sufficient electrical response of GFET, we proposed a competitive dehybridization strategy based on the aptamer-target specific association. We experimentally demonstrated that on the graphene surface, aptamer dehybridization caused by DHEA-S specific association provides strong response of GFET. And the concentration of target DHEA-S can be quantitatively detected by observing the ''half time period'' of aptamer dehybridization kinetic process.

W-215 **INTERROGATING CONTACT-MODE SILICON CARBIDE (SiC) NANOELECTROMECHANICAL SWITCHING DYNAMICS BY ULTRASENSITIVE LASER INTERFEROMETRY.....1079**

T. He, J. Lee, Z. Wang, and P.X.-L. Feng
Case Western Reserve University, USA

We report the experimental demonstration of probing the dynamics of nanoscale contacts in robust nanoelectromechanical switches based on silicon carbide (SiC) nanocantilevers. For the first time, we measure the dynamical behavior of contact-mode SiC nanoelectromechanical switches, in both frequency- and time-domain, by directly probing the tips of the SiC nanocantilevers, using ultrasensitive laser interferometric techniques.

Th-216 **MATRIX INDEPENDENT LABEL-FREE NANOELECTRONIC BIOSENSOR.....1083**

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We fabricated a novel, label free and real time electrical impedance biosensor, referred to as the nanoneedle biosensor. The nanoneedle is an ultrasensitive and localized device, which has the ability to directly measure biomolecular binding as a function of time (real-time). The utility of this sensor in affinity biosensing was demonstrated. As a practical example with clinical relevance, we demonstrated the detection of Vascular Endothelial Growth Factor (VEGF) for cancer diagnosis. Our demonstration of label-free and real-time detection of VEGF with this sensor can be envisioned to allow for one-step point-of-care cancer diagnosis. This work provides a strong starting point for a new class of electronic biosensing devices with the capability of rapid direct large-scale integration.

M-217 **MECHANICAL PROPERTIES OF FEW LAYER GRAPHENE CANTILEVER.....1087**

K. Matsui, A. Inaba, Y. Oshidari, Y. Takei, H. Takahashi, T. Takahata, R. Kometani, K. Matsumoto, and I. Shimoyama
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We report the spring constant measurement of few-layer (1-, 2-, and 3-layer) graphene (FLG) cantilevers by optical heterodyne interferometry. We fabricated FLG cantilever with a weight of diamond-like carbon using focused ion beam. The effective spring constants were obtained from the measured resonant frequency and the mass of the weight, and were calculated to be about 2.7×10^{-3} N/m. This result indicates FLG cantilever structure is more rigid than that predicted from the literature data.

T-218 **NANO-OPTO-MECHANICAL MEMORY BASED ON OPTICAL GRADIENT FORCE INDUCED BISTABILITY.....1091**

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[2]*Agency for Science, Technology and Research (A*STAR), SINGAPORE, and* [3]*Xi'an Jiao Tong University, CHINA*

A bistable nano-opto-mechanical memory is designed, fabricated and experimentally demonstrated.Fabricated with CMOS compatible process, this optical memory can be easily packaged and integrated with otherphotonic devices. The nano-size of the memory enable for large scale integration, high speed operation and low powerconsumption. It has other potential applications such as optical switch, logic gate and actuator.

W-219 **SUBMICRON THREE-TERMINAL SIGE-BASED ELECTROMECHANICAL OHMIC RELAY.....1095**

M. Ramezani[1,2], S. Cosemans[1], J. De Coster[1], X. Rottenberg[1], V. Rochus[1], H. Osman[1], H.A.C. Tilmans[1], S. Severi[1], and K. De Meyer[1,2]
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We demonstrate functional cantilever switches based on a CMOS-compatible low-T(400ºC) CVD SiGe process flow. Devices with dimensions in the micrometer range, thickness and gap smaller than 100nm were successfully fabricated and electrically characterized. Typical switches characteristics such as high I_{on}/I_{off} ratio, sharp sub-threshold slope and zero off-state leakage current were observed. A minimum of 1000 cycles device lifetime was demonstrated. The maximum current which can flow through the device without causing stiction due Joule-heating was investigated.

Th-220 **PIEZOELECTRIC BUCKLING-BASED NEMS RELAYS FOR MILLIVOLT MECHANICAL LOGIC.....1099**

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[2]*Electronics Research Institute, EGYPT*

We report on the design, fabrication, characterization, and scaling analysis of novel NEMS relays that use, for the first time, buckling piezoelectric actuators. The fabricated switches exhibit low actuation voltage (< 2 V) and reduced threshold voltage (~110 mV). Also, hysteresis in the switching process was observed and limits the minimum swing voltage to ~250 mV. A scaling analysis highlights the possibility of achieving milliVolt switching at aggressively scaled device footprints.

M-221 **NANOELECTROMECHANICAL TUNNELING SWITCHES BASED ON SELF-ASSEMBLED MOLECULAR LAYERS 1103**

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[2]*University of California, Berkeley, USA*

We propose and experimentally investigate nanoelectromechanical switches that operate via electromechanical modulation of tunneling current through compressible molecular films. This approach utilizes self-assembled molecular layers to define few nanometer-thick switching gaps, and has the potential to enable low-voltage operation while simultaneously mitigating device failure due to stiction.

