Wednesday, December 5

Plenary Presentation I

**WPA-01** OPTIMIZING THE ENERGY BALANCE TO ACHIEVE AUTONOMOUS SELF-POWERING FOR VIGILANT HEALTH AND IoT APPLICATIONS  
*Veena Misra*, A. Bozkurt, B.H. Calhoun, S. Datta, M. Dickey, M. Kiani, J. Lach, B. Lee, J. Jur, O. Oralkan, M. Ozturk, R. Rajagopalan, S. Roundy, J. Strohmaier, S. Trolle-McKinstry, D. Vashaee, D. Wentzloff and D. Werner  

1North Carolina State University, USA, 2University of Virginia, USA, 3Notre Dame University, USA, 4Pennsylvania State University, USA, 5University of Utah, USA, and 6University of Michigan, USA

With the right combination of disruptive features, such as battery free self-powered operation, multimodal sensing capability, comfort, wearability, and continuous data gathering leading to actionable information, the potential of autonomously powered smart sensing nodes can be realized to provide long-term monitoring for health and IoT applications. This paper reports on recent breakthroughs in technologies essential for achieving self-powered operation and shows how engineering both sides of the power equation, namely generation and consumption, can lead to always on operation. This work is being conducted in the NSF funded ERC Center on Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST).

Focus Session I - Wearable Energy Harvesters

**WFA-01** FLEXIBLE TEXTILE POWER MODULE  
*S. Yong, J. Shi, and S.P. Beeby  
University of Southampton, UK*

This paper presents for the first time an energy textile that enables both biomechanical energy harvesting and simultaneously energy storing by ferroelectret and a solid-state supercapacitor fabricated into the same piece of woven cotton layer. This work shows a promising combination of devices for achieving a self sustained integrated energy module that can power up e-textile applications.
WFA-02 FABRICATION AND CHARACTERIZATION OF A WRIST-DRIVEN ROTATIONAL ENERGY HARVESTER USING MULTIPLE PLUCKED PIEZOELECTRIC UNIMORPHS
M.A. Halim¹, T. Xue¹, R. Rantz¹, Q. Zhang², L. Gu², K. Yang², and S. Roundy¹
¹University of Utah, USA and ²Analog Devices Inc., USA

We present fabrication and characterization of a wrist-worn rotational energy harvester for wearable applications. It consists of an eccentric rotor with multiple magnets and unimorph beams with a magnet at the tip of each beam, in an in-plane plucking configuration. An electromechanical model has been developed to predict the system performance for different plucking magnet configurations and verified experimentally. Experimental results are in good agreement with the simulation.

WFA-03 A FULLY-ENCLOSED WRIST-WEARABLE HYBRID NANOGENERATOR FOR SELF-POWERED SENSORS
P. Maharjan and J.Y. Park
Kwangwoon University, KOREA

Smart body-worn electronic devices and sensors are trending in wearable fitness and healthcare applications but has dependency on batteries. We designed, developed and demonstrated a fully-enclosed wrist-wearable hybrid nanogenerator for harvesting diverse human wrist motions and sustainably power those wearable electronic devices and sensors. A commercial electronic wrist-watch is successfully powered continuously for more than 23 mins for just 5 s of wrist motion.

Session W1A: FUEL CELLS AND REACTORS

W1A-01 TESTING OF A 3D-PRINTED SOLAR MICRO-REACTOR FOR HYDROGEN PRODUCTION VIA NATURAL GAS REFORMING
P. Camus, J.-F. Dufault, D. Mehanovic, N. Braidy, L.G. Fréchette, and M. Picard
Université de Sherbrooke, CANADA

We developed and tested a solar micro-reactor for hydrogen production via natural gas reforming. The 3D-printed prototype of the micro-reactor has been successfully tested and a complete methane conversion has been observed during tests in real conditions.

W1A-02 MICRO ALKALINE FUEL CELL SUPPORTED BY MEMS-BASED BACKBONE
M. Pilaski¹, S.-H. Sun², G. Dura¹, J. Wartmann¹, F. Letzkus², and A. Heinzel¹
¹Hydrogen and Fuel Cell Center, GERMANY and ²Institut für Mikroelektronik Stuttgart, GERMANY

This work presents the application of Si₃N₄-membranes produced with Si-MEMS-technology as a platform to build up new membrane-electrode assemblies (MEA) for alkaline fuel cells (AFC). Active AFC-MEAs were combined by integrating OH–-permeable electrolyte into micro-channels of MEMS-based membranes. A Pt/C catalyst was sprayed onto the surface and after an electric conductive layer was applied these systems could be used to power small devices with low energy demand.
W1A-03  THERMALLY SELF-SUSTAINING TUBULAR SOFC POWER GENERATOR WITH NO MOVING PARTS
J. Wongwiwat, P. Bhuripanyo, T.S. Welles, V.P. DeBiase, J. Ahn, and P.D. Ronney
1University of Southern California, USA and 2Syracuse University, USA

We develop a self-sustaining, self-pressurizing power generator with no moving parts using thermal transpiration membrane to pump air from the outside, catalytic combustion to generate heat and SOFC to generate electricity from hydrocarbon fuels. To improve the efficiency, we also study and do modeling of each component as well as using simulation model to optimize the design of the power generator.

W1A-04 MINIATURE FUEL CELL WITH MONOLITHICALLY FABRICATED SI ELECTRODE - FIRST PROTOTYPE WITH Au-Pd-Pt MULTILAYER CATALYST
T. Kurose, R. Shirai, N. Vasiljevic, and M. Hayase
1Tokyo University of Science, JAPAN and 2University of Bristol, UK

Our first miniature fuel cell with a novel Au-Pd-Pt catalyst successfully demonstrated power generation. Electrochemical atomic layer depositions of Pd and Pt were applied on the porous Au. 5 ML Pd and sub-ML Pt deposition was attempted and amounts of Pd and Pt were estimated to be 125 µg/cm² and 6 µg/cm², respectively. No catalyst poisoning to 100 ppm CO was observed during the power generation. Though the peak power was poor around 100 mW/cm², results were satisfying for the first prototype.

Session W1B: TUNABLE, BROADBAND, AND NONLINEAR

W1B-01 MODELING AND DESIGN OF HIGHLY COUPLED PIEZOELECTRIC ENERGY HARVESTERS FOR BROADBAND APPLICATIONS
D. Gibus, P. Gasnier, A. Morel, S. Boisseau, and A. Badel
1Université Grenoble Alpes, CEA-Leti, FRANCE and 2Université Savoie Mont Blanc, FRANCE

We model, design, and build highly coupled piezoelectric energy harvesters for frequency tuning capabilities using nonlinear electrical techniques. The geometrical parameters of a cantilever with proof mass and single crystal patches are optimized to maximize the global electromechanical coupling coefficient and increase the frequency bandwidth.

W1B-02 CO-OPTIMIZATION OF A PIEZOELECTRIC ENERGY HARVESTING SYSTEM FOR BROADBAND OPERATION
S. Zhao, U. Radhakrishna, S. Hanly, J. Ma, J.H. Lang, and D. Buss
1Tianjin University, CHINA, 2Massachusetts Institute of Technology, USA, 3Mide Technology, USA, 4Guangdong University of Technology, CHINA, and 5Texas Instruments, USA

This work presents the co-design of a piezoelectric energy harvester (PEH) and bias-flip (BF) electronics to increase the power extraction bandwidth. The PEH is designed for high electromechanical coupling resulting in the separation of the open-circuit and short-circuit resonance frequencies. The BF-circuit is switched at universal phase to approximate impedance matching over a wide bandwidth. The system achieves higher power over a wider bandwidth compared to prior work.
W1B-03  TOWARD SELF-POWERED NONLINEAR WIDEBAND VIBRATION ENERGY HARVESTING WITH HIGH-ENERGY RESPONSE STABILIZATION

S. Ushiki and A. Masuda
Kyoto Institute of Technology, JAPAN

This paper describes an effort to develop a nonlinear wideband vibration energy harvester with self-powered stabilization control of its high-energy response. The power balance of the harvester under intermittent disturbances is first experimentally studied, and a harvesting circuit that can power the negative impedance converter (NIC) in the control circuit is then developed. It is concluded that the energy consumed by the NIC can be recovered by the harvested energy in several tens of seconds.

W1B-04  SELF-TUNABLE VIBRATION ENERGY HARVESTER

J. Esch¹, D. Hoffmann¹, D. Stojakov¹, and Y. Manoli²
¹Hahn-Schickard-Gesellschaft für Angewandte Forschung e.V, GERMANY and ²University of Freiburg, GERMANY

We present a small frequency tunable vibration energy harvester with an integrated electronic circuit board. The designed board includes a microcontroller for autonomous tuning and a power management for energy storage and for powering the system components. A movable anchor is used to vary the effective length of a cantilever beam. The expected tuning bandwidth is 16 to 58 Hz.

Session W2A: THERMOELECTRIC ENERGY HARVESTERS

W2A-01  POWER ENHANCEMENT OF SILICON MEMBRANE-BASED THERMOELECTRIC ENERGY HARVESTER WITH TAILORED HOLEY NANOSTRUCTURES

R. Yanagisawa¹ and M. Nomura¹²
¹University of Tokyo, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

We develop SOI-based silicon membrane thermoelectric power generator with phononic crystal nanostructures. Phononic crystal nanostructures reduce thermal conductivity of silicon membranes and improve their thermoelectric figure of merit twice. By using nanoimprint lithography method, we pattern this phononic crystal nanostructures in 3 x 2 mm area of silicon membrane thermoelectric devices. We demonstrate power enhancement of thermoelectric generator with nanostructure patterning.

W2A-02  VERTICAL SELF-DEFINED THIN-FILM THERMOELECTRIC THERMOCOUPLES BY ANGLED CO-EVAPORATION FOR USE IN µTEGS

Y. Yuan and K. Najafi
University of Michigan, USA

We report the design, fabrication and characterization of novel thermocouple structure and associated TE films for use in micro-thermoelectric generators. The structure consists of Bi2Te3 and Sb2Te3 films co-evaporated onto sidewall surfaces of high-aspect columns. This structure allows fabrication of tall vertical thermocouples using thin films with high fill factor.
W2A-03  DESIGN AND IMPLEMENTATION OF A SOIL PROFILE PROBE POWERED BY AIR AND SOIL TEMPERATURE DIFFERENCES
N. Ikeda, R. Shigeta, J. Shiomi, and Y. Kawahara
University of Tokyo, JAPAN

We present a novel approach to the realization of a battery-free soil profile probe that uses the temperature difference between the near-surface air and underground soil as a power source. The temperature change in underground soil is slower than that in the near-surface air, and thus a large temperature difference occurs between the near-surface air and underground soil for most of the day. Hence, we developed a sensor prototype driven by a TEG and simulated this performance.

Session W2B:  POWER ELECTRONICS AND ENERGY MANAGEMENT CIRCUITS

W2B-01  A SELF-SUSTAINED ENERGY STORAGE SYSTEM WITH AN ELECTROSTATIC AUTOMATIC SWITCH AND A BUCK CONVERTER FOR TRIBOELECTRIC NANOGENERATORS
H. Zhang¹, D. Galayko², and P. Basset¹
¹Université Paris-Est, FRANCE and ²Sorbonne Universités, FRANCE

We present a complete energy harvesting system for triboelectric nanogenerators (TENGs) that includes as a first stage a half-wave rectifier, and as a second stage an electrostatic automatic switch combined with a buck converter. The output of this simple two-stage system allows to deal with the very high output voltages of TENGs and to power a commercial low-voltage output regulator, which cannot be realized by directly charging the storage capacitor only with diode rectifiers.

W2B-02  DUAL-STAGE ELECTRODE DESIGN OF ROTATIONAL ELECTRET ENERGY HARVESTER FOR EFFICIENT SELF-POWERED SSHI
Y. Liu¹, A. Badel², and Y. Suzuki¹
¹University of Tokyo, JAPAN and ²Université Savoie Mont Blanc, FRANCE

We present a dual-stage electrode design for electret-based rotational energy harvester (EH) for efficient synchronized switch harvesting on inductor (SSHI) technique. With the aid of the present parallel SSHI circuit, output power of the rotational electret EH developed in our group becomes 4.2 times higher if compared with the conventional full-bridge rectifier.

