15th International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS 2015)

Journal of Physics: Conference Series Volume 660

Boston, Massachusetts, USA
1 - 4 December 2015

ISBN: 978-1-5108-1814-9
ISSN: 1742-6588

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571

Some format issues inherent in the e-media version may also appear in this print version.

Printed by Curran Associates, Inc. (2016)

Institute of Physics
Dirac House, Temple Back
Bristol BS1 6BE UK

Phone: 44 1 17 929 7481
Fax: 44 1 17 920 0979

techtracking@iop.org

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2634
Email: curran@proceedings.com
Web: www.proceedings.com

TABLE OF CONTENTS

Wednesday, December 2, 2015

PLENARY PRESENTATION I

SESSION W1A: ELECTRET-BASED ENERGY HARVESTING

We have developed an energy harvester that is specifically desired for impulse acceleration of infrastructure vibrations such as sudden motion at railway bridges. The energy harvester, based on potassium-ion-electret on the sidewalls of 1.8um-gap comb drives, generated 64uAp-p current during low impulse acceleration. This current was high enough to light a LED brightly.

We developed for the first time a MEMS electrostatic vibration energy harvester (e-VEH) with corona-charged vertical electret having a very large bandwidth due to the presence of nonlinear elastic stoppers. At 2.0 gRMS, for a bias voltage of 21 V the device harvests more than 0.1 μW within 45~ 444 Hz, and more than 0.4 μW within 147~444 Hz. With a bias of 46 V, the bandwidth for 0.9 μW is 45~432 Hz, and for 2.1 μW is 146~432 Hz. The maximum RMS harvested power is 6.6 μW at 428 Hz.

We have developed a soft electret gel for vibrational energy harvesters. The soft electret material was obtained by solidifying ionic liquid and immobilizing cations (+) on the surface. When a piece of soft electret gel is sandwiched between a pair of electrodes, large amount of charge is induced in an electrical-double-layer capacitor (1.0-10 μFcm^{-2}) appearing at the interface of the electrode and the ionic liquid gel. By retracting the electrode repeatedly, we obtained the current output of a several $\mu A_{p\text{-}p}/cm^{-2}$ stably.

SESSION W1B: MAGNETIC SYSTEMS

We present a new hybrid micromachined contactless suspension (CS) based on combining electromagnetic inductive and electrostatic actuation. The stiffness components are dynamically adjusted during the operation phase using a series of integrated electrodes. We experimentally demonstrate vertical linear positioning of a disk-shaped conductive proof mass in a range from 30 to 200μm, controlled tilting about two orthogonal axes in the horizontal plane ranges from ±1 to ±4 degrees, controlled oscillation about the vertical axis with angular displacement of 37° at 1.5Hz frequency. To demonstrate dynamical stiffness adjustment, we experimentally show that the angular stiffness component is increased by a factor of two at 100μm levitation height.

This work pertains to a selective magnetization method for batch-patterning magnetic poles into magnetic layers, recently developed by our group. This method is important to the PowerMEMS community for expanding the use of permanent magnetic materials in MEMS via the ability to create complex magnetic field patterns. In this paper, we show, for the first time, systematic experimental validation of a simulation tool that models the process.

We demonstrate a stretchable magnetic core inductor based on liquid metal traces around a ferrofluid core. Using ferrofluid allows a higher inductance density without affecting the mechanical properties of the surrounding silicone. The low frequency inductance was found to increase from 255 nH before fill to 390 nH after fill with ferrofluid, an increase of 52%. The inductor was also shown to survive uniaxial strains of up to 100%.

SESSION W2A: ADDITIVE MANUFACTURING FOR ENERGY STORAGE

This paper reports an on-chip micro battery which can be fabricated by printing method. The battery consists of screen-printed Mg and AgCl thick films. The open circuit voltage as high as 1.58 V and the maximum power as high as 1.4 mW were obtained. A demonstration device self-powered by the on-chip battery worked in a 0.14 M NaCl solution, and digital data transmission from the device was confirmed.