T-222 **TRANSITION OF Q-DOT DISTRIBUTION ON MICROTUBULE ARRAY ENCLOSED BY PDMS SEALING FOR AXONAL TRANSPORT MODEL 1107**

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

We developed an experimental system which enables kinesin driven transport on arrayed microtubules in enclosed micro channels. To avoid an expected difficulty of exchanging solution, surface fabricated micro tracks were encapsulated after reagents introduction using flow cells with deformable PDMS chip at its top. After enclosed micro channels were formed, directed transport and continuous accumulation of fluorescent labeled kinesin molecules were observed. These results indicate a possibility of application as in vitro model of intracellular transport as seen in axons.

W-223 **WAFER-SCALE FABRICATION OF SCANNING THERMAL PROBES WITH INTEGRATED METAL NANOWIRE RESISTIVE ELEMENTS FOR SENSING AND HEATING 1111**

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[2]*SmartTip B.V., THE NETHERLANDS,* [3]*University of Tokyo, JAPAN, and*
[4]*Korea Institute of Science and Technology (KIST), GERMANY*

We present a novel scanning resistive probe aimed for thermal imaging and localized thermal analysis. The probe features an AFM cantilever with a sharp pyramidal tip. Metal nanowires are integrated at the inner edges of the pyramidal tip forming an electrical cross-junction at the apex. The cross-junction can be utilized both as a local temperature sensor and a heater.

Packaging Technologies (PCK)

Th-224 **CAPILLARY EFFECT BASED TSV FILLING METHOD 1115**

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We explore a capillary liquid solder through-hole filling method, which utilizes liquid bridge pinch-off effect. The filling is completed by first pushing solder into via holes from a solder pool through nozzle orifices, and then followed by cutting the solder pillars in the via holes off from the solder pool in the nozzle orifices. The whole TSV filling process can be completed by a cycle of pressure change. In addition, 'wafer sandwich' structure is utilized to neutralize pressure differential, which causes wafer breakage.

M-225 CHARACTERISATION AND SIMULATION OF LOW TEMPERATURE Si-Si-DIRECT BONDING THROUGH VELCRO-LIKE SURFACES BASED ON POROUS SILICON 1119

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[2]*University of Freiburg – IMTEK, GERMANY*

We develop, characterize and model a new bonding technique based on Pours Silicon (PS) technology. PS allows strong permanent bonding between needle like surfaces as well as multiple bonding and un-bonding of chips similar to Velcro principle. This approach provides low temperature Si-Si direct bonding, a fully CMOS compatible approach suitable in system integration using the Si-motherboard concept.

T-226 FROM CHIPS TO DUST: THE MEMS SHATTER SECURE CHIP 1123

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University of Utah, USA

This paper presents the implementation of transience silicon microchips through post-processing microfabrication and micropackaging steps that transform almost any electronic, optical or MEMS substrate chips into transient ones. When transience is activated the chip mechanically shatters, and it is literally reduced to a heap of silicon dust. The massive cleavage action is achieved by the triggered release of mechanical energy stored within the silicon substrate in expandable microparticles.

W-227 LONG TERM GLASS-ENCAPSULATED PACKAGING FOR IMPLANT ELECTRONICS 1127

J.H. Chang, Y. Liu, and Y.C. Tai
California Institute of Technology, USA

This paper studies a new long-term packaging scheme for implant electronics using glass encapsulation featuring a controlled failure mode from fast diffusion to slow undercut. The experimental results show that this packagingscheme can easily survive for more than 10 years by accelerated “active" lifetime soaking test (i.e. with electric field applied) in 0.9 wt.% saline solution. This method provides advantages of easy employment, controllable long life time, and enhanced heat dissipation."

Th-228 LOW-TEMPERATURE GOLD-GOLD BONDING USING SELECTIVE FORMATION OF NANOPOROUS POWDERS FOR BUMP INTERCONNECTS.....1131

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We proposed low-temperature Au-Au bonding using nanoporous Au-Ag powders as an electrical connective adhesion between bump interconnects. The nano-porous powders were formed by de-alloying Au-Ag alloy sheet with Au:Ag. The influence of the annealing temperature on the porous structures was investigated. Selective formation of the powders on bumps was achieved by stamping. Bonding strength of about 2.4 MPa was achieved by using nanoporous Au-Ag powders at 150 °C. This result indicates that the proposed powder is a useful material for low-temperature Au-Au bonding.

M-229 **MICRO DEVICES INTEGRATION WITH LARGE-AREA 2D CHIP-NETWORK USING STRETCHABLE ELECTROPLATING COPPER SPRING 1135**

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[2]*imec Taiwan Inc., TAIWAN*

This study presents a large-area multi-devices integration scheme using stretchable electroplating copper spring. Advantages of this approach: (1) using the existing process technologies and materials for semiconductor in large-area applications; (2) stretchable electroplating-copper spring with large maximum strain acts as mechanically and electrically connection; (3) Si-node acts as a hub for devices implementation and integration; and (4) the chip-network can apply to curved surfaces. The proposed expand network using stretchable spring integrated multi devices has been implemented and tested.