W2B-03  A SIMPLE PASSIVE 390 mV AC/DC RECTIFIER FOR ENERGY HARVESTING APPLICATIONS
A. Santiago Rodriguez, N. Garraud, D. Alabi, A. Garraud, and D.P. Arnold
University of Florida, USA

This presentation reports a simple ac/dc rectifier architecture intended for magnetic energy harvesters that offers the lowest reported passively rectified ac input voltage of 400 mVpk. This rectifier satisfies a critical technology need, since today there exist many commercial dc energy harvesting power management chips but few (none?) that can accommodate low-amplitude ac inputs.
Session W3A: ION SOURCES AND THERMOIONIC EMITTERS

W3A-01 COMPACT, 3D-PRINTED ELECTRON IMPACT ION SOURCE WITH MICROFABRICATED, NANOSHARP SI FIELD EMITTER ARRAY CATHODE
C. Yang and L.F. Velásquez-García
Massachusetts Institute of Technology, USA

We report the design, fabrication, and characterization of a novel electron impact gas ionizer for compact mass spectrometry manufactured via CMOS silicon micromachining and high-resolution 3D printing. Our ionizer utilizes an array of 2,500 nano-sharp silicon field emitters (20 µm pitch) with proximal gate as electron source, and a finely featured, three-dimensional ion-generating structure made of dielectric and conductive parts manufactured via high-resolution 3D-printing technology. The ionizer reaches up to ~0.4% ionization efficiency while operating at 5×10^{-4} Torr.

W3A-02 GLOW-DISCHARGE ION SOURCE FOR ON-CHIP INTEGRATED MINIATURE MEMS MASS SPECTROMETER
T. Grzebyk, P. Szyszka, A. Górecka-Drzazga, and J.A. Dziuban
Wrocław University of Science and Technology, POLAND

This work describes a construction, technology, working principle and properties of an ion source dedicated for a miniature MEMS mass spectrometer. The influence of such parameters as shapes, dimensions and distances between the electrodes, as well as applied magnetic and electric field and pressure level on the operation of the instrument has been investigated.

W3A-03 THERMIONIC ENERGY CONVERTER BASED ON MICRON-GAP NANOSTRUCTURED SPACERS: ACHIEVING RECORD-HIGH SHORT-CIRCUIT CURRENT
S.M. Nicaise¹, C. Lin¹, M. Azadi¹, T. Bozorg-Grayeli², P. Adebayo-Ige¹, K. Van Houten², F. Schmitt³, D.E. Lilley¹, Y. Pfitzer¹, W. Cha¹, N. Melosh², R.T. Howe², J.W. Schwede¹, and I. Bargatin¹
¹University of Pennsylvania, USA, ²Stanford University, USA, and ³Spark Thermionics, USA

Micron-gap spacers can increase the current and efficiency in thermionic energy converters by mitigating space charge effects. We designed, fabricated and characterized thin alumina spacers that provided insulating 3-8 µm gaps between planar substrates. In large-scale testing, the spacers sustained compressive stresses of over 10 atm without fracture and showed thermal conductances of 10-30 mW/(cm^2 K), suggesting a conductivity lower than aerogels.
Session W3B: MICROFABRICATED HARVESTERS

**W3B-01** PUSH-BUTTON KINETIC ENERGY HARVESTER WITH SOFT-X-RAY-CHARGED FOLDED MULTILAYER PIEZOELECTRET
J. Lu and Y. Suzuki
*University of Tokyo, JAPAN*

In this study, we propose a push-button energy harvester based on soft-X-ray charged folded multilayer piezoelectret. With an early prototype, 15.5 µJ has been obtained with the max pushing force of only 1 N at 2.7 mm max structure deformation. Its record-high quasi-static piezoelectric coefficient $d_{33}$ is 30000 pC/N. LED light-up is also demonstrated upon finger press.

**W3B-02** A SILICON MEMS EM VIBRATION ENERGY HARVESTER
Y. Yang, U. Radhakrishna, D. Ward, A.P. Chandrakasan, and J.H. Lang
*Massachusetts Institute of Technology, USA*

We model, design, and optimize MEMS electromagnetic vibration-energy harvesters comprising DRIEetched silicon suspensions, pick-and-place N42-NdBFe magnets and copper coils. The harvesters will power autonomous devices from near-50-Hz and sub-g vibrations. A four-bar linkage silicon suspension is used to bear a large stroke (2 mm), enabling record output power (2.2 mW), power density (1.23 mW/cm$^3$) and normalized power density (1.02 mW/g2cm$^3$) among Si-based MEMS harvesters reported to date.

**W3B-03** A POWER-DENSITY-ENHANCED MEMS ELECTROSTATIC ENERGY HARVESTER WITH SYMMETRIZED HIGH-ASPECT RATIO COMB ELECTRODES
H. Honma$^1$, H. Mitsuya$^2$, G. Hashiguchi$^3$, H. Fujita$^4$, and H. Toshiyoshi$^1$

$^1$*University of Tokyo, JAPAN*, $^2$Saginomiya Seisakusho, Inc., $^3$Shizuoka University, JAPAN, and $^4$Tokyo City University, JAPAN

We develop an electret-type MEMS vibrational energy-harvester with highly symmetric structures to overcome a dilemma between small footprint and large output. Power density is 4.3-fold enhanced to 270 µW/cm$^3$ after increasing the aspect ratio of the comb-electrodes from 7.1 to 33.3.
Thursday, December 6

**Plenary Presentation II**

**TPA-01** MULTIFERROIC MATERIALS, DEVICES AND SYSTEMS: 
P(VDF–TrFE) BASED SPIRAL THERMO-MAGNETO-ELECTRIC GENERATORS 
FOR HARVESTING LOW GRADE THERMAL ENERGY 
R.A. Kishore\(^1\), D. Singh\(^1\), P. Kumar\(^1\), R. Sriramdas\(^1\), M. Sanghadasa\(^2\), 
and Shashank Priya\(^3\) 
\(^1\)Virginia Polytechnic Institute and State University, USA, 
\(^2\)U.S. Aviation & Missile Research Development and Engineering Center, USA and 
\(^3\)Pennsylvania State University, USA

This study proposes a novel P(VDF–TrFE) based spiral-shaped cantilever beam for thermo-
magneto-electric generator (TMEG). Using numerical simulations, it was found that the spiral 
beam experiences higher stresses, and consequently exhibits higher voltage output, as compared 
to the rectangular cantilever beam. Experiments revealed that 2.5 mm x 2.5 mm spiral structure 
generates peak voltage of ~ 4.0 mV, when oscillation displacement is 0.5 mm and frequency is 1 
Hz. The peak voltage increases to ~25 mV at oscillation frequency of 10 Hz.

**Focus Session II - Multiferroic Devices and Systems**

**TFA-01** ELECTRIC-FIELD CONTROLLED MAGNETIC REORIENTATION IN EXCHANGED 
COUPLED COFEB/NI BILAYER MICROSTRUCTURES 
Z. Xiao\(^1\), R. Lo Conte\(^2\), M. Goiriena\(^3\), R.V. Chopdekar\(^2\), X. Li\(^1\), S. Tiwari\(^1\), C.-H. Lambert\(^2\), 
S. Salahuddin\(^1\), G.P. Carman\(^1\), K. Wang\(^1\), J. Bokor\(^2\), and R.N. Candler\(^4\) 
\(^1\)University of California, Los Angeles, USA, 
\(^2\)University of California, Berkeley, USA, 
\(^3\)University of the Basque Country, SPAIN, and 
\(^4\)California Nano Systems Institute, USA

We investigate the electric-field-controlled behavior of bilayer magnetostrictive microstructures on 
ferroelectrics. To study the coupling behavior in the system, x-ray magnetic circular dichroism-
photoemission electron microscopy and micromagnetic simulation are used to reveal the interplay 
between the two layers with opposite signs in saturation magnetostriiction. The result of this work 
paves a way to developing more sophisticated energy-efficient composite multiferroic devices.

**TFA-02** BAR-SHAPED MAGNETOELECTRIC GYRATOR 
C.M. Leung, X. Zhuang, J. Li, and D. Viehland 
Virginia Polytechnic Institute and State University, USA

A dual-resonance bar-shaped magnetoelectric (ME) gyrator has been developed based on 
Terfenol-D and PZT bars. It features a dual-resonance power transfer and a dual I-V conversion 
effect. In addition, this gyrator provides several advantages such as dual resonance frequency 
along the length direction, as well as half-wave and full-wave vibration mode; reduced laminate 
bonding avoiding adhesive breakdown, and ease of fabrication.
TFA-03 WIDE-BAND MULTIFERROIC QUARTZ MEMS ANTENNAE
R.L. Kubena¹, X. Pang², K.G. Lee¹, Y.K. Yong¹, and W.S. Wall¹
¹HRL Laboratories, LLC., USA and ²Rutgers University, USA

MEMS-based multiferroic antennae are currently being studied for high sensitivity, extreme sub-wavelength RF receivers. The sensitivity of high-Q resonant-mode piezoelectric RF sensors can approach values typical of much larger dipole antennae (e.g., << 1 pT√Hz), but with very limited bandwidth. In this paper, we propose to use UHF quartz MEMS oscillators within a high frequency phase lock loop to provide wide BW operation at HF bands and with sensitivities approaching 5 pT√Hz.

Session T4A: BIOCHEMICAL AND BIO-INSPIRED POWER/ENERGY SYSTEMS

T4A-01 SUPERCAPACITIVE MICRO-BIO-PHOTOVOLTAICS
L. Liu, M. Mohammadiar, and S. Choi
State University of New York-Binghamton, USA

We develop innovative supercapacitive micro-bio-photovoltaic systems (or micro-BPVs) with maximized bacterial photoelectrochemical activities in a well-controlled, tightly enclosed micro-chamber. The technique is based on a 3-D double-functional bio-anode concurrently exhibiting bio-electrocatalytic and charge-storage features so that it offers the high-energy harvesting function of BPVs and the high-power operation of an internal supercapacitor for charging and discharging.

T4A-02 A COMPLETE TATTOO-BASED WIRELESS BIOFUEL CELL USING LACTATE DIRECTLY FROM SWEAT AS FUEL
R.A. Escalona-Villalpando¹, E. Ortiz-Ortega¹, J.P. Bocanegra-Ugalde², S.D. Minteer³, L.G. Arriaga¹, and J. Ledesma-García²
¹Centro de Investigación y Desarrollo Tecnológico, MEXICO, ²Universidad Autónomous de Querétaro, MEXICO, and ³University of Utah, USA

A tattoo-type enzymatic biofuel cell (p-EBFC) was developed using bilirubin oxidase- and lactate oxidase-based electrodes as biocathode and bioanode, respectively, these was immobilized on flexible Toray carbon paper. The wireless p-EBFC on the skin monitor via a cell phone delivered an open circuit voltage of 0.56 ± 0.02 V and a current and power of 93 ± 4 µA and 14 ± 2 µW, respectively. Also, the BFC maintains its performance for 30 minutes in a sweat delivery from the arm during workouts.

T4A-03 VIRUS-ASSEMBLED TECHNOLOGY FOR NEXT GENERATION BIOENERGY HARVESTING DEVICES
S. Chu, A.D. Brown, J.N. Culver, and R. Ghodssi
University of Maryland, USA

We report Tobacco mosaic virus (TMV)-templated glucose oxidase (GOx) electrodes for the development of advanced enzymatic-biofuel-cells (EBCs). Leveraging the robust and high density self-assembly of TMV1cys on Au surface, enhanced enzymatic reaction density is achieved resulting in a higher electrochemical current response, compared to previous work using a similar strategy, and a promising EBC performance characteristics in combination with Pt cathodes.
T4A-04 A NOVEL FLEXIBLE CONDUCTIVE SPONGE-LIKE ELECTRODE CAPABLE OF GENERATING ELECTRICAL ENERGY FROM THE DIRECT OXIDATION OF AQUEOUS GLUCOSE

D. Desmaële¹, F. La Malfa², F. Rizzi¹, A. Qualtieri¹, M. Di Lorenzo³, and M. De Vittorio¹,²
¹IIT-CBN, ITALY, ²Universita del Salento, ITALY, and ³University of Bath, UK

This paper presents a new sponge-like electrode (SLE) material structured with porous gold (PG). The fabrication process is simple and no specific equipment is required: the use of liquid metal particles enables the direct growth of PG into the pores of a flexible conductive support matrix. With a SLE sample 13 mm long, 6 mm wide and 1.5 mm thick immersed in a 10 mM glucose solution, we demonstrate that a power density of 2.4 mW/cm³ at 0.5V can be reached without using any enzymes.

Session T4B: ELECTRET MATERIALS AND HARVESTERS

T4B-01 DEVELOPMENT OF A HIGH-PERFORMANCE AMORPHOUS FLUORINATED POLYMER ELECTRET BASED ON QUANTUM CHEMICAL ANALYSIS

S. Kim, K. Suzuki, and Y. Suzuki
University of Tokyo, JAPAN

In the present study, for the first time, we propose a new high-performance amorphous fluorinated polymer electret based on quantum chemical analysis. We found that the specific chemical bonds connected to the end group of CYTOP attract electron and lead CYTOP to have high electron affinity. A new material based on this concept has been developed, and extremely-high thermal stability of charges and higher surface charge density than CYTOP EGG, the best fluorinated polymer electret, have been obtained.