This research created direct layer-by-layer printed zinc-based secondary batteries with an ionic liquid-based gel polymer electrolyte to power micro- and meso-scale devices. Fully printed cells have demonstrated average discharge capacities of 0.548 mAh/cm^2, energy densities of 8.20 mWh/cm^3, and specific energies of 2.46 mWh/g with some cells achieving over 1000 cycles without catastrophic failure. Layer-by-layer printed devices exhibited decreased DC internal resistance and longer cycle life over previous mechanically assembled cells.

We report the utilization of capillary microfluidics to rapidly create nanostructure-patterned electrodes for energy storage applications. Using open-channel capillary photoresist microfluidics, virus bio-nanoscaffolds are autonomously delivered on gold electrodes, forming a dense and porous bio-nanoscaffold layer. The performance enhancement was evaluated in a NiO supercapacitor electrode system, where the galvanostatic charge/discharge cycle showed a 3.6-fold increase in areal capacitance for the nanostructured electrode compared to the planar electrode.

SESSION W2B: ENERGY HARVESTING I

An EM low frequency vibration energy harvester is newly developed based on dual halbach array which is suspended in two magnetic springs. Each halbach array concentrates the magnetic flux lines on one side of the array while suppressing the flux lines on the other side. Dual halbach array allows the concentrated magnetic flux lines to interact with the same coil in a way where maximum flux linkage occurs. The prototype device offers 33.4μWcm-3 average power density which is much higher than recently reported EMEH.

This paper presents experiments on how to approach the physical limits on power from vibration energy harvesting under displacement-constrained operation. A harvester with voltage-control of system stiffness is used for the purpose. Power saturation is shifted to higher accelerations by load optimization and tunable electromechanical coupling. The obtained effectiveness is beyond 60% under optimization. This work shows a first demonstration of reaching optimal power in intermediate acceleration-range between two extremes of maximum efficiency and maximum power transfer.

We design, model and fabricate a novel MEMS device for low-frequency, low-g vibration energy harvesting. The bi-stable buckled beam structure based new design is aiming to address the remained challenge of applying the energy harvesting technology to the real environment – working at low frequencies (<100Hz) and low g's (<1g). An electromechanically coupled lumped model has been formulated with Lagrangian equations and solved by harmonic balance method. A macro-scale prototype has been built for validation. A MEMS prototype has been fabricated and tested, showing wide bandwidth below 150Hz at 0.2g.

PLENARY PRESENTATION II

SESSION W3A: POWER ELECTRONICS

This paper presents the design and simulation results of a self-starting electrical interface circuit for parametric frequency increased vibrational energy harvesters. Due to the inherent ring down of frequency up-converting harvesters, an active rectifier is interfaced to a buck-boost stage in order to decouple the load and always provide an optimal impedance to the transducer. The circuit provides an efficiency between 75% - 93% for input voltages in the range of 0.5 - 2V. The minimum input voltage and power are 800mV and 3μW respectively.

We develop a new interface circuit for electrostatic vibration energy harvesting with adjustable bias voltage. An electronic switch is used to modify the circuit configuration so that the harvested energy increases the voltage across a biasing capacitor. Decrease of this biasing capacitor voltage occurs naturally due to the circuit imperfections. Such a control of the bias voltage enables to adjust the amount of energy converted by the variable capacitor on each cycle.

We design, fabrication, and testing of a novel integrated interface topology for ultra-low voltage step up converter in 0.18 µm CMOS technology without the use of off-chip components.Fully integrated center-tap differential inductors are introduced in proposed LC oscillator design to enhance the efficiency of the system by eliminating the traditional clock buffer circuits used to drive the charge-pump.

SESSION W3B: CATALYSIS, COMBUSTION, AND THRUSTERS

We have developed a visual constant volume bomb to study the micro-scale flame propagation. By spark ignition, under certain experimental conditions, it can be observed to flame propagation speed is far slower than the speed of flame propagation under normal scale. Uneven heat and mass diffusion and hydrodynamic reasons caused flame oscillation which is very easily observed.