T-230 **SOLID-STATE ISFET FLOW METER FABRICATED WITH A PLANAR PACKAGING PROCESS FOR INTEGRATING MICROFLUIDIC CHANNEL WITH CMOS IC CHIP 1139**

J.J. Wang[1], C.F. Lin[2], Y.Z. Juang[2], H.H. Tsai[2], H.H. Liao[2], and C.H. Lin[1]
[1]*National Sun Yat-sen University, TAIWAN and*
[2]*National Applied Research Laboratories, TAIWAN*

We presents a solid-state ISFET flow meter fabricated with an innovative planar packaging process. The developed method provides a simple yet efficient method to integrate CMOS IC chip with microfluidic systems and the whole packaging process can be achieved in 40 min. The sealed ISFET chip is used for measuring the flow rate of non-ionic solutions including acetone, ethanol and glycerol of slow flow rate. And the flow rate measurement exhibited good reproducibility in the flow rate ranging from 66 to 1700 μm/s.

Physical MEMS (PHYS)

W-231 **A TUNABLE LASER BASED ON NANO-OPTO-MECHANICAL SYSTEM.....1143**

M. Ren[1], H. Cai[2], Y.D. Gu[2], P. Kropelnicki[2], A.B. Randles[2], and A.Q. Liu[1]
[1]*Nanyang Technological University, SINGAPORE and*
[2]*Agency for Science, Technology and Research (A*STAR), SINGAPORE*

A tunable laser based on nano-opto-mechanical system is presented in this paper. A novel tuning approach is demonstrated which applies optical force to adjust the cavity mode via controlling the mechanical displacement of the silicon waveguide. In the experiments, a 24-nm wavelength tuning is realized due to a deflection of 14-nm. The optomechanical wavelength tuning coefficient is 214 GHz/nm. The demonstrated device has potential applications for optical communication system, pulse trapping/release, and chemical sensing, with easy on-chip integration on a silicon platform.

Th-232 **A TUNABLE OPTICAL IRIS BASED ON ELECTROMAGNETIC ACTUATION FOR A HIGH-PERFORMANCE MINI/MICRO CAMERA.....1147**

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[2]*Samsung Advanced Institute of Technology (SAIT), SOUTH KOREA*

This paper presents a tunable optical iris based on electromagnetic actuation for a high-performance mini/micro camera. In optics, an iris, an aperture stop, is placed in the light path of a lens or objective and regulates the amount of light that passes through the lens by controlling the size of the aperture, an opening at it center. The iris not only controls light flux, field of view, depth of field (DOF), but also blocks scattered light and improves image quality by limiting spherical aberration. Hence, the iris is an indispensable element in most optical systems. However, the conventional mechanical iris, consisting of movable sliding blades, requires a complicated sliding rotary mechanism that has to be operated by bulky motors and is therefore difficult to miniaturize. We develop a variable optical iris operated by electromagnetic actuation. According to electromagnetic induction, when an electrical current flows in an electric coil, a magnetic field is generated in its surroundings. In this work, the magnetic field is used to actuate or pull an optically opaque ferrofluid initially filled inside the sub-channel of the iris to the center of the main channel, resulting in controlling the diameter of an aperture.

M-233 **CALORIMETRIC DEVICE FOR NON-DESTRUCTIVE MEASUREMENT OF THE THERMAL DIFFUSIVITY DEPENDENCY BY PHASE DELAY.....1151**

T. Suzuki, Y. Ichikawa, T. Takahata, K. Matsumoto, and I. Shimoyama
University of Tokyo, JAPAN

We developed a device for measuring thermal diffusivity dependency of the contacted surface layer non-destructively. The device was based on the principle that temperature phase delay between a heater and a resistance temperature detector (RTD) is affected by thermal diffusivity of the contacted surface layer. The device consisted of an Au wire, as oscillating heat source and a piezoresistance as a RTD. We exerted the simulation and the experiment for the device, and found that the phase delay decreased as thermal diffusivity increased.

T-234 **CAPACITIVE FEEDBACK CONTROLLED PZT MICRO MIRROR ARRAYS FOR WAVELENGTH SELECTIVE SWITCH 1155**

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Sumitomo Precision Products Co., Ltd., JAPAN

We develop a single-axis mechanical micro mirror array used for gridless wavelength selective switch (WSS). The mirrors are driven by lead zirconate titanate (PZT) unimorph actuators, which is adequate for low-voltage actuation and low interference with adjacent mirrors in operation. In addition, the mirror tilt angle is feedback controlled using comb-shaped capacitance in order to realize high control resolution. We fabricated a prototype of the mirror array, and evaluated its basic performance.

W-235 CARBON SP2-SP3 TECHNOLOGY: GRAPHENE-ON-DIAMOND THIN FILM UV DETECTOR.....1159

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[2] *Chinese Academy of Sciences, CHINA*

We for the first time demonstrates the graphene-diamond-metal (GDM) vertical sandwich structure as a thin film UV detector. New scientific and engineering breakthroughs are: (1) first experimental investigation of the carbon-based sp2-sp3 junctions; (2) a peel-and-stick fabrication process to make flexible diamond films; and (3) first GDM vertical UV sensors. As such, the proposed detector/architecture can open up a new class of scheme to build diamond-based optoelectronic systems.