T4B-02 DEMONSTRATION OF AN ELECTRET GENERATOR FOR ENERGY HARVESTING WITHOUT ANY CHARGING PROCESS: UTILIZATION OF SPONTANEOUS ORIENTATION OF POLAR MOLECULES

Y. Tanaka¹,², N. Matsuura¹, and H. Ishii¹
¹Chiba University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

In order to improve productivity of electret generators (EGs) for energy harvesting, simplification of fabrication process of the electret is highly desired. In this study, we found that a giant surface potential of 46.5 V at 739 nm appeared in TPBI vacuum evaporated film due to spontaneous orientation polarization of the molecule. By utilizing this film as electret, we developed a novel EG without the need for any charging process.

T4B-03 STOCHASTIC MODELING OF HUMAN ARM SWING TOWARD STANDARD TESTING FOR ROTATIONAL ENERGY HARVESTER

Y. Tanaka, T. Miyoshi, and Y. Suzuki
University of Tokyo, JAPAN

We propose a stochastic model of arm swing for rotational energy harvester (EH) during human walking. Using the mean value and standard deviation of arm swing motion, the effect of nonlinear characteristics of the rotational EH are properly taken into account for estimating mean output power during human walking. A multi-axis robot is also introduced to mimic the arm motion precisely.
In this paper, we propose an e-VEH with the out-of-the-plane gap closing scheme, which could release the energy to recharge the electret surface. A few corona needles are embedded in the device. If the surface potential of the electret decays after the device has been working for a long time, we can use the corona charging setup to recharge the device directly. Also, we have developed a portable corona charging system which can be powered by our e-VEH directly.

Session T5A: BATTERY TECHNOLOGIES

T5A-01 A LONG-LASTING MICROLITER-SCALE MICROBIAL BIOBATTERY USING SOLID-STATE IONICS
M. Mohammadifar and S. Choi
State University of New York-Binghamton, USA

We report a microliter-scale bacteria-powered biobattery providing a long-term operational capability for potentially powering unattended wireless sensor networks. In a 20µL-chamber, the biobattery contains a horizontally arranged anode/salt-bridge/cathode configuration with solid-state agar electrolytes. A slow release of bacterial nutrients from a synthetic solid anolyte enables a continuous current generation over 8 days while a liquid-based anolyte is completely depleted within 4 hours.

T5A-02 DESIGN, MICROFABRICATION AND CHARACTERIZATION OF FREE FORM FACTOR, LIGHTWEIGHT THIN FILM BATTERY FOR POWERING BIOINSPIRED NANO-DRONES BASED ON MEMS ACTUATION
S. Oukassi\(^1\), S. Poncet\(^1\), J.R. Frutos\(^2\), and R. Salot\(^1\)
\(^1\)University Grenoble Alpes, FRANCE and \(^2\)Silmach SA, FRANCE

This paper presents the realization and characterization of biomimetic shaped thin film batteries with power and energy densities among the highest values reported in the literature for such miniaturized energy devices, which will contribute to bring new solutions for powering MEMS actuation-based micro/nanorobotics.

T5A-03 DEVELOPMENT OF ALL-SOLID-STATE THIN-FILM SECONDARY BATTERY FOR MEMS AND IOT DEVICE
A. Suzuki, S. Sasaki, and T. Jimbo
ULVAC, Inc., JAPAN

All-solid-state thin-film batteries (TFB) have come to be recognized as one of the key enabling technologies for stand-alone MEMS/sensor devices which are indispensable for internet-of-things (IoT) solution. We have developed reliable hardware and processes for the mass-production using vacuum technology. Our manufacturing process, battery performance and recent development will be introduced.
Session T5B: PYROELECTRIC ENERGY HARVESTERS

T5B-01 HYBRIDIZED THERMAL ENERGY HARVesting MECHANISM

M. Kang and E.M. Yeatman
Imperial College London, UK

We present a hybridized thermal energy harvesting mechanism using bimetallic and PZT beams for use adjacent to a heat source with modest temperature variation at low frequency (below 0.1 Hz). To improve the output power, the coupling effect is investigated between the piezo- and pyro-electric effects. A theoretical model has been established and experimentally verified.

T5B-02 A PYROELECTRIC THIN FILM OF ORIENTED TRIGLYCINE SULFATE NANO-CRYSTALS FOR THERMAL ENERGY HARVESTING

R. Ghane-Motlagh and P. Woias
University of Freiburg, GERMANY

Inspired by nature we develop highly efficient technological microsystems which can produce their own energy and work with sophisticated materials and concepts for sensors and actuators.

T5B-03 PIEZOELECTRIC AND PYROELECTRIC ENERGY HARVESTING FROM LITHIUM NIOBATE FILMS

G. Clementi, S. Margueron, M.A. Suarez, T. Baron, B. Dulmet, and A. Bartasyte
Université de Bourgogne Franche-Comté, FRANCE

In this paper we present the first implementation of lead-free Lithium Niobate as piezoelectric transducer for energy harvesting applications. The fabrication process of cantilever beams and square chips is explained. The two different types of samples have been characterized with different techniques in order to investigate vibrational harvesting and pyroelectric effect. The first tests show promising results for the application of Lithium Niobate in hybrid energy harvesting field.

Session T6A: WIRELESS POWER TRANSFER TECHNOLOGIES

T6A-01 FLEXIBLE SCREEN-PRINTED COILS FOR WIRELESS POWER TRANSFER USING LOW-FREQUENCY MAGNETIC FIELDS

K. Sondhi, N. Garraud, D. Alabi, D.P. Arnold, A. Garraud, Z.H. Fan, and T. Nishida
University of Florida, USA

We report the fabrication and the testing of a 3D flexible screen-printed transmitter antenna geometry that can be used for low-frequency magnetic field applications, such as electrodynamic wireless power transmission (EWPT) at <100 Hz. We demonstrate the capability of flexing the coils to a high bending radii. These characteristics of such a 3D flexible transmitter coil are necessary to develop a technical roadmap for incorporation into flexible products.
T6A-02  EXPERIMENTAL STUDY OF THE EFFECT OF DEPTH, ORIENTATION, AND ALIGNMENT FOR A MEMS DIAPHRAGM RECEIVER IN ACOUSTIC POWER TRANSFER SYSTEMS
H. Basaeri, Y. Yu, D. Young, and S. Roundy
University of Utah, USA

We present a pMUT (Piezoelectric Micromachined Ultrasonic Transducer) receiver suitable for wirelessly powering implantable medical devices (IMDs). In an acoustic power transfer system, the power that the receiver generates can be a function of its position (depth, orientation, and alignment relative to the transmitter). We numerically and experimentally study the sensitivity of the generated power of a pMUT to any change in its location, which is not well studied in the literature.

Session T6B:  PUMPS AND HEAT ENGINES

T6B-01  LOW-COST, MONOLITHICALLY 3D-PRINTED, MINIATURE HIGH-FLOW RATE LIQUID PUMP
A.P. Taylor1 and L.F. Velásquez–García2
1Edwards Vacuum LLC, USA and 2Massachusetts Institute of Technology, USA

We report the design, fabrication, and characterization of monolithically 3D-printed, high-flow rate miniature liquid pumps. Our leak-tight, miniature pumps are microfabricated using 150 to 300 µm layers in Nylon 12 via fused filament fabrication with a multi-step printing process. Each pump has a rigid frame, a 21 mm-diameter, 150 µm-thick membrane connected at its center to a piston with an embedded magnet, a chamber, passive ball valves, and two barbed connectors. Pump maximum water flow rate is 1.37 ml/min @ 15.1 Hz –comparable to literature but at 200X slower actuation frequency.

T6B-02  MISTIC - MICRO STIRLING HEAT ENGINES FOR THERMAL ENERGY HARVESTING
T. Avetissian1, É. Léveillé1, M.-A. Hachey1, F. Formosa2, and L.G. Fréchette1
1Université de Sherbrooke, CANADA and 2Université Savoie Mont Blanc, FRANCE

We develop and fabricate a new concept of micro-engine, which works with a Stirling cycle. Named the MISTIC, its purpose is heat energy harvesting for temperatures less than 200° C. We designed and fabricated an external electromagnetic actuator in order to help the MISTIC during his start-up phase. The actuator could also be converted to a harvesting system during the micro-engine operation.
Friday, December 7

Plenary Presentation III

FPA-01 ZERO AND NEAR ZERO POWER INTELLIGENT MICROSYSTEMS
Roy (Troy) H. Olsson, III, C. Gordon, and R. Bogoslovov

The Near Zero Power RF and Sensor Operations (N-ZERO) program from DARPA has created a new, nanowatt class of intelligent sensors and RF receivers enabling systems that are passive or nearly passive while operating in an intelligent standby mode. Such systems can be persistently powered by small batteries for many years or perpetually via miniature energy harvesters. The program sought wake-up receivers with a sensitivity of -100dBm and physical sensors that could classify vehicles at a range of 10 m, with power consumption on order of the self-discharge rate of a small battery. Furthermore, researchers with designs that fit other applications, such as chemical and IR sensors, were open to participate as well. From the program multiple approaches have emerged featuring passive and active MEMS devices and subthreshold CMOS circuits. The overall goals of the program have helped to redefine the state-of-the-art in ultra-low power receivers, machine learning processors, and passive physical sensors.

Focus Session III – Zero-Power Devices and Systems

FFA-01 AN AUTONOMOUS INTERFACE CIRCUIT BASED ON SELF-INVESTING SYNCHRONOUS ENERGY EXTRACTION FOR LOW POWER PIEZOELECTRIC ENERGY HARVESTERS
B. Çiftci, S. Chamanian, H. Uluşan, and H. Külah

This work presents a self-powered interface circuit fabricated in 180nm standard CMOS technology to improve, rectify, and manage AC output of the piezoelectric energy harvesters (PEH) by utilizing Self-Investing Synchronous Electric Charge Extraction technique. It invests charges from the battery to PEH to improve the electromechanical coupling factor and consequently the energy extraction by utilizing only one external component.

FFA-02 ENERGY HARVESTING PIEZOELECTRIC WIND SPEED SENSOR
M. Shi, E.M. Yeatman, and A.S. Holmes

In this paper, we demonstrate a miniature wind speed sensor consisting of a triangle-shaped bluff body and a cantilever incorporating a commercial PVDF film. The bluff body causes regular vibration of the cantilever based on galloping, and the PVDF film converts vibration energy into electrical energy. Because the vibration frequency is linearly dependent on the wind speed, the vibration frequency is used to detect the wind speed directly with a high accuracy.
FFA-03 EVENT DRIVEN TIME-LOGGING SYSTEM BASED ON CONTINUOUS OPERATION OF REAL TIME CLOCK TOWARDS PERPETUAL ELECTRONICS
S. Yamada and H. Toshiyoshi
University of Tokyo, JAPAN

Real time clock or RTC is an inevitable component in the IoT (Internet-of-Things) wireless sensor nodes because the collected digital data need to be correlated with the time stamp information for the subsequent big data analysis. In this paper, we report on a circuit architecture to imprint the time stamp of an RTC into the memory by using a vibrational energy harvester as an event driven switch.

Session F7 - LATE NEWS AND EMERGING TOPICS

F7A-01 SYNCHRONOUS CIRCUITS WITH SELF-ADAPTIVE MECHANICAL SWITCHES OF VISCOSOUS MATERIAL: A PARAMETER STUDY
Z. Yuan, W. Liu, W. Tian, Y. Huang, and Z. Zhao
Southwest Jiaotong University, CHINA

Dedicated switching units are generally needed in synchronous extraction circuits with additional power consumption. This paper presents a novel self-adaptive mechanical switch using viscous materials. Due to slow restoring time, this switch can trace displacement peaks and perform switching operations synchronously with higher performance, less electronic components and lower voltage threshold. A parameter study shows the power increases with the relaxation constant in the harmonic case and an optimal relaxation constant exists for bandlimited noise excitations.

F7A-02 WEARABLE TRIBOELECTRIC GENERATOR BASED ON A HYBRID MIX OF CARBON NANOTUBE AND POLYMER LAYERS
M. Su, J. Brugger, and B.J. Kim
1University of Tokyo, JAPAN and 2École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND

This paper reports the design and fabrication of a novel triboelectric generator (TEG) based on hybrid layers of carbon nanotube and silk. The mixing of two materials in liquid phase for proven effective power generation is shown, which differs from previous studies using electrodes and friction materials that are independent, and then combined in a coating manner. The proposed TEG shows great potential in simplifying TEGs’ structure and manufacturing process.