We report the development of a flexible wireless wall temperature sensor and its performance evaluation in an unsteady thermal field. The sensor is made of thermally stable polyimide and can be fitted onto a curved surface. A 1 mm-sized sensing resistor is additionally sputtered on the copper coil to improve the spatial resolution of the sensor. It is demonstrated that the temperature measurement uncertainty of ±6.4 ℃ has been achieved with the measurement time interval as small as 2.48 ms.

We design and fabricate the liquid micro thruster with regenerative cooling channels, to relieve thermal shock on the micro structure. Photosensitive glass is main material for the micro thruster fabrication and platinum catalyst is inserted to the catalyst bed of the micro thruster for propellant decomposition. Two micro thruster with and without channels are used for the experimental test. The results shows lower thermal shock for the regenerative cooling channel added micro thruster. However, chamber temperature and pressure is also reduced with excessive cooling effect.

Thursday, December 3, 2015

PLENARY PRESENTATION III

SESSION T4A: POWER MANAGEMENT AND CONTROL OF HARVESTER SYSTEMS

This paper reports the design, implementation, and testing of a newly proposed analogue maximum power point tracking (MPPT) circuit with microwatt power consumption for piezoelectric energy harvesting. The proposed MPPT circuit uses an analogue differentiator and comparator to monitor the changes in the voltage induced by the PEH and enables a DC-DC converter for energy transfer at maximum power point (MPP) with efficiency of 81% to 99%, without using sensing and control circuits and microcontroller, that are in traditional MPPT scheme.

This study presents a novel hybrid energy scavenger system that combines the power generated simultaneously by a vibration-based (<10Hz) electromagnetic harvester and a UHF band (900 MHz) RF harvester. The novel scavenger interface uses a power management circuit in 180 nm CMOS technology to step-up and to regulate the combined output. The system volume is 6.5 cm^3. The hybrid system behaves as a typical battery, and keeps the output voltage stable at 3 V up to 18 μW of output power.

We develop the first self-sufficient nonlinear harvester system which is based on a ultra-low power electronic control. For the implementation of a closed loop control, the phase shift between the excitation and the system response is used as control variable. Depending on the speed and frequency of changes in the excitation different control concepts were implemented and tested to optimize the power output of the system.

We show through experimental results that MEMS electrostatic vibration energy harvester charged with electret can benefit in some situations of the use of recently reported unstable auto-synchronous conditioning circuits, instead of primitive or simple rectifier conditioning circuits that have been extensively used with electret electrostatic devices.

SESSION T4B: PUMPS AND ACTUATORS

We present the design, fabrication, and demonstration of a set of 2 mm^2, high-force actuators that combine piezoelectric in-plane actuators with MEMS-enabled scissor mechanisms (motion amplifiers) to simultaneously produce out-of-plane forces of >4 mN and out-of-plane displacements of >4 um. The actuators utilize a new fabrication approach to achieve 15 times smaller area than previous generation of devices, while offering greater actuator displacement and force per unit area of device footprint.

We have designed, fabricated, and characterized an electrostatic ion pump architecture that is compatible with novel applications such as chip-scale, cold-atom interferometry systems. This design improves upon previous designs to increase the ionization probability using a new arrangement and structure of electrodes. Electrons from a nanostructured field emitter array impact ionize the gases within the chamber; the ions are then gettered by a titanium electrode, creating vacuum.

We develop, simulate and test a MEMS out-of-plane (vertical) translational lead-zirconate-titanate (PZT) Archimedes' spiral arm bimorph actuator, which offers large deflection and large force in a compact, mechanically and thermally robust structure that is readily fabricated by commercial PZT manufacturing processes, simply connected to its voltage supply, and readily integrated into more complex MEMS systems. To characterize the unique behavior of spiral-arm actuators, two types of actuators with different electrode patterns (arms are half actuated or fully actuated) were simulated, fabricated, and tested.