Th-236 CLOSE-PACKED LIQUID-FILLED TUNABLE MICROLENS ARRAY 1163

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We develop close-packed liquid-filled tunable microlens arrays for optical devices such as integral imaging systems. These lenses are simply composed of poly (dimethylsiloxane)(PDMS) microchannels and applied pressure deforms the top membrane of microchannels to become convex lenses. These lenses have three advantages: (i)Uniform deformation by pressure-driven actuation, (ii)Adjustable optical characteristics without patterned electrode, (iii)High-density integration of tunable microlenses. We fabricated three types of lenses based on closed-packed structure and showed that the Spiderweb type packing is the most suitable for closer packing.

M-237 COMPACT TUNABLE HYPERSPECTRAL IMAGING SYSTEM.....1167

P.-H. Cu-Nguyen[1], A. Grewe[2], C. Endrödy[2], S. Sinzinger[2],
H. Zappe[1], and A. Seifert[1]
[1] *University of Freiburg – IMTEK, GERMANY and*
[2] *Ilmenau University of Technology, GERMANY*

We demonstrate a compact tunable hyperchromatic lens system for imaging an object with highly resolved spectral information. This hybrid device is composed of a diffractive optical element, a tunable concave liquid-filled membrane lens, and an integrated magnetic actuator for hydraulically tuning the focal length of the refractive lens. The lens system can generate a hyperspectral datacube in the visible wavelength range, 400 – 730 nm, proved here with a spectral sampling interval of 2.4 nm.

T-238 CYLINDRICAL LENS WITH INTEGRATED PIEZO ACTUATION FOR FOCAL LENGTH TUNING AND LATERAL SCANNING 1171

M. Stuermer, A. Schatz, and U. Wallrabe
University of Freiburg – IMTEK, GERMANY

We present a cylindrical lens which features integrated piezo bending actuators for focal length tuning. The design is based on a PDMS membrane which encloses an optical liquid. We optimize the shape of the actuators for good cylindricity and show a process for prototype fabrication. The lens provides a large usable aperture of ca. 4 x 10 mm, a tuning range of more than 20 dpt, and the possibility to move the lens vertex along one axis. Therefore, it enables scanning of the line focus.

W-239 **FRESNEL LENS BASED ON SILICON NANOWIRES.....1175**

Y.-S. Lu, J. Fernandes, H. Liu, and H. Jiang
University of Wisconsin-Madison, USA

We demonstrate silicon-based Fresnel lenses by photolithography techniques and metal assisted chemical etching, where the opaque zones are composed of 2 μm-tall silicon nanowires formed directly in silicon. The reflective Fresnel lens showed a high-contrast light intensity distribution between the bright and dark zones, leading to a focused spot with strong contrast above the lens. The lens has the potential to be integrated with dye-sensitive solar cells by reflecting and focusing light onto the photosensitive dye to improve their light absorption efficiency and photocurrent.

Th-240 **ENHANCED WAVELENGTH SELECTIVE INFRARED EMISSION USING SURFACE PLASMON POLARITON AND THERMAL ENERGY CONFINED IN MICRO-HEATER 1179**

T. Sawada[1], K. Masuno[2], S. Kumagai[1], M. Ishii[2], S. Uematsu[2], and M. Sasaki[1]
[1] *Toyota Technological Institute, JAPAN and* [2] *Yazaki Corporation, JAPAN*

A new surface plasmon polariton (SPP) based wavelength selective IR emitter is combined with microheater. IR emitted from the microheater is basically confined except SPP propagation on the metal grating carrying IR energy to the outside. The limited condition for SPP excitation realizes the narrow wavelength filtering. SPP related emission is obtained having the peak width similar order compared with the bandwidth of gas absorption. Since the microheater can minimize the thermal conduction loss, the high efficiently is expected at SPP related wavelength.

M-241 **EFFECT OF NEEDLE SHAPE ON PERFORMANCE OF NEEDLE-TYPE ELECTRO TACTILE DISPLAY 1183**

N. Kitamura[1], J. Chim[1], and N. Miki[1,2]
[1] *Keio University, JAPAN and*
[2] *Japan Science and Technology Agency (JST), JAPAN*

In our prior work, we revealed that a needle-type electrotactile display that penetrates through a stratum corneum of a finger skin can display tactile information at 20 times as low voltage as that with flat electrodes. We discovered that the needle-tip shapes greatly affected the performance of the display. In this work, we experimentally deduced the optimum shape of the needle tip using titanium micro-needles patterned by electrochemical etching. The needles can be readily applicable to efficient electrotactile displays.