F7A-03 A PD/AL2O3-BASED MICRO-REFORMER UNIT FULLY INTEGRATED IN SILICON TECHNOLOGY FOR H-RICH GAS PRODUCTION
M. Bianchini, N. Alayo, L. Soler, M. Salleras, L. Fonseca, J. Llorca, and A. Tarancon
1Catalonia Institute for Energy Research (IREC), SPAIN, 2IMB-CNMT (CSIC), SPAIN, 3Universitat Politècnica de Catalunya, SPAIN, and 4ICREA, SPAIN

We report the design, manufacturing and characterization of a micro-reformer unit for on-board hydrogen generation for portable-solid oxide fuel cells (µ-SOFCs). The reformer has been designed as a silicon micro monolithic substrate compatible with the mainstream microelectronics fabrication technologies. The selected fuel is dimethyl ether (DME) and the chosen catalyst consists of Pd nanoparticles deposited on an alumina active support deposited by ALD into vertical micro-channels.
F7A-04 MAGNETIC PENDULUM ARRAYS FOR EFFICIENT WIRELESS POWER TRANSMISSION
S.P. Mysore Nagaraja¹, R.U. Tok¹, R. Zhu², S. Bland³, A. Propst³, and Y.E. Wang¹
¹University of California, Los Angeles, USA, ²Axend Inc, USA, and ³Nextgen Aeronautics, USA

We propose an innovative electromechanical transmitter called Magnetic Pendulum Array, for efficient wireless power transmission at Ultra Low Frequencies (ULF). A proof of concept demonstration of the system at 447 Hz is presented. The theory and experimental results demonstrate that such a system can achieve high quality factors and can be easily scaled to the ULF range of frequencies.
Poster Presentations A

**Energy-Autonomous Wireless Sensors for IoT**

**PW-01a**  ROBUST SELF-POWERED WIRELESS PLANT-MONITORING SENSOR SYSTEM WITH SAP-ACTIVATED BATTERY  
S. Okamoto¹, R. Furumori¹, A. Tanaka¹, F. Utsunomiya², and T. Douseki¹  
¹Ritsumeikan University, JAPAN and ²ABLIC Inc., JAPAN

A sap-activated battery to extend the operating margin of a self-powered wireless plant-monitoring sensor is proposed. The battery is composed of a galvanized iron nail inserted into the stem of a plant and multiple stainless-steel rods planted in the soil make operation possible without damage to the plant. The effectiveness of the battery was evaluated using our sensor system for a tomato grown in a commercial greenhouse.

**Zero-Power Devices and Systems**

**PW-02a**  A MECHANICALLY TUNABLE GHZ PASSIVE VOLTAGE ELEMENT USING MICROSTRIP RESONATOR  
D. Ni, A. Ravi, K.B. VinayaKumar, and A. Lal  
Cornell University, USA

The ability to detect RF signals at low power can be used to turn on sensor nodes only when needed to sense or transmit data, reducing the sensor node power consumption. In such a system, passive gain elements and filters are required to increase detectable RF voltage while rejecting out-of-band signals. Here, we developed a GHz passive voltage amplifier, using a mechanically tunable strip-line resonator, achieving gains over 19dB with load capacitances of 0.8-2.4pF.

**Biochemical and Bio-Inspired Power/Energy Systems**

**PW-03b**  A DIATOM INSPIRED NEAR INFRARED METAMATERIAL ABSORBER WITH HIERARCHICAL NANODISK ARRAYS  
J. Li¹, X. Zhao², S. Anderson², and X. Zhang¹  
¹Boston University, USA and ²Boston University Medical Center, USA

Electromagnetic metamaterial absorbers use subwavelength resonators to achieve engineered absorptions. Inspired by diatoms, a photosynthetic micro algae that live in water systems, we fabricated and analyzed a hierarchical nano-resonator array based near infrared (IR) metamaterial absorber. With simulation and experimental results, the absorber demonstrated strong absorption in the near IR range. The proposed structures have the potential to be used in IR sensor and thermal emitter applications.
PW-04b ANODE BASED ON ALCOHOL DEHYDROGENASE ENZYME AND TITANIUM DIOXIDE NANOTUBES FOR PHOTOCATALYTIC MICROFLUIDIC DEVICE
J. Galindo-de-la-Rosa¹, G. González-Solano², J.A. Díaz-Real³, J. Ledesma-García², and L.G. Arriaga¹
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO, ²Universidad Autónoma de Querétaro, MEXICO, and ³University of British Columbia, CANADA

In this work we carried out the immobilization of the alcohol dehydrogenase enzyme on titanium dioxide nanotubes for the development of bioanodes for ethanol oxidation in a microfluidic fuel cell. The evaluation of the bioanodes was accomplished in a microfluidic fuel cell using different concentrations of ethanol in the presence or absence of ultraviolet light increasing the power of the fuel cell, achieving promising results for photocatalytic devices.

PW-05b IMMOBILIZATION OF GLUCOSE OXIDASE ENZYME ON NIAL-LDHS FOR APPLICATION IN MICROFLUIDIC FUEL CELL AND SEROTONIN DETECTION
J. Galindo-de-la-Rosa¹, M.G. Araiza-Ramírez², A. Hernández-Torres³, J. Ledesma-García², and L.G. Arriaga¹
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO and ²Universidad Autónoma de Querétaro, MEXICO

In this work NiAl-Layered double hydroxides (NiAl-LDHs) were used as support for the immobilization of glucose oxidase enzyme for the development of an electrode for application in a microfluidic fuel cell and sensing of serotonin. The electrode was used for the detection of serotonin and evaluated in the microfluidic cell using different concentrations of glucose in solution buffered phosphate and 0.3M of KOH saturated with O² as oxidant resulting in a maximum power density of 1.35mWcm⁻².

C – DIRECT THERMAL ENERGY-HARVESTING
Thermoelectric Energy-Harvesting

PW-06c DEVELOPMENT OF THERMOELECTRIC THIN FILMS AND CHARACTERIZATION METHODS
T. Mori¹², T. Aizawa¹, S. Mitani¹³, N. Tsujii¹, I. Ohkubo¹, T. Tynell¹, Y. Kakefuda¹, T. Baba¹, M. Mitome¹, N. Kawamoto¹, and D. Golberg¹
¹National Institute for Materials Science (NIMS), JAPAN and ²University of Tsukuba, JAPAN

This work reports on the fabrication of thin films of inorganic thermoelectric materials like borides, germanides, manganese compounds, and characterization of their thermoelectric properties. We have utilized a unique high temperature molecular beam epitaxy (MBE) apparatus to grow hexaboride thin films. Magnetic manganese compound thin films were also grown, also using sputtering, since we are interested in the possibilities of utilizing magnetism to develop thermoelectric materials.
PW-07c  METAL-METAL THERMOELECTRIC HARVESTER  
E. Köhler and P. Enoksson  
Chalmers University of Technology, SWEDEN

Thermoelectric couples are generally short, to reach high power output. With metal couples the Seebeck coefficients are substantially lower and maintaining the temperature gradient is difficult because of the high thermal conductivity. However, in applications where heat and cooling are abundant a metal-metal thermoelectric harvester could be beneficial, due to its simplicity. A 3-couple proof-of-concept harvester was assembled from Mo and Ni and gave 450 µW with a temperature gradient of 172°C.

PW-08c  PRINTED THERMOELECTRIC DEVICE  
K. Miyazaki, K. Kuriyama, and T. Yabuki  
Kyushu Institute of Technology, JAPAN

We have developed a printable thermoelectric material of a composite with Bismuth telluride and conductive polymer. High thermoelectric property is relatively high due to the low thermal conductivity. The measured thermal conductivity is much lower than the effective thermal conductivity calculated by a conventional model. We discuss the measured thermal conductivity from the view point of interfacial thermal resistance between organic and inorganic materials.

Other Energy-Harvesting

PW-09c  ELECTRICAL MODELING AND CHARACTERIZATION OF A THERMO-MAGNETICALLY ACTIVATED PIEZOELECTRIC GENERATOR (TMAG)  
A. Rendon-Hernandez¹, M. Ferrari², S. Basrour¹, and V. Ferrari²  
Université Grenoble Alpes, FRANCE and ²University of Brescia, ITALY

We develop, model and characterize a thermo-magnetically activated piezoelectric generator which is able to use small and slow temperature variations to generate mechanical movement of a piezoelectric transducer, this mechanical energy is then converted into electricity. The model presented here is implemented through LTspice.

d - ELECTRICAL ENERGY HARVESTING, MANAGEMENT, STORAGE AND TRANSFER  
Batteries, Super-Capacitors, and Chemical Energy Storage

PW-10d  OPTIMIZATION OF CARBON ELECTRODES FOR SOLID-STATE E-TEXTILE SUPERCAPACITORS  
N. Hillier, S. Yong, and S. Beeby  
University of Southampton, UK

Flexible supercapacitors (FSCs) offer a solution to powering electronic textiles, with high power densities, long cycle-life and fast charge/discharge rates. This paper presents the optimisation of porous carbon electrodes for FSCs through investigation of differing activated carbons, carbon loading and ratios of activated carbon to Carbon Black. Low cost materials and a scalable production methodology have been chosen to enable a transition from laboratory prototype to a real-world device.
**Power Electronics and Energy Management Circuits**

**PW-11d**  
**A TUNABLE HYBRID SSHI STRATEGY FOR PIEZOELECTRIC ENERGY HARVESTING WITH ENHANCED OFF-RESONANCE PERFORMANCES**  
A. Morel\(^1\), G. Pillonnet\(^1\), and A. Badel\(^2\)  
\(^1\)University Grenoble Alpes, FRANCE and \(^2\)Université Savoie Mont Blanc, FRANCE

We propose an electrical strategy that greatly enhances the off-resonance scavenged power of highly coupled piezoelectric harvesters. This tunable strategy is based on a hybrid Synchronized Switch Harvesting on Inductor (hybrid SSHI) concept, combining features of the series SSHI and the parallel SSHI. We present a thorough model of this strategy and analyze its performances in enlarging the harvesting bandwidth of highly coupled harvesters.

**PW-12d**  
**AN UP-CONVERSION MANAGEMENT CIRCUIT FOR ELECTRICAL FIELD ENERGY HARVESTER**  
Y.M. Wen, P. Li, T. Han, and X.J. Ji  
Shanghai Jiao Tong University, CHINA

This paper presents a high-efficiency management circuit using a maximum power point tracking (MPPT) matching circuit for power-line electrical energy harvesting. In order to achieve maximum output power during whole charging process, an up-conversion MPPT matching circuit is developed. Higher charging power, and larger ultimate charging voltage in a power-line voltage of 4000V can be obtained by using the MPPT up-conversion matching circuit.

**PW-13d**  
**POWER MANAGEMENT WITH DYNAMIC POWER ADAPTION FOR A ROTATIONAL ENERGY HARVESTER IN A MARITIME GEARBOX**  
J. Esch\(^1\), D. Schillinger\(^1\), D. Stojakov\(^1\), D. Hoffmann\(^1\), and Y. Manoli\(^2\)  
\(^1\)Hahn-Schickard-Gesellschaft für Angewandte Forschung e.V., GERMANY and \(^2\)University of Freiburg, GERMANY

We develop an energy harvesting system for rotational motion with a new power management concept to generate energy for a wireless condition monitoring system. The challenge is to generate enough energy with a high efficiency factor at the minimum revolution speed but also to avoid problems with energy excess and high voltages at the maximum revolution speed. The power management concept avoids the generation of excess energy that would lead to increased temperature.

**RF, Inductive and Acoustic Power Transfer**

**PW-14d**  
**EXPERIMENTS ON A WIRELESS POWER TRANSFER SYSTEM FOR WEARABLE DEVICE WITH SOL-GEL THIN-FILM PZT**  
B.D. Truong\(^1\), D. Wang\(^2\), T. Xue\(^1\), S. Trolier-McKinstry\(^2\), and S. Roundy\(^1\)  
\(^1\)University of Utah, USA and \(^2\)Pennsylvania State University, USA

This paper presents experiments on a low-frequency wireless power transfer system (WPTS) using a piezoelectric transducer with magnet tip mass as a receiver. This method allows much higher external magnetic flux densities that can be applied to humans due to safety standards. This motivates us to investigate the performance of a WPTS based on PZT thin-film beam fabricated by sol-gel processing, with the aim to miniaturize the system for wearable devices.
PW-15d  REDUCING HUMAN BODY HEATING AND TEMPERATURE RISES DUE TO INDUCTIVELY-POWERED IMPLANTABLE MEDICAL DEVICES
C.H. Kwan, D.C. Yates, and P.D. Mitcheson
Imperial College London, UK

Maximizing link efficiency is normally the design aim of inductive power transfer (IPT) systems in air. However, if a receiver coil is implanted in a patient, more suitable objectives are required to meet safety standards and regulations (e.g. ICNIRP and EN 45502-1). This paper investigates methods of reducing heating and temperature rises in human tissue due to an IPT system for medical implants and presents experimental results conducted in salt water to validate the theory and simulations.