We propose, fabricate and validate a novel ECF (electro-conjugate fluid) micropump with TPSEs (triangular prism and slit electrode pair) by electroforming process using newly developed self-aligned micro molds in order to improve alignment accuracy and alleviate fabrication difficulty. Compared with the traditional MEMS process, the concept is to utilize back-side UV light and electrode pattern on the glass wafer for patterning thick photoresist, instead of using ordinary front-side UV light and photomasks.

SESSION T5A: ENERGY HARVESTING II

This paper reports a membrane-based MEMS piezoelectric vibration energy harvester with incorporating design approaches to achieve broader band response than a comparable device with a classical topology. A key drawbacks of a plain membrane compared to cantilevers, is the strain neutralisation of regions of high strain energy through housing the centred proof mass. Experimental results reported up to two folds of power enhancement, over plain membrane, when subjected to band-limited white noise.

This paper reports the design, prototyping and experimental validation of a human-machines interface (HMI) integrated into a glove with energy harvesting from the motion of fingers. The device is addressed to industrial applications where the interaction with machines is restricted by safety procedures, to medical applications, design tools and virtual reality field.

We develop a triboelectric mechanism based large size energy harvesting device using roll-to-roll ultraviolet embossing. These large size devices can be embedded in the indoor floorings, pathways and roads, to harvest mechanical impact energy from human and vehicle movement. This work is aimed towards developing fabrication flow and processes for large volume manufacturing of triboelectric nanogenerators for commercial applications.

SESSION T5B: THERMAL, NUCLEAR, AND COMBUSTION SYSTEMS

We report an arrayable micro-scale electrical to thermal energy amplification approach utilizing a graphene based micro-valve trigger and an alkali metal fuel source. Using this approach we can react nanoliter droplets of rubidium with ambient air on demand, producing electrical to thermal energy gains of seventy five times. By arraying the fuel into discrete packets, we can achieve temporal control of the fuel source, allowing for tailored peak and average power output.

This work reports the design, simulation and measurement results of a portable high-efficiency radioisotope thermophotovoltaic system (RTPV) powered by one plutonia fuel pellet. Two dimensional photonic crystal is used to realize spectral control. Our RTPV has the potential to reach higher efficiency and specific power than conventional RTGs and meet the energy demands of systems requiring long lifetime and low maintenance such as spacecrafts and remote sensors.

We used a 2D axisymmetric model to simulate the characteristics of n-butane/air flame propagation in a Φ35mm × 2.0mm disk-like gap micro constant volume chamber at 0.1Mpa and 300K. Three kinds geometry of flamefront (i.e convex, plat and concave flames) exist along the direction to unburned mixture. The velocity of flame propagation in the micro chamber is not uniformed and is lower than that in a conventional chamber bomb.

PLENARY PRESENTATION IV

SESSION T6A: RF AND HIGH-CURRENT SYSTEMS

This paper reports the design, fabrication, and characterization of improved solid-state elements intended for individual regulation of field emitters part of high-density arrays. The work demonstrates a high-yield, CMOS fabrication process that creates silicon vertical ungated field-effect transistors (FETs) that achieve current saturation with ~3.5 V bias voltage while limiting the current to ~ 6μA (4 A/cm2). Experimental characterization of arrays of FETs with different array size demonstrates the same per-FET value. Finite element simulations of the device predict a saturation voltage close to the experimental value and a saturation current within a factor of two of the experimental value.

A miniaturized antenna was fabricated and integrated with a commercialized RFID chip to form a micro-tracer. The micro-tracer was wirelessly powered and interrogated through near field coupling with reader antennas embedded under a microfluidic channel, which can manipulate large number of tracers simultaneously by in channel focusing and separation. The total size of the micro-tracer is 2mm by 1mm, with a 380μm by 380μm integrated miniaturized antenna, optimized at the frequency of 840MHz. The wireless power transfer and real-time communication was demonstrated as the micro-tracer flows inside the microfluidic channel carried by pump oil.