T-242 **INCLINATION-INDEPENDENT TRANSFORMATION OF LIGHT BEAMS USING HIGH-THROUGHPUT UNIQUELY-CURVED MICROMIRRORS 1185**

Y.M. Sabry[1,2], D. Khalil[2,3], B. Saadany[2], and T. Bourouina[1,2]
[1] *Université Paris-Est, FRANCE,* [2] *Si-Ware Systems, EGYPT, and*
[3] *Ain-Shams University, EGYPT*

This paper reports a novel class of deeply-etched, specifically-designed curved micromirrors enabling phase-transformation of light beams independent of the inclination angle of the incident light with respect to the mirror surface. The micromirrors were fabricated on silicon by deep reactive ion etching technology. The profile of the specifically-designed mirrors' surfaces was controlled precisely, thanks to the photolithographic process. High optical throughput micromirrors exhibiting submillimeter focal lengths were fabricated with depth larger than 300 μm. Optical measurements show stable dimensions for the optical beam spot with less than ± 5% dependence on the inclination angle up to 60 degrees.

W-243 **MAGNETOSTRICTIVE TYPE TACTILE SENSOR BASED ON METAL EMBEDDED POLYMER ARCHITECTURE.....1189**

H.-C. Chang[1], W.-L. Sung[1], H.-S. Hsieh[1], J.-H. Wen[1], C.-C. Fu[1], S.-C. Liao[1], C.-H. Lai[1], W.-C. Lai[2], C.-H. Chang[2], C.-P. Chang[2], C.-H. Chen[2], and W. Fang[1]

[1]*National Tsing Hua University (NTHU), TAIWAN and*
[2]*WinMEMS Technologies Co., Ltd., TAIWAN*

This study presents new process scheme to fabricate polymer structure with embedded metal on silicon substrate. The primary merit of presented process scheme is: simple approach for the integration of 3D structures with different materials (e.g. metal, glass, polymer) on substrate. To demonstrate the feasibility, a tactile sensor design consisting of polymer structure with embedded 3D Ni inductor is demonstrated. As the polymer diaphragm deformed by tactile force, the magnetostriction effect of 3D Ni inductor will induce the permeability change. Thus, the permeability change as well as the tactile force can be detected by the inductance difference of embedded 3D Ni inductor.

Th-244 **A MULTI-MATERIAL Q-BOOSTED LOW PHASE NOISE OPTOMECHANICAL OSCILLATOR 1193**

T. Beyazoglu, T.O. Rocheleau, K.E. Grutter, A.J. Grine, M.C. Wu, and C.T.-C. Nguyen

University of California, Berkeley, USA

We present a multi material Radiation Pressure driven Optomechanical Oscillator (RP-OMO) with simultaneously high mechanical Qm >22,000 and optical Qo >190,000 achieving best-to-date phase noise performance of -125 dBc/Hz at 5 kHz offset from its 52-MHz carrier, which is 12 dB better than the previous best RP-OMO constructed of silicon nitride alone. The device not only reduces phase noise, but does so with a lower input laser power of only 3.6 mW. The key to achieving this performance is the addition of polysilicon material as an inner ring that boosts the overall mechanical Qm of the total structure. The addition of polysilicon further provides a mechanism for voltage-controlled electrical stiffness tuning of the oscillation frequency.

M-245 **NOVEL TUNABLE OPTICAL MODULATION LENS USING MAGNETHORHEOLOGICAL EFFECT 1197**

F.-M. Hsu, R. Chen, and W. Fang

National Tsing Hua University (NTHU), TAIWAN

This study extends the fluid dispensing and sealing technology to realize a novel MR-fluid lens (MR-fluid: liquid polymer with magnetic particles) for light intensity modulation. Merits of the device: Optical transmittance of lens is controlled by (1) weight fraction of magnetic powder, and (2) orientation of columnar particles controlled by magnetic field. In applications, the MR-fluid lens is realized on glass substrate and suspended MEMS structures. The light intensity modulation of MR-fluid lens (diameter: 2000μm) by magnetic field is demonstrated. Measurements show the NdFeB- liquid polymer (10wt%) has a 40% dark area change and 290% laser transmittance difference after applying magnetic field.

T-246 **OPTICAL CONTROL AND TUNING OF THERMAL-PIEZORESISTIVE SELF-SUSTAINED OSCILLATORS 1201**

H.J. Hall[1], L. Wang[1], J.S. Bunch[1], S. Pourkamali[2], and V.M. Bright[1]

[1]*University of Colorado, Boulder, USA and* [2]*University of Texas, Dallas, USA*

We experimentally demonstrate the ability to frequency tune and provide on/off control of electrically driven thermal-piezoresistive self-sustained oscillators through the direct application of HeNe laser illumination at the device surface. These phenomena, which are unique to this class of oscillator, are explained by photoexcitation of charge carriers in the device's single crystal silicon structure inducing changes to the effective electrical resistivity and piezoresistivity.

W-247 **PHOTOTHERMAL PROBING OF PLASMONIC HOTSPOTS WITH NANOMECHANICAL RESONATOR 1205**

S. Schmid, K. Wu, T. Rindzevicius, and A. Boisen
Technical University of Denmark, DENMARK

We present a novel technique to probe and image plasmonic structures with nanoscale resolution by measuring the photothermally induced frequency detuning of highly temperature sensitive nanomechanical resonators. We employ the high temperature sensitivity of a nanomechanical string resonator to directly probe the heating pattern produced by a gold nanoslit illuminated by a scanning laser beam. The experimental approach allows a sensitive heat mapping of single localized surface plasmons, thereby helping to shed light on the underlying thermal effects in hotspots.