PW-16e  MINIATURE, 3D-PRINTED, MONOLITHIC ARRAYS OF CORONA IONIZERS
Z. Sun and L.F. Velásquez-García
Massachusetts Institute of Technology, USA

We report the design, fabrication, and characterization of the first 3D-printed, monolithic corona ionizer arrays in the literature. The devices are binder inkjet-printed in stainless steel 316L and have 5, 9, or 32 emitters (emitter pitch equal to 6 mm, 4 mm, or 2 mm, respectively); each emitter is 5 mm tall, with 1.7 mm diameter at the base and 300 µm diameter at the tip. Finite element simulations predict inter-tip field shadowing and a corona region ~400 µm thick. Current-voltage data in air in the negative polarity (tips negative, collector grounded) follow Townsend current-voltage law.

PW-17f  GENERATION OF ASYMMETRIC INCOMMENSURABLE TORQUE SIGNALS
L. Kurmann¹ and J.L. Duarte²
¹University of Freiburg, GERMANY and
²Eindhoven University of Technology, THE NETHERLANDS

We develop, model and optimize kinetic energy harvester systems and focus in this research on permanent magnet (PM) 2D/3D spring systems. The mayor findings are (1) the confirmation that asymmetric incommensurable torque signals are feasible (2) using non-conservative rotor PM-field trajectories and (3) that magnetic fields can do work if a 2D/3D charge-ring/cylinder (with geometrical extension) is considered. These claims are in full agreement with the classical Electromagnetic Theory.
PW-18g HIGH-RATE ETCHING OF SINGLE ORIENTED ALN FILMS BY CHLORINE-BASED INDUCTIVE COUPLED PLASMA FOR VIBRATIONAL ENERGY HARVESTERS
H.H. Nguyen, L.V. Minh, and H. Kuwano
Tohoku University, JAPAN

Here we report our development of a high-rate etching process of (0002)-oriented AlN films for the fabrication of vibrational energy harvesters by using Cl₂-based ICP and Ni thin film as a hard mask. We have achieved etching-rate of 723 nm/min, the highest value developed for single-oriented AlN films. In this paper, etching selectivity was optimized at 11. XPS measurements offered a look inside the etching processes and revealed the etching mechanism of AlN by chlorine for the first time.

PW-19g USING GALISTAN TO FABRICATE POROUS GOLD ELECTRODES: TOWARD NON-ENZYMATIC GLUCOSE FUEL CELLS WITH ENHANCED PERFORMANCE FOR DRIVING WEARABLE/BIOELECTRONIC DEVICES
D. Desmaële¹, F. La Malfa¹², F. Rizzi¹, A. Qualtieri¹, M. Di Lorenzo², and M. De Vittorio¹²
¹Istituto Italiano de Tecnologies (IIT), ITALY, ²Università del Salento, ITALY, and ³University of Bath, UK

We present a new facile route for the fabrication of enzyme-free porous gold electrodes (PGEs) which can directly convert the chemical energy of glucose into electricity. The method is low-cost and does not require any special equipment: porous gold is simply grown on carbon paper containing liquid metal particles. The process is also versatile and scalable: PGEs of various sizes/shapes can be straightforwardly fabricated in order to meet the power budget of wearables/implantables.

PW-20g GRAPHENE-POREUS SEMICONDUCTOR NANOCOMPOSITES SCALABLE SYNTHESIS FOR ENERGY APPLICATIONS
A. Dupuy, S. Sauze, M. Jellite, R. Arvinte, R. Arés, and A. Boucherif
Université de Sherbrooke, CANADA

The aim of this work is to develop a cost effective and scalable synthesis process of producing graphene-based composite nanomaterials, called graphene-coated porous semiconductor nanocomposite (GCPS-nC). The idea is to harness and combine the remarkable properties of graphene and porous semiconductors namely silicon (Si) and germanium (Ge) to create systems with entirely new and unexplored characteristics, and to tune these properties for use in real-world applications.
PW-21g HYDROGEN EVOLUTION CATALYTIC PERFORMANCE OF METAL DOPED MOS₂
X. Leng¹, Y. Wang¹, and F. Wang¹²
¹Southern University of Science and Technology, CHINA and
²Chinese Academy of Sciences, CHINA

This paper reports the synthesis of metal element doped Molybdenum disulfide (MoS₂) and their application in hydrogen evolution reaction (HER). MoS₂ has been demonstrated as an efficient HER catalyst at lower price than noble metal. The phase control and defect rich structure of MoS₂ has recently attracted a lot of researchers' interest. In this work, we have introduced Co, Cu, Ni, Fe into MoS₂ and study the influence of these element on the HER activity.

PW-22h A CM-SCALE, LOW WIND VELOCITY AND 250°C-COMPLIANT AIRFLOW-DRIVEN HARVESTER FOR AERONAUTIC APPLICATIONS
P. Gasnier, J. Willemin, S. Boisseau, B. Goubault De Brugière, G. Pillonnet, B. Gomez, and I. Neyret
University Grenoble Alpes, CEA-Leti, FRANCE

This paper reports the design, fabrication, and testing of a centimeter-scale (Ø=35mm), 250°C-compliant microturbine for aeronautic applications. Dedicated to low air flows ≈3 m/s), this device is the first flow-driven harvester withstanding such high temperatures and high vibration levels (10⁷ cycles at 20G). The harvester has been designed to supply a wireless sensor system interfacing with aeronautic-grade transducers.

PW-23h A MAGNETICALLY-SPRUNGED NONLINEAR RESONATOR FOR WIDEBAND VIBRATION ENERGY HARVESTING CONSISTING OF MAGNETIC COMPOSITE AND RING MAGNETS
Y. Miyata, A. Masuda, F. Zhao, and S. Ushiki
Kyoto Institute of Technology, JAPAN

This paper presents a novel design of a magnetically-sprung mechanical resonator for wideband vibration energy harvesting. In this design, a magnet composite consisting of two cylindrical magnets composed in a repelling arrangement is used as a moving mass, which is magnetically suspended between two ring magnets. This configuration yields more significant variation of stiffness in a shorter stroke compared with the previous design, resulting in wider operation band even under small excitation.
PW-24h  INDUSTRY 4.0-TYPE WIRELESS SENSOR APPLICATION POWERED BY A SEMI-AUTOMATICALLY DESIGNED MINI-SCALE ELECTROMAGNETIC ENERGY HARVESTER  
B. Leistritz, F. Senf, E. Chervakova, S. Engelhardt, and W. Kattanek  
IMMS Institut für Mikroelektronik- und Mechatronik-Systeme  
Gemeinnützige GmbH, GERMANY  

We developed an energy-autonomous and adaptive wireless sensor system for a wide range of Industry 4.0-type applications. By taking a holistic view of the overall system and of the specific interactions of these components, technological barriers of individual system elements can be overcome. As a result it can be shown that increasing power requirements resulting from Industry 4.0-type communication paradigms and required intelligence can be met by even small electromagnetic energy harvesters.

PW-25h  MEMS POWER GENERATOR OPERATED BY FLUOROCARBON GAS  
M. Kaneko, K. Kudo, K. Ebisawa, K. Tanaka, and F. Uchikoba  
Nihon University, JAPAN  

We developed a MEMS magnetic induction type air turbine generator. The miniature components of the MEMS air turbine was fabricated by a silicon material. And a miniature magnetic circuit that had a magnetic core and a coil pattern like a winding wire was fabricated by a ceramic material and a silver conductor. By combining these technologies, the fabricated generator realized the millimeter size generator. It demonstrated the rotational motion by a fluorocarbon gas, and it showed output power.

PW-26h  PERFORMANCES OF A CM-SCALE WATER FLOW ENERGY HARVESTER IN REAL ENVIRONMENT FOR AUTONOMOUS FLOWMETERS  
E. Saoutieff¹, P. Gasnier¹, S. Boisseau¹, J. Ojer-Aranguren¹, and I. Rodot³  
¹University Grenoble Alpes, FRANCE, ¹NAITEC, SPAIN, and ¹SERM, FRANCE  

We reports the optimization and the measurement results of a 4 cm diameter water flow energy harvester inserted in pipes. In this work, a test-bench has been implemented to measure the harvester's electrical output powers, rotation frequencies and pressure losses. Furthermore, long-term tests have been carried out in a district heating and cooling system in order to validate its operation in a real environment.

PW-27h  WEARABLE GENERATOR WITH ROTATING OSCILLATING MASS  
M. Ortiz¹, E. Fenollal¹, B. Restrepo², A. Espinoza², and E. Romero³  
¹University of Puerto Rico, USA, ²Universidad del Turabo, USA, and ³Florida Polytechnic University, USA  

This work reports the design, fabrication, and testing of a rotating, oscillating mass electromagnetic generator for wearable applications. A custom design architecture was done to assess the differences in generation for swinging motion at different conditions. The proposed study evaluates a rotational generator mounted on a swing arm driven by a sinusoidal input motion to determine the parameters that lead to constant rotations.
**Mechanical Energy-Harvesting - Electrostatic**

**PW-28h** DYNAMIC ANALYSIS OF ELECTROSTATIC ENERGY HARVESTING DEVICE WITH MULTI-STEP STRUCTURE  
X. Guo¹, Y. Zhang¹, and F. Wang¹²  
¹Southern University of Science and Technology, CHINA and  
²Chinese Academy of Sciences, CHINA

We have studied the dynamic features of an out-of-the-plane gap closing electrostatic energy harvester with different steps. The displacement and output power of pull-in effect and harvesters with various stopper heights have been simulated, measured and analyzed. The pull-in effect is observed, which limits the output power for device with high surface potential, and a decrease of output power for device with higher stoppers is also noticed.

**PW-29h** NEMS ELECTROSTATIC RF WAKEUP SWITCH WITH PT FIB CONTACT  
A. Ruyack, L. Pancoast, N. Shalabi, A. Molnar, and A. Lal  
Cornell University, USA

Advances in the development of a near-zero power NEMS RF energy detector are presented. We develop a process for achieving below 3V operation of a NEMS RF wakeup switch utilizing focused ion beam to pattern sub-100 nm Pt contacts. Switch design and the potential benefit of FIB patterning are discussed along with the testing setup and a custom control loop for the contact-based switch. Preliminary results are reported with a focus on probability of detection and false alarm rate as metrics.

**Mechanical Energy-Harvesting – Piezoelectric**

**PW-30h** AGING ASSESSMENT OF PIEZOELECTRIC ENERGY HARVESTER USING ELECTRICAL LOADS  
T. Hoang, G. Ferin, C. Bantignies, B. Rosinski, P. Vince, and A. Nguyen-Dinh  
Vermon S.A., FRANCE

The aging of bending piezoelectric structures is assessed using an electrical stress induced approach. Using FE modeling the equivalence of the stress distribution of a clamped-free cantilever when mechanically operated and electrically operated at its first eigen frequency. The electrical solicitation technique allows to get similar stress distribution profile compared to mechanical induced approaches but for a higher resonating frequency (X20), thus considerably accelerating the aging process.

**PW-31h** EQUIVALENT CIRCUIT MODEL OF PIEZOELECTRIC VIBRATION ENERGY HARVESTERS COMPOSED OF TRAPEZOIDAL UNIMORPH CANTILEVERS  
T. Umegaki, T. Ito, G. Tan, and I. Kanno  
Kobe University, JAPAN

We have constructed a time-resolved equivalent circuit model of the piezoelectric vibration energy harvesters (PVEHs) with the trapezoidal unimorph structure not only to optimize the dimensional parameter of trapezoidal PVEHs but also to anticipate the output power by a variety of external vibrations. To calculate the output responses by arbitrary mechanical input accelerations such as impulses or sinusoidal, we have formulated simultaneous first order differential equations based on this model.
PW-32h  INTEGRATION AND CHARACTERISATION OF PIEZOELECTRIC MACRO-FIBRE COMPOSITE ON CARBON FIBRE COMPOSITE FOR VIBRATION ENERGY HARVESTING
Y. Shi, C. Piao, D. El Fadlaoui, A. Al-Saadi, and Y. Jia
University of Chester, UK

Carbon fibre composite is a strong and a lightweight structural material. The integration of piezoelectric films add vibration energy harvesting capabilities to an otherwise purely mechanical structure. A PZT macro-fibre composite is co-cured with a carbon/epoxy pre-preg in order to manufacture the multi-functional composite plate. Without noticeably increasing profile, adding weight or compromising mechanical integrity, the resultant mechanical plate can recover power from vibration.

PW-33h  MEMS ENERGY HARVESTING BASED ON UNIFORM-STRESS CANTILEVER WITH MULTILAYER PZT THIN FILMS
S. Hirai, K. Kanda, T. Fujita, and K. Maenaka
University of Hyogo, JAPAN

Multilayered piezoelectric MEMS energy harvesters based on sputtering depositions are designed and fabricated. To obtain high endurance and output power, the unimorph cantilever structure with totally 10 µm-thick multilayered PZT thin films and 80 µm-thick Si elastic layer is designed. In addition, the cantilever is designed to undergo a uniform stress on the PZT. The output power and voltage was 90 µW and 1.0 Vrms under the input acceleration of 1.2 G (=11.76 m/s²) and optimum load resistance.

PW-34h  OUTPUT POWER OF PIEZOELECTRIC MEMS VIBRATION ENERGY HARVESTERS UNDER RANDOM OSCILLATION
S. Murakami¹, T. Yoshimura², M. Aramaki³, Y. Kanaoka¹, K. Tsuda¹, K. Satoh¹, K. Kanda³, and N. Fujimura²
¹Osaka Research Institute of Industrial Science and Technology, JAPAN, ³Osaka Prefecture University, JAPAN, and ²University of Hyogo, JAPAN

We fabricated piezoelectric cantilever-type vibration energy harvesters based on silicon MEMS fabrication technology. The characteristics were investigated under random oscillation. We made it clear that the power generation under random oscillation is proportional to the square of the vibrational acceleration. We also observed the nonlinearity in the power spectral density and considered the mechanism by using the mass-spring-damper system model.

PW-35h  REACTIVE ION BEAM ETCHING OF PIEZOELECTRIC SCAlN FOR BULK ACOUSTIC WAVE DEVICE APPLICATIONS
R. James, Y. Pilloux, and H. Hegde
Plasma Therm, USA

We have developed Reactive Ion Beam Etching (RIBE) processes for the facile etching of ScAlN with high concentration of Sc. A combination of wafer tilt, Reactive Gas/Ar ratio, beam voltage and current were used to achieve very smooth etched surface, high etch rate and selectivity to photoresist, and desired profile angle. This research has huge implications in fabricating ScAlN based BAW RF filters for next generation mobile and wireless applications.
**Mechanical Energy-Harvesting - Triboelectric**

**PW-36h  TRIBOELECTRIC EFFECT TO HARNESS FLUID FLOW ENERGY**  
R.I. Haque, A. Arafat, and D. Briand  
*École Polytechnique Fédérale de Lausanne (EPFL), SWITZERLAND*

We are reporting energy scavenging from fluid flows inside tube structures using triboelectric effects. Two separate designs of triboelectric nanogenerators (TENGs) were proposed. A tubular design that uses liquid-solid interaction mechanism for water, and freestanding flapping films design utilizing contact-separation mechanism for wind flow energies conversions. Under optimum operational conditions, both TENGs generated average output powers of tens of microwatts.

**Mechanical Energy-Harvesting - Other**

**PW-37h  UPPER BOUND FOR THE POWER OUTPUTS OF LINEAR VIBRATIONAL POWER HARVESTERS: TRANSLATIONAL VS. ROTATIONAL GEOMETRIES**  
A. Ananthakrishnan and I. Bargatin  
*University of Pennsylvania, USA*

We present a method to estimate the maximum power of both translational and rotational harvesters when excited by a vibration source with an arbitrary power spectral density. We show how the height and widths of the peaks in the vibration power spectral density determine the maximum power output as well as the minimum harvester size that is needed to reach this maximum power. To provide an example, we considered the case human walking vibrations for both vibrational and rotational harvesters.

**Motors/Generators, Pumps and Actuators**

**PW-38h  DETERMINATION OF MECHANICAL FORCE GENERATED BY GROWING SEED IN INKJET 3D PRINTED MICRODEVICE**  
K. Adamski, B. Kawa, J. Dziuban, and R. Walczak  
*Wroclaw University of Science and Technology, POLAND*

In this paper we present an inkjet 3D printed microdevice for determination of growing seed actuation force. The device consists of two cantilever-type sensors for the forces monitoring. Deflection of the cantilevers is determined by optical analysis of the captured microdevice images and then deflection is converted to force value. Successful monitoring of the mechanical force generated by the root and stalk in different cultivation mediums was obtained.
PW-39h  STABILITY OF SYMMETRICAL COMB-DRIVE ACTUATOR
A. Galisultanov, G. Pillonnet, Y. Perrin, L. Hutin, P. Basset, and H. Fanet
Université Grenoble Alpes, FRANCE and Université Paris-Est, FRANCE

This paper studies the potential energy wells of symmetrical comb-drive actuators by taking into account the fringing effect. Depending on the actuation voltage and geometry, the actuator has as a one, two, and three stable states. These equilibriums have been calculated from FEM simulations and the overlap between the fingers affects the well depths. Based on this study, a optimal design of the symmetrical actuator for the recently proposed capacitive adiabatic logic has been proposed.

PW-40j  DYNAMICS OF DIRECT HYDROCARBON POLYMER ELECTROLYTE MEMBRANE FUEL CELLS
E.H. Kong, P.D. Ronney, and G.K. Surya Prakash
University of Southern California, USA

Hydrocarbons have 50-100 times higher energy per unit weight compared to commercially available batteries, thus operating at only 10% overall efficiency could provide far lighter and less expensive energy sources for portable electronic devices. With this motivation, the feasibility of using Polymer Electrolyte Membrane (PEM) fuel cells with propane fuel, operating at low temperatures (< 100°C), was explored.

PW-41j  IMPROVED SENSITIVITY OF THIN FILM SENSOR FOR HUMIDITY MEASUREMENT INSIDE A OPERATING PEMFC
N. Hasegawa, Y. Otsuki, M. Kurosu, and T. Araki
Yokohama National University, JAPAN

In this study, we improved sensitivity of capacitive humidity sensor suitable for humidity measurement inside an operating proton exchange membrane fuel cell (PEMFC). Specifically, we designed and manufactured the sensor, evaluated the characteristics of the sensor. Finally, we inserted the sensor in a PEMFC during operation, and measured the humidity.
**k – Late News**

**PW-42k** A RESONANCE-MAINTAINING CIRCUIT FOR HIGH-EFFICIENCY ELECTRET-BASED MEMS VIBRATIONAL ENERGY HARVESTERS
H. Mitsuya¹, H. Ashizawa¹, M. Morita¹, H. Homma², G. Hashiguchi³, and H. Toshiyoshi³
¹Saginomiya Seisakusho, Inc., JAPAN, ²University of Tokyo, JAPAN, and ³Shizuoka University, JAPAN

We have developed a high-efficiency MEMS vibrational energy harvester with a resonance-maintaining circuit. Of particular note, the circuit is capable of both (1) rectifying the output to compensate for the electret bias voltage in the harvester and (2) avoiding electromechanical feedback by maintaining a relatively stable apparent load and resonance state. These improvements to the control circuitry allow the energy harvester to achieve useable energy outputs of over 500µW with highly efficient energy conversion ratios (79%).

**PW-43k** MICROFABRICATION OF A SILICON TURBOPUMP WITH EMBEDDED THERMAL ISOLATION FOR A RANKINE MEMS HEAT ENGINE
A. Amnache and L.G. Fréchette
Universite de Sherbrooke, CANADA
Poster Presentations B

a - APPLICATIONS AND INNOVATIONS IN MICRO ENERGY SYSTEMS

Energy-Autonomous Wireless Sensors for IoT

PT-01a MINIMIZING POWER CONSUMPTION OF LoRa® AND LoRaWAN FOR LOW-POWER WIRELESS SENSOR NODES
E. Bäumker, A. Miguel Garcia, and P. Woias
University of Freiburg, GERMANY

In this paper we show that RF transmissions using the physical layer of the LoRa® interface, and with some limitations also the link layer LoRaWAN, is suitable even for extremely power-restricted devices, like energy-autonomous wireless sensor nodes (WSNs), if configured well. We reveal the impact on the power consumption of different outer circuitry and ICs for a wireless transmission and derive a design strategy for a maximal power efficiency.

PT-02a A NARROW-BAND AND ULTRA-LOW-POWER 433 MHZ WAKE-UP RECEIVER
S. Koeble, S. Heller, and P. Woias
University of Freiburg, GERMANY

We present an ultra-low-power wake-up receiver to be integrated into wireless sensor nodes (WSNs), for enabling a power-saving asynchronous communication between the WSN and a host. The receiver is based on an optimized modulation/demodulation concept to achieve high RF sensitivity and narrow-band operation at the same time. The device works in the 433 MHz ISM band, with a high RF sensitivity (-63.4 dBm), an ultra-low power consumption (8.7 µW), and with a low supply voltage (2 V).

b - BIOCHEMICAL AND BIO-INSPIRED POWER/ENERGY SYSTEMS

Biochemical and Bio-Inspired Power/Energy Systems

PT-03b A PAPERTRONIC SENSING SYSTEM FOR RAPID VISUAL SCREENING OF BACTERIAL ELECTROGENICITY
M. Tahernia, M. Mohammadifar, and S. Choi
State University of New York-Binghamton, USA

We create the ability to achieve easy, rapid, and sensitive characterization of bacterial electrogenicity from a single drop of culture. We use paper as a device substrate that inherently produces favorable conditions for easy, rapid, and sensitive controlling of a microbial liquid sample. Through an innovative microscale device structure and a simple transistor amplifier circuit directly integrated into a single sheet of paper substrate, a powerful sensing array is constructed.
PT-04b GLUCOSE OXIDASE BIOELECTRODES IN DEVICES IMPLANTED IN LIVING PLANTS FOR ENERGY APPLICATIONS
J. Galindo-de-la-Rosa¹, A. Hernández-Torres², M.G. Araiza-González³, L.G. Arriaga¹, and J. Ledesma-García²
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO and ²Universidad Autónoma de Querétaro, MEXICO

The use of a living plant as a fuel cell comes from the idea of taking advantage of more efficiently the conversion of chemical energy, which comes from the plant's photosynthesis until it is converted into electrical energy. Glucose oxidase was immobilized on graphite rods for the development of the anodes and as a Pt/C cathode. When the enzyme is immobilized on the surface of the graphite electrode as the anode implanted in plants (cacti) was evaluated for fuel cell.

PT-05b MICROFLUIDIC BIOFUEL CELL BASED ON CHOLESTEROL OXIDASE/LACCASE ENZYMES
J. Galindo-de-la-Rosa¹, E. Ortiz-Ortega¹, B. López-González¹, L.G. Arriaga¹, and J. Ledesma-García²
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO and ²Universidad Autónoma de Querétaro, MEXICO

In this research two electrodes were developed, a bioanode where the enzyme oxidase was immobilized in Sigracet GDL 39 and a biocathode with laccase enzyme, for their evaluation in a cell of microfluidic. The microfluidic fuel cell was constructed by PMMA for the fuel and oxidant channels. The evaluation of the microfluidic cell was carried out using different solutions of cholesterol, obtaining a maximum power density of 1.38 mW/cm² with and 0.75V using 500mg/dL cholesterol.

C - DIRECT THERMAL ENERGY-HARVESTING
Thermoelectric Energy-Harvesting

PT-06c IMPROVED MICRONANOGENERATORS BASED ON SILICON COMPATIBLE MATERIALS AND PROCESSING
I. Donmez¹, M. Dolcet¹, A. Stranz¹, M. Salleras¹, L. Fonseca¹, G. Gadea², M. Pacios³, A. Morata², and A. Tarancon³
¹IMB-CNM (CSIC), SPAIN, ²IREC, SPAIN, and ³ICREA, SPAIN

An all-silicon microthermocouple fabricated by means of top-down silicon technologies and bottom-up deposition techniques has been optimized by using dense arrays of SiGe nanowires as thermoelectric material, and outperforms the one previously attempted with Si nanowires. Performance boosted even more after assembling a small size heat exchanger reaching power densities in the range of 40µW/cm² when resting on a hotplate at 100 °C, which are adequate for powering IoT nodes.
PT-07c  MILLIWATT POWER SUPPLY BY DYNAMIC THERMOELECTRIC HARVESTING
M.E. Kiziroglou1,2, S.W. Wright1, M. Shi1, D.E. Boyle1, Th. Becker3, J.W. Evans4, and E.M. Yeatman1
1Imperial College London, UK, 2ATEI Thessaloniki, GREECE, 3Natural Science and Technical Academy Isny, GERMANY, and 4University of California, Berkeley, USA

In this work we will demonstrate a power supply that collects thermal energy from temperature fluctuations in time, to provide regulated power in the mW range. It employs the dynamic thermoelectric energy harvesting concept and comprises an insulated heat-storage unit, a thermoelectric generator, a bipolar power management circuit based on the LTC3109 commercial microchip and a 0.5 F super capacitor. It demonstrates harvesting and storing over 2.5 J per cycle, and regulated 2.2/3.3 V outputs.