Th-248 **RADIATION-PRESSURE ENHANCED OPTO-ACOUSTIC OSCILLATOR.....1209**

M.J. Storey, S. Tallur, and S.A. Bhave
Cornell University, USA

We present a driving scheme for integrated chip-scale opto-acoustic oscillators (OAO) in silicon with improved phase noise performance. Through simultaneous incorporation of radiation-pressure (RP) and RF feedback oscillating mechanisms, we have demonstrated a silicon RP enhanced OAO with a 10dB close-to-carrier phase noise improvement and thereby 10dB improvement in the oscillator's figure of merit.

M-249 **THERMOPILE INFRARED ARRAY SENSOR FOR HUMAN DETECTOR APPLICATION 1213**

J. Tanaka, M. Shiozaki, F. Aita, T. Seki, and M. Oba
OMRON Corporation, JAPAN

This paper reports the design of thermopile infrared sensor for human detector application. Sensitivity and response time of thermopile infrared sensor element are important for human detector application. In order to fulfill the specification, we developed S-shaped structure for thermopile infrared sensor element and fabrication process of chip scale vacuum package for mass production of the thermopile infrared sensors. As the result, 140V/W sensitivity and 17msec response time of the thermopile infrared sensor element are achieved.

T-250 **TRANSFER-PRINTED COMPOSITE MEMBRANES FOR ELECTRICALLY-TUNABLE ORGANIC OPTICAL MICROCAVITIES 1217**

A. Wang, W. Chang, A. Murarka, J. Lang, and V. Bulovic
Massachusetts Institute of Technology, USA

We present a method for fabricating organic optical microcavities using a transfer-printed composite membrane which can be electrostatically actuated for dynamic tuning of the cavity emission spectra. Electrical actuation and optical characterization of a completed device show cavity mode tuning greater than 20 nm. The device structure and transfer technique is easily applicable to large area fabrication of electrostatically tunable organic lasers, and potentially allows single-point contactless-readout for large area pressure sensor arrays.

W-251 **TUNABLE METAMATERIALS BY CONTROLLING SUB-MICRON GAP FOR THE THZ RANGE 1221**

A. Isozaki[1], T. Kan[1], H. Takahashi[1], N. Kanda[2], N. Nemoto[1], K. Konishi[1], M. Kuwata-Gonokami[1], K. Matsumoto[1], and I. Shimoyama[1]
[1]*University of Tokyo, JAPAN and*
[2]*Institute of Physical and Chemical Research (RIKEN), JAPAN*

We propose a tunable metamaterial actuated by pneumatic force. The tunable metamaterial has a double of sprit-ring-resonators (SRRs) whose gap between each other is controllable in sub-micron-order. Results of a terahertz (THz) spectroscopy confirmed that controlling gap in sub-micron-order or a few micron order was suitable for tuning resonant frequency of a metamaterial compared with that in 10 micron-order.

Th-252 **UNCOOLED MULTI-BAND IR IMAGING USING BIMATERIAL CANTILEVER FPA 1225**

W. Ma[1], S. Wang[1], Y. Wen[1], Y. Zhao[2], L. Dong[2], M. Liu[2], X. Liu[2], and X. Yu[1]
[1]*Peking University, CHINA and* [2]*Institute of Beijing Technology, CHINA*

A 256×256 bimaterial cantilever focal plane array (FPA), which is able to work in the three infrared atmospheric windows simultaneously, is fabricated and characterized. The FPA employs a silicon-framed structure by selectively etching away the substrate with Deep Reactive Ion Etching technique, and can be conveniently readout by an optical system. By combining the Chromium nano-films with silicon nitride as the multi-band IR absorber, the images of short wavelength, middle wavelength and long wavelength infrared are captured successfully with the same FPA.

M-253 **VERY LOW POWER CONSUMPTION MEMS SCANNER WITH ALKALI ELECTRET COMB DRIVE 1229**

T. Sugiyama, M. Aoyama, K. Kawai, and G. Hashiguchi
Shizuoka University, JAPAN

We developed the very low power consumption MEMS scanner that utilizes the electrostatic field generated by alkali-ion electret. The alkali-ion electret formed on comb electrodes of the scanner provides built-in potential for the electro-static actuator so that no bias voltage is necessary. The power consumption of prototype MEMS scanner was 0.57 μW (bias voltage: DC 0 V, driving voltage: AC 9 Vpp, deflection angle: 12°, resonance frequency: 1.4 kHz).

RF MEMS (RF)

T-254 **A LOW-LOSS RF MEMS SILICON SWITCH USING REFLOWED GLASS STRUCTURE.....1233**

J. Hwang, S.-H. Hwang, Y.-S. Lee, and Y.-K. Kim
Seoul National University, SOUTH KOREA

This paper firstly reports on a low-loss RF MEMS switch that contains a reflowed glass structure beneath a contact metal. The reflowed glass structure is employed to reduce the electromagnetic wave loss brought about by the conductive silicon bulk underneath the contact metal. RF MEMS switch totally made of silicon is used as a reference model and the insertion loss is reduced as much as 0.26 dB for the proposed model in the frequency range of 5 to 30 GHz.

W-255 **A UHF 4TH-ORDER BAND-PASS FILTER BASED ON CONTOUR-MODE PZT-ON-SILICON RESONATORS 1237**
H. Yagubizade, M. Darvishi, M. Elwenspeok, and N.R. Tas
MESA+, University of Twente, THE NETHERLANDS

A novel RF-MEMS filter configuration around 700 MHz is proposed. It is based on a differential read-out of two in-phase actuated contour-mode resonators with slightly different resonance frequencies. The resonators are actuated independently in-phase and the outputs of the resonators are subtracted. This method is effective for improving the stopband rejection by canceling the feed-through signal. The BPF is presented using 50Ω termination with bandwidth of approximately 28.6 MHz and 35 dB stopband rejection. The ultimate rejection of the filter is improved by more than 20 dB compared to the individual resonators.

Th-256 **AN 880MHZ LADDER FILTER FORMED BY ARRAYS OF LATERALLY VIBRATING THIN FILM LITHIUM NIOBATE RESONATORS.....1241**
S. Gong[1], and G. Piazza[2]
[1]*University of Illinois, Urbana Champaign, USA and*
[2]*Carnegie Mellon University, USA*

This paper reports on the first implementation of a ladder filter using Lithium Niobate (LN) based laterally vibrating resonator (LVR) arrays. This demonstration is made possible by engineering the device orientation and using a distributed configuration of resonator arrays to simultaneously reduce spurious vibrations and insertion loss in a low impedance RF system. An almost spurious-free filter with < 3.5 dB of IL at 880 MHz was demonstrated by arraying properly sized devices into a ladder configuration. A total of 37 resonators were used for this demonstration. This work sets an important milestone in the development of a thin film LN technology platform for wide-band and frequency-agile RF filtering.

M-257 **CAPACITIVE SILICON RESONATOR STRUCTURE WITH MOVABLE ELECTRODES TO REDUCE CAPACITIVE GAP WIDTHS BASED ON ELECTROSTATIC PARALLEL PLATE ACTUATION 1245**
N.V. Toan and T. Ono
Tohoku University, JAPAN

This paper presents the design and fabrication of a capacitive silicon resonator with movable electrodes to obtain smaller capacitive gap widths, which results in smaller motional resistance and lower insertion loss. It also helps to increase tuning frequency range for compensation of temperature drift of silicon resonator.

T-258 **COMBINED ELECTRICAL AND MECHANICAL COUPLING FOR MODE-RECONFIGURABLE CMOS-MEMS FILTERS 1249**
C.-Y. Chen, M.-H. Li, C.-H. Chin, C.-S. Li, and S.-S.Li
National Tsing Hua University (NTHU), TAIWAN

This work presents a novel filter scheme which combines electrical and mechanical coupling implemented in a CMOS-MEMS filter to simultaneously attain narrow bandwidth and decent stopband rejection. As compared to the parallel-class filters and mechanically-coupled filters, the proposed filter structure features flexible electrical routing and non-conductive mechanical couplers, hence enabling single-ended to differential (SIDO) and differential to single-ended (DISO) reconfigurable modes in a single device. The proposed 8.6-MHz CMOS-MEMS filter was successfully demonstrated with narrow passband of 0.41% bandwidth and stopband rejection more than 20dB under proper termination.

W-259 **DYNAMIC CHARACTERIZATION OF TUNABLE RF MEMS PRODUCTS 1253**

D. DeReus, S. Cunningham, S. Natarajan, A. Morris, and J. Hilbert
WiSpry, Inc., USA

We present the dynamic characterization of tunable capacitors for RF MEMS products.The dynamic measurements have been made electrically by laser doppler vibrometry, and correlated with conventional finite element and high-order, parametric finite element models.

Th-260 **ETCH-HOLE-ASSISTED ENERGY DISPERSION FOR ENHANCING QUALITY FACTOR IN SILICON BULK ACOUSTIC RESONATORS 1257**

C. Tu and J.E.-Y. Lee
City University of Hong Kong, HONG KONG

This paper empirically demonstrates how the quality factor (Q) of a width-extensional mode silicon bulk-acoustic-resonator (SiBAR) can be enhanced by three times through strategic placement of holes on the structure. The holes serve to disperse the strain energy field concentrated around the nodal lines, ultimately re-distributing strain energy away from the anchors. This in turn reduces anchor loss and thus enhances Q. These results agree well with our finite-element (FE) simulations and we envisage the concepts herein to be transferable to other higher performance resonators like piezoelectric-AIN CMRs.

M-261 **NANO-OPTO-ELECTRO-MECHANICAL (NOEM) OSCILLATOR WITH CONTROLLABLE NON-LINEAR DYNAMICS 1261**

B. Dong[1,2], J.G. Huang[3], H. Cai[2], P. Kropelnicki[2], A.B. Randles[2], Y.D. Gu[2], and A.Q. Liu[1]
[1]*Nanyang Technological University, SINGAPORE,*
[2]*Agency for Science, Technology and Research (A*STAR), SINGAPORE, and* [3]*Xi'an Jiao Tong University, CHINA*

An opto-mechanical oscillator with controllable non-linear dynamics is designed, fabricated and experimentally demonstrated. Fabricated with CMOS compatible process, this opto-mechanical oscillator can be easily packaged and integrated with other photonic devices. It has potential applications such as optical resonator type gyroscope, accelerometer and optical communication devices.