PT-08c  THIN-FILM π-TYPE MICRO TEG USING VACUUM/INSULATOR-HYBRID ISOLATION WITH CONVEX-SHAPE HOT-PLATE MODULE STRUCTURE FOR WEARABLE DEVICE APPLICATIONS
Y. Shiotsu, T. Seino, N. Chiwaki, and S. Sugahara
Tokyo Institute of Technology, JAPAN

Design optimization and performance of a micro thermoelectric generator (μTEG) using human body heat are investigated. A thin-film type μTEG module using vacuum/insulator-hybrid isolation with the convex-shape hot-plate is useful to achieve a high thermal resistance of the module and to suppress the heat flow passing through the supportive wall for the vacuum isolation. The optimum design of this module exhibits sufficiently high output power suitable for self-powered wearable devices.

d - ELECTRICAL ENERGY HARVESTING, MANAGEMENT, STORAGE AND TRANSFER

Batteries, Super-Capacitors, and Chemical Energy Storage

PT-09d  DEVELOPMENT OF A FLEXIBLE POLY(ETHER ETHER KETONE) SUPERCAPACITOR AS ELECTROLYTE AND SEPARATOR
R. López Mayo1, A. Rico1, L.G. Arriaga1, M.P. Gurrola1,2, and J. Ledesma-García2
1Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO and 2Universidad Autónoma de Querétaro, MEXICO

We have developed a SPEEK supercapacitor, which is also utilized as solid-state electrolyte, binder, and ion-conducting surfactant with good stability and easy fabrication. Considering the easy processability of SPEEK, that can be deposited in various forms without further processing, the proposed process represents a new step towards the fabrication of advanced functional and smart materials for flexible and wearable electronic devices.
### Power Electronics and Energy Management Circuits

**PT-10d**  
A HIGH-EFFICIENCY MANAGEMENT CIRCUIT FOR PIEZOELECTRIC ENERGY HARVESTER  
P. Li, Y.M. Wen, T. Han, and X.J. Ji  
*Shanghai Jiao Tong University, CHINA*

This paper proposes a maximum power point tracking circuit that can automatically match piezoelectric energy harvesters with different internal capacitances. The proposed double-resonance up-conversion matching circuit has a lower loss and higher resonant response. The matching circuit can automatically adjust the turn-on time of the up-conversion switch and the input impedance by tracking the input maximum power.

**PT-11d**  
A VOLTAGE-BOOST RECTIFIER CIRCUIT FOR ENERGY HARVESTING FROM ENVIRONMENTAL VIBRATIONS  
Y. Tohyama\(^1\), H. Honma\(^1\), N. Ishihara\(^2\), H. Sekiya\(^2\), H. Toshiyoshi\(^1\), and D. Yamane\(^3,4\)  
\(^1\)University of Tokyo, JAPAN, \(^2\)Tokyo Institute of Technology, JAPAN,  
\(^3\)Tokyo City University, JAPAN, and \(^4\)Japan Science and Technology Agency (JST), JAPAN

We propose a VBR (voltage-boost rectifier) circuit based on the 0.18-µm Si CMOS technology, which is designed for vibrational energy harvesters utilizing environmental vibrations. The VBR employs a single-end Dickson type charge pump topology, and the circuit would be realized as a monolithic chip. The evaluation results obtained by multi-physics simulations on a circuit simulator revealed that the proposed circuit was able to deliver boosted DC voltage at the input of sub-threshold AC voltage.

**PT-12d**  
DESIGN OF A MEMS RELAY BASED ON SOI FABRICATION TECHNOLOGY  
M. Schwarz\(^1\), F. Lambrecht\(^1\), A. Bauer\(^1\), and H. Seidel\(^2\)  
\(^1\)Siemens AG, GERMANY and \(^2\)Saarland University, GERMANY

To use MEMS for high power switching applications the single MEMS relay units have to be arranged in a matrix. For consistent performance the sameness of the individual switches representing the array is crucial. We present the design, simulation and fabrication of a MEMS relay based on silicon-on-insulator (SOI) technology. The measurement results show high accordance with simulations hence confirming the predictability and thereby the homogeneity of SOI-based MEMS relays.

**PT-13d**  
SECONDARY-SIDE DE-TUNING TO ENABLE WIDE-RANGE INDUCTIVE POWER TRANSFER FOR A WRIST WORN SENSOR  
S. Burrow and L. Clare  
*University of Bristol, UK*

In this paper we consider IPT systems with a very wide range of coupling and address one of the core challenges of such systems, namely excessive voltage/power induction during periods of close coupling by implementing a circuit which is able to de-tune the secondary tuned circuit during periods of excess.
RF, Inductive and Acoustic Power Transfer

**PT-14d** SIMULATION AND MODELLING OF A SPATIALLY-EFFICIENT 3D WIRELESS POWER TRANSFER SYSTEM FOR MULTI-USER CHARGING

H.-W. Wang¹, N.X. Wang², and J.H. Lang²

¹Tsinghua University, CHINA and ²Massachusetts Institute of Technology, USA

We develop an innovative method to achieve effective wireless power transfer to multi-user application in the 3-D space. A rotating magnetic field using two types of coil structures respectively is used to produce a nearly uniform power efficiency around the 3-D space.

**F - GENERAL**

Energy Conversion Physics

**PT-15f** FEASIBILITY OF A V-SHAPED MAGNET ROTOR TO CONVERT VIBRATION INTO ROTATION

D.J. Clarkson¹, L. Kurmann², G.N. Moubarak¹, and Y. Jia¹

¹University of Chester, UK and ²University of Freiburg, GERMANY

Majority of the reported kinetic energy harvesting mechanisms involve translatory transduction mechanisms. A rotary design can offer greater electromagnetic efficiency. This research investigates the feasibility of implementing a V-shaped magnet rotor for the purpose of coupling base point excitation into rotation, which can then be coupled to a generator motor. The resultant device aims to enhance the overall power conversion efficiency and bandwidth of the captured vibration energy.

**g - MATERIALS FOR ENERGY CONVERSION**

Fabrication Technology for Power/Energy Systems

**PT-16g** FACILE FABRICATION OF SILICON MICRO/NANOSTRUCTURES FOR MICROELECTRODES BY SILVER-ASSISTED ETCHING USING NANO-SPONGE AS A TEMPLATE

Y. Chen, J. Ruan, J. Huang, L. Qian, and S. Jiang

Southwest Jiaotong University, CHINA

This paper reports a facile and cost-effective method for the fabrication of silicon micro/nanostructures by silver-assisted etching using nano-sponge as a template. The silicon micro/nanostructures show uniform and erective morphology. The silicon micro/nanostructures show good electrochemical performances which can be attributed to the good stability and large effective surface area.
PT-17g  LASER-BONDING OF FEP/FEP INTERFACES FOR A FLEXIBLE MANUFACTURING PROCESS OF FERROELECTRETS
D. Flachs, F. Emmerich, G.-L. Roth, R. Hellmann, and C. Thielemann
University of Applied Sciences Aschaffenburg, GERMANY

This paper presents an optimized laser-bonding process for ferroelectrets based on thin fluorinated-ethylene-propylene (FEP) foils, using an ultra-short-pulse (USP) laser. Due to the minimized thermal stress in the material during bonding, achieved by pulse durations of few picoseconds, we created seams down to 40 µm. Using a galvanometer scanning system allowed for fast bonding speeds up to several centimeters per second, making the process also suitable for large structures and areas.

Materials for Energy Conversion and Storage

PT-18g  ETHANOL TOLERANT CATALYST BASED IN PLATINUM AND SILVER IN GRAPHENE
M.J. Estrada-Solís¹, B. López-González¹, M. Guerra-Balcázar², and F.M. Cuevas-Muñiz¹
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO and
²Universidad Autónoma de Querétaro, MEXICO

In this work, the use of the electrochemical deposit PtAg on the glassy carbon modified with graphene (AgPt/G) is proposed. The electrochemical test (RDE) showed a better performance to reduce oxygen for AgPt/G compared to a similar material obtained in vulcan carbon (PtAg/V). The reduction potential is around 0.82 V versus RHE in PtAg/G compared to 0.77 V versus RHE in PtAg/V. Th PtAg/G has a smaller particle size, this was attributable to the better distribution of active graphene sites.

PT-19g  HIGHLY ORIENTED AND STRESS MODIFIED THICK ALN FILMS DEPOSITED ON LOW THERMAL EXPANSION ALLOY SUBSTRATES FOR FLEXIBLE ELECTRONICS IN HARSH ENVIRONMENT
N. Moriwaki¹², L.V. Minh¹, and H. Kuwano¹
¹Tohoku University, JAPAN and ²Dai Nippon Printing Co., Ltd., JAPAN

Highly oriented and stress modified thick aluminium nitride (AlN) films were depositions by reactive AC magnetron sputtering on 4-inch substrates and foils made of the low thermal expansion alloy "42Alloy" for flexible electronics in harsh environment. A flat three micrometer thick AlN film was deposited successfully on the 50 µm thick 42Alloy foil, and its full width at half maximum of AlN(002) was 5.00 degree.
PT-20g PLD ELECTRODES IN A COUPLED MICROFLUIDIC FUEL CELL TO A LAB ON A CHIP SYSTEM FOR ENERGY GENERATION
B. López-González¹, J.C. Abrego-Martínez², B.S. Hernández-Sarmiento³, A. Moreno-Zuria¹, Y. Wang², M. Mohamedi, L.G. Arriaga¹, and F.M. Cuevas-Muñiz¹
¹Centro de Investigación y Desarrollo Tecnológico en Electroquímica, MEXICO, ²Institut National de la Recherche Scientifique (INRS), CANADA, and ³Instituto Tecnológico de Oaxaca, MEXICO

An inorganic microfluidic fuel cell (i-µFFC) was integrated in a glucose sensor LOC device. This device was constructed by using a mini CNC and evaluated for energy harvesting from glucose. The i-µFFC with PLD electrodes exhibits the highest performance compared to the i-µFFC with spray electrodes microfluidic fuel cell for the three conditions, obtained the best performance in alkaline conditions (3.53 µW), which is enough energy to power low-consumption microelectronic chips or microsensors.

h - MECHANICAL ENERGY HARVESTING AND ACTUATION

PT-21h A COMPACT ELECTROMAGNETIC VIBRATION ENERGY HARVESTER WITH HIGH OUTPUT VOLTAGE
X. Wang, X. He, K. Li, and S. Jiang
Chongqing University, CHINA

The performance of a non-resonant electromagnetic vibration energy harvester was improved by adding mild steel sheets to enlarge magnetic flux density. The wire diameter of coils, thicknesses of magnets and coils, and thickness of mild steel plates were optimized by simulations. For the fabricated prototype under 0.3 g at 8.3 Hz, the experimental RMS voltage across a 10.4 kΩ resistor was 15.53V, with the normalized power density of 304 µW cm⁻³, about 18.75% higher than the previous device.

PT-22h HEATING PERFORMANCE BY AN INSOLE ENERGY HARVESTER
M.M. Rahman, S. Noh, K.H. Kim, and H. Kim
University of Utah, USA

This paper reports the heating performance of the 4th generation shoe-insole-based hydraulic electromagnetic energy harvester (HEEH) in connection with a micromachined polysilicon heater & a commercial copper shoe insole heater. The HEEH was integrated with two heaters to produce temperature rises of 2 & 3.2°C and the heating rates of 12 & 1.6°C /min, respectively, from polysilicon (0.15x0.1mm², 6.05e⁻⁶ of thermal time constant) and copper heaters (78x28mm², 8.31s of thermal time constant).
We have fabricated a magnetostrictive vibration energy harvester using a poly-crystalline Fe-Ga alloy omitting the high-cost single crystallization process and compared its performance with a device using a single crystal. It was estimated that the manufacturing cost of poly-crystal can be reduced to 1/6 of single crystal. The poly-crystal device could generate power of 1.1 mW, which is about 28% of a single crystal.