T-262 **ON/OFF SWITCHABLE HIGH-Q CAPACITIVE-PIEZOELECTRIC ALN RESONATORS 1265**

R.A. Schneider and C.T.-C. Nguyen
University of California, Berkeley, USA

AIN disk resonators having suspended (non-contacting) electrodes are demonstrated to have quality factors as high as 8,850 at 300 MHz, show no spurious modes, have single disk motional impedances of 3.0kOhm, and to possess an electrode collapse based off/on switching capability that operates via the application and subsequent removal of a strong bias voltage.

W-263 **PARAMETRIC FILTERING SURPASSES RESONATOR NOISE IN ALN CONTOUR-MODE OSCILLATORS 1269**

C. Cassella, N. Miller, J. Segovia-Fernandez, and G.Piazza
Carnegie Mellon University, USA

We developed a new method for lowering the phase noise of oscillators where the intrinsic resonator frequency fluctuations represent the dominant noise source. We called this technique ''parametric filtering''.This method has been applied to a 227 MHz aluminum nitride contour-mode MEMS resonator that shows high level of intrinsic noise which limits the oscillator phase noise. By using this new approach we have obtained an improvement of more than 20 db and 26 db respectively at 1 khz and 10 khz offset. This resulted in the lowest phase noise level ever measured for any MEMS based oscillator.

Th-264 **POLYCIDE CONTACT INTERFACE TO SUPPRESS SQUEGGING IN MICROMECHANICAL RESOSWITCHES.....1273**

Y. Lin, R. Liu, W. Li, and C.T.C. Nguyen
University of California, Berkeley, USA

The use of a Pt-silicide-based contact interface has greatly reduced impact-induced energy loss in comb-driven resonant micromechanical switches (a.k.a., resoswitches) to the point where squegging phenomena (whereby impacts do not occur on every cycle) are eliminated, so no longer constrain the clock frequency of recently demonstrated mechanical charge pumps. This opens the application range of such charge pumps to higher power converters capable of delivering currents much higher than those of previously demonstrated version, which targeted low current-draw MEMS dc-biasing applications.

M-265 **STABLE CHARGE-BIASED CAPACITIVE RESONATORS WITH ENCAPSULATED SWITCHES 1277**

E.J. Ng, K.L. Harrison, C.L. Everhart, V.A. Hong, Y. Yang, C.H. Ahn, D.B. Heinz, R.T. Howe, and T.W. Kenny
Stanford University, USA

We show that an electrically isolated silicon resonator within an epi-seal polysilicon encapsulation can retain a charge for prolonged periods of time with no noticeable leakage, even at elevated temperature. The charge is applied using a silicon contact switch that operates within the epi-seal cavity to isolate the resonator from the environment.

T-266 **STABLE PULL-IN ELECTRODES FOR NARROW GAP ACTUATION 1281**

E.J. Ng[1], Y. Yang[1], V.A. Hong[1], C.H. Ahn[1], D.L. Christensen[1], B.A. Gibson[2], K.R. Qalandar[2], K.L. Turner[2], and T.W. Kenny[1]
[1]*Stanford University, USA and*
[2]*University of California, Santa Barbara, USA*

We report on the use of pull-in electrodes for achieving narrower gaps than lithography/etch capabilities. Resonant devices with sub-ppm stability are demonstrated within the epi-seal polysilicon encapsulation process using pulled-in electrodes. The pull-in effect is reversible and can be made permanent by welding.

W-267 **ULTRA-STABLE NONLINEAR THIN-FILM PIEZOELECTRIC-ON-SUBSTRATE OSCILLATORS OPERATING AT BIFURCATION 1285**

H. Fatemi, M. Shahmohammadi, and R. Abdolvand

Oklahoma State University, USA

Presented is a ~27MHz oscillator incorporating a thin-film piezoelectric-on-silicon (TPoS) resonator with a phase noise (PN) of -139 dBc/Hz at 1kHz and -157 dBc/Hz at 1MHz from the carrier. The close-to-carrier PN is equivalent to -148 dBc/Hz when normalized to 10MHz and is the lowest reported to date for MEMS oscillators. Additionally, it is experimentally proven that the PN significantly improves when the resonator is driven at or beyond the bifurcation point in the closed-loop oscillator circuit.

Th-268 **VARIABLE CAPACITOR WITH SWITCHING MECHANISM FOR WIDE TUNING RANGE AND LOW POWER CONSUMPTION.....1289**

D. Baek, Y. Eun, D.S. Kwon, M.O. Kim, T. Chung, and J. Kim

Yonsei University, SOUTH KOREA

We developed a variable capacitor with mechanical switching mechanism and reversible mechanical latching system to enhance tuning ratio and reduce power consumption. The switching mechanism could connect four sets of capacitors arranged in parallel sequentially by controlling the displacement of a microactuator for abrupt and coarse tuning of total capacitance. Continuous and fine tuning was also achieved by gap-closing mode of comb-finger type capacitors. The resultant maximum tuning ratio was 5.71 by combining coarse and fine tuning.

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