In this paper we are present 3D printed energy harvester with pendulum for electric power generation from motion. Pendulum for spring tension is widely use in watches from centuries. Also, it is used for electromagnetic (EM) energy generation for watch powering. This kind of energy harvester is based on inertial move of pendulum and electromagnetic energy conversion. Pendulum microgenerators are patented and produced by at least 3 companies (i.e. Seiko, Eta, Kinetron) but their solutions are indirect, based on one inductor coil and microgear system. This approach is expensive (involved precision micromechanic processes) and harvested power is low (only for quartz clock powering). Here we propose direct power generation where the pendulum is integrated with magnets. Inductor coils are below pendulum in the generator housing. This kind of generator is simpler, easier to fabricate and power generated is higher.

An automated design methodology for electromagnetic harvesters was developed and implemented, which allows a cost-effective design of adapted energy harvesters for application-specific requirements. In the current study the influence of different boundary conditions on the evaluation of basic structures is shown and sensitivity analyses are carried out. It can be shown that none of the structures always provides the highest output power.
**Mechanical Energy-Harvesting - Electrostatic**

**PT-26h** DEMONSTRATION OF AN ELECTRET GENERATOR USING SELF-ASSEMBLED ELECTRET FOR ENERGY HARVESTING WITHOUT ANY CHARGING PROCESS

N. Matsuura¹, H. Ishii², and Y. Tanaka¹²

¹Chiba University, JAPAN and ²Japan Science and Technology Agency (JST), JAPAN

Giant surface potential (GSP) of 46.5 V at 739 nm appears in TPBi vacuum evaporated film due to spontaneous orientation of the molecules. In this study, we found that the GSP of the film was relatively stable even in atmosphere under room light illumination. By taking advantage of this film, we demonstrated that electret generator for energy harvesting including TPBi, which does not need any charging process, operated well in living environment.

**PT-27h** INVESTIGATION OF PARALLEL-CONNECTED MEMS ELECTROSTATIC ENERGY HARVESTER FOR ENHANCING OUTPUT POWER OVER A WIDE FREQUENCY RANGE

J. Li, X. Tong, J. Oxaal, Z. Liu, M. Hella, and D.-A. Borca-Tasciuc

Rensselaer Polytechnic Institute, USA

We develop, model, and test an energy harvesting system with parallelly connected selected MEMS devices for enhanced power output and broadened bandwidth. A nonlinear numerical model is built and studied to find the proper operating conditions as well as the relationship between the devices’ design parameters for constructive interaction. Testing results show that the system exhibits a 2x broadened operational region along with a 32.5% increase in maximum power compared to a single device.

**PT-28h** TEXTILE BASED FERROELECTRET FOR WEARABLE ENERGY HARVESTING

J. Shi and S.P. Beeby

University of Southampton, UK

This paper reports the fabrication and testing of a ferroelectret-textile which is made from two fluorinated ethylene propylene (FEP) films and a conventional textile (cotton, silk or poly-cotton) formed into a sandwich structure. The ferroelectret textile harvester is based on a rapidly assembled fabrication method.

**Mechanical Energy-Harvesting - Piezoelectric**

**PT-29h** A 120°C 20G-COMPLIANT VIBRATION ENERGY HARVESTER FOR AERONAUTIC ENVIRONMENTS

P. Gasnier¹, M. Boucaud², M. Gallardo¹, J. Willemin¹, S. Boisseau¹ A. Morel¹, D. Gibus¹, and M. Moreau²

¹University Grenoble Alpes, CEA-Leti, FRANCE, ²ABYLSEN, FRANCE, and ³SAFRAN Power Units, FRANCE

Our paper reports the design, fabrication, and testing of a piezoelectric energy harvester operating at 90°C and withstanding 120°C and 20G of acceleration. This harvester, along with its dedicated power management circuit, have been designed to supply a 3-channel Acceleration Measurement System (AMS) for the structural health monitoring of an aircraft engine.
PT-30h  AN UMBRELLA-SHAPED TOPOLOGY FOR BROADBAND MEMS PIEZOELECTRIC VIBRATION ENERGY HARVESTING
Y. Jia\textsuperscript{1,2}, S. Du\textsuperscript{1}, and A.A. Seshia\textsuperscript{1}
\textsuperscript{1}University of Cambridge, UK and \textsuperscript{2}University of Chester, UK

Cantilever topologies offer high power responsiveness for MEMS vibration energy harvesting (VEH), but they are less robust than membrane topologies. This paper proposes an umbrella-shaped topology to address the problem of having to compromise between power density and robustness. An implemented AlN on Si device recorded a peak power of 173µW. The normalised power density compares favourably against the state-of-the-art cantilever piezoelectric MEMS VEH, while not sacrificing robustness.

PT-31h  INCREASED PIEZOELECTRIC COUPLING FORCE IN AUTOPARAMETRIC EXCITATION HARVESTER CONNECTING TO SELF-POWERED SERIES AND PARALLEL SYNCHRONIZED SWITCH HARVESTING ON INDUCTOR (SSHI) INTERFACES
H. Asanuma, T. Komatsuzaki, and Y. Iwata
Kanazawa University, JAPAN

We report the importance of the increase in the piezoelectric coupling force in a high output piezoelectric autoparametric excitation harvester connecting to the self-powered synchronized switch harvesting on inductor (SSHI) interface. The piezoelectric coupling force, which increases as the piezoelectric voltage enhanced by the SSHI technique increases, may suppress harvester's displacement and thus decrease output power and shift the optimal resistive load.

PT-32h  MEMS MEANDER HARVESTER WITH TUNGSTEN PROOF-MASS
E. Köhler\textsuperscript{1}, P. Johannisson\textsuperscript{2}, D. Kolev\textsuperscript{2}, F. Ohlsson\textsuperscript{2}, P. Ågren\textsuperscript{3}, J. Liljeholm\textsuperscript{3}, P. Enoksson\textsuperscript{1}, and C. Rusu\textsuperscript{2}
\textsuperscript{1}Chalmers University of Technology, SWEDEN, \textsuperscript{2}RISE Acreo, SWEDEN, and \textsuperscript{3}Silex Microsystems, SWEDEN

This work investigates the use of a MEMS piezoelectric harvester as complementary energy source to the battery in a leadless pace maker (20 mm x 4 mm x 2 mm). This requires a harvester with low mass displacement. The fabricated harvester is a meander-type bridge harvester with a large 500 mg tungsten mass. To protect the fragile harvester the proof-mass was fixed with small support bridges that was later released with FIb. Measured power output with 50 µm deflection reached 0.13 nW at 60 Hz.

PT-33h  OMNIDIRECTIONAL LOW FREQUENCY ENERGY HARVESTER FOR WEARABLE APPLICATIONS
C. Ou, V. Pinrod, B. Davaji, and A. Lal
Cornell University, USA

We present an omnidirectional energy harvester with lowest resonance mode at 14.85 Hz. The geometry is designed as a spiral shape to achieve a low resonance frequency while minimizing the area required. Multiple resonance modes widen bandwidth and enable harvesting energy from all directions. The device is fabricated by a rapid laser micromachining process on PZT. The energy harvester is mounted on a 3D printed package mimicking a typical smartwatch so that it can be worn on a human wrist.
PT-34h  POLYMER-BASED PIEZOELECTRIC ENERGY HARVESTER FOR LOW-FREQUENCY VIBRATION USING FREQUENCY UP-CONVERSION DRIVEN BY COLLISION WITH A FLEXIBLE BEAM
T. Tsukamoto1, Y. Umino1, K. Hashikura1, S. Shiomi1, K. Yamada1, and T. Suzuki1,2
1Gunma University, JAPAN and 2Japan Science and Technology Agency (JST), JAPAN

We developed a polymer-based piezoelectric vibration energy harvester (PVEH) using mechanical frequency up-conversion driven by collision with a flexible beam, targeting for low-frequency vibration (under 10 Hz). By driving the flexible beam with low-frequency, the beam periodically hits against the impact-driven piezoelectric component and excites the free oscillation, i.e. frequency up-conversion. The PVEH generates several tens of microwatts at the excitation frequency of under 10 Hz.

PT-35h  TEXTILE-BASED FREESTANDING TRIBOELECTRIC-LAYER NANOGENERATOR WITH ALTERNATE POSITIVE AND NEGATIVE GRATING STRUCTURE
W. Paosangthong, R. Torah, and S. Beeby
University of Southampton, UK

We report a novel design of textile-based triboelectric nanogenerator (TENG) with alternate grated strips of positive and negative triboelectric material operating in freestanding triboelectric-layer mode. Whereas most grating-structured TENGs operate in this mode comprising gratings of one type of triboelectric material separated by air gaps, this design presents a replacement of the air gaps by a triboelectric material with the opposite polarity to the existing triboelectric material.

Motors/Generators, Pumps and Actuators

PT-36h  MACROSCOPIC ACTUATION FOR DEPLOYABLE MICROVALVES: COUPLING MECHANICALLY WHILE ISOLATING THERMALLY
C. Kelly, X. Xie, A. Dodge, and C. Livermore
Northeastern University, USA

This paper presents the design and initial experimental validation of a system that couples macroscale actuations to a micro flow control system via a hydraulic coupler that isolates the actuator from the valve both spatially and thermally. Gas flow is successfully controlled via actuations that are delivered through the hydraulic coupler.
PT-37j EXPERIMENTAL AND NUMERICAL INVESTIGATION OF MICRO CATALYTIC REACTOR FOR AUTOTHERMAL REFORMING USING METHANOL AND HYDROGEN PEROXIDE WITH BUILT-IN CHROME SILICIDE THERMOCOUPLE
E.S. Jung
Pusan National University, KOREA

This paper reports new concept of hydrogen generation method using hydrogen peroxide. Development, performance evaluation and numerical simulation of micro hydrogen generator by autothermal reforming process using hydrogen peroxide are carried out. To prove the micro reaction mechanism, chrome silicide thermocouple is built in the micro catalytic reactor by in-situ system. This paper is studied the temperature and pressure effects as parameters for hydrogen generation.

PT-38j USEFULNESS AND PERFORMANCE COMPARISON OF COMPLEX ENZYME-TYPE BIOFUEL CELL USING ELECTRODE MODIFIED WITH TWO DET-TYPE ENZYMES BY COVALENT BONDING
H. Fujita, Y. Nishioka, and S. Imai
Nihon University, JAPAN

In this paper, we report the usefulness of the EBFC in which two DET-type enzymes were used to modify to the anode by a chemical modification method and show its long-term stability. EBFCs do not require a separator. There are several reports on EBFCs, but none describe modifications of the anode with complex DET-type enzymes. By modifying to the anode with multiple enzymes, and thus, produce a battery that can handle various fuels.

PT-39k A PROOF-OF-CONCEPT 70 NA ECG PROCESSOR FOR REAL-TIME R-WAVE AND NN50 DETECTION
H. Töreyin
San Diego State University, USA

Unobtrusive health monitoring applications necessitate accurate, real-time, and energy-efficient computation of health-related parameters. Two important parameters for cardiovascular and cardiac autonomic health assessment are heart rate (HR) and heart rate variability (HRV). This study presents a proof-of-concept energy-efficient mixed-signal ASIC processor designed in a 0.5 µm CMOS technology; detecting R-waves of ECG signals and comparing successive R-R intervals to identify NN50 events, an HRV metric, in real-time.
PT-40k  LOW-VOLTAGE-DRIVEN ELECTROSTATIC MICROSPKERS WITH POTASSIUM-ION-ELECTRETS
C. Sano¹, V. Menon¹, H. Honma¹, G. Hashiguchi², and H. Toshiyoshi¹
¹University of Tokyo, JAPAN and ²Shizuoka University, JAPAN

Electrostatic microactuators require external DC biasing in order to achieve the widest possible range of displacements for a given AC input. This report proposes a novel microspeaker structure that utilizes a potassium-ion-electret to reduce the need for such DC voltage application. Electrets exhibiting quasi-permanent charges enable large fixed voltages to be integrated directly within the MEMS structure, acting as an ersatz DC bias. Prototype devices were fabricated and characterized to approximate the effects of electret incorporation on the device performance.

PT-41k  THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A MULTI-STABLE ENERGY HARVESTER FOR ROTATION MOTION
X. Mei¹, S. Zhou², T. Kaizuka¹, and K. Nakano¹
¹University of Tokyo, JAPAN and ²Northwestern Polytechnical University, CHINA

Recently, the development in low-power electrical systems has led to increasing requirements for self-power technology due to fixed storage capacity and low energy density of traditional batteries. Thus, energy harvesting from the rotation motion for the self-powered wireless sensors has attracted a lot of interests, and different kinds of nonlinear energy harvesters in rotation environments were proposed to achieve more effective broadband energy harvesting for low-level excitation. To enhance the energy harvesting efficiency, a lot of researches proposed broadband energy harvesting