We report an electrodynamic wireless power transmission system using a 450 Hz magnetic field to transmit watt-scale power levels to multiple compact receivers. A single 3.0 cm^3 receiver achieves 1.25 W power transfer at 1 cm (0.35 W/cm^3 power density), a 12x increase in power density compared to previous research. Moreover, we demonstrate simultaneous recharging of two wearable devices, using two receivers located in arbitrary positions and orientations.

SESSION T6B: ENGINEERED MATERIALS FOR ENERGY HARVESTING

This paper reports a novel low-cost fabrication process of a charged cellular micro-structured polydimethylsiloxane (PDMS) material referred as piezo-electret or ferro-electret for micro-sensors applications. The dielectric spectra reached on these structures exhibit a high piezoelectric longitudinal coefficient d_{33} of 350pC/N. A mechanical characterization method proves the reliability of this material for low-frequencies applications around 100Hz.

This paper reports the optimization, fabrication and testing of an optimized PDMS ferroelectret material for energy harvesting applications. The optimized ferroelectret structure was fabricated by PDMS molding using 3D-printed plastic moulds. To quantify the applied compressive forces and its frequency, an electrodynamic test instrument was used to apply compressive forces to the material.

A novel SiO2 electret having micro/nano-scale-textured surfaces was fabricated and characterized its surface potential. The textures were formed by lithography and wet etching using hydrofluoric acid. The width/pitch of each pattern is 0.2 μm/0.6 μm or 1.0 μm/2.0 μm. Both initial value and stability of surface potential of textured electret was better than that of non-textured electret. On the other hand, the stiction force between textured electret and movable electrode was smaller than that between non-textured electret and electrode.

Friday, December 4, 2015

PLENARY PRESENTATION V

SESSION F7A: ENGINEERED MATERIALS FOR ENERGY SYSTEMS

This paper reports on a simple and low-cost technique using a CO2 laser engraver to create high-surface-area carbon nanoparticles by pyrolyzing the polyimide layer of a commercially-available Cu/Kapton substrate. This strategy offers improvements over previous laser-assisted supercapacitor efforts by offering three distinctive advantages: (1) improved electrical contact between the carbon nanoparticles and the bottom current collector to reduce the internal resistance; (2) an increase of 55% in specific capacitance with a MnO2/carbon hybrid structure; and (3) more compact, stackable architecture with low interconnection resistance.

The fabrication of porous silver microstructured surfaces on copper substrates by a modified freeze casting process is described. These surface layers display a hierarchical porous structure that can be controlled by process parameters such as nanoparticle loading, polymer concentration or the freeze rate. Due to the large surface area, void structure and high thermal conductivity these structures have potential in energy transfer applications, and their use in enhancing heat transfer during the nucleate phase of pool boiling is evaluated.

This paper presents fabrication and characterization of high aspect-ratio (AR) bio-nanotemplated hierarchical NiO supercapacitor electrodes. The hierarchical structure is based on self-assembly of Tobacco mosaic viruses (TMVs) on high AR micropillar arrays. Enhanced assembly of the bio-nanoparticles was achieved by increasing TMV solution accessibility into the deep microcavities of the pillar arrays. Electrochemical characterization of the hierarchical NiO supercapacitor electrodes revealed a 25-fold increase in charge capacity compared to flat NiO with excellent cycle stability over 1500 charge/discharge cycles at 2mA/cm2

SESSION F7B: THERMAL SYSTEMS

The bimetallic strip heat engines (BSHE) are devices exploiting the first-order phase transition of thermo-mechanically bistable membranes to turn heat fluxes generated by thermal gradients into mechanical energy. This strain energy can be converted into electric charges by means of electromechanical transducers. In this paper we model the coupling between a BSHE and a piezoelectric transducer and we evaluate the theoretical performances of these engines when they describe a Stirling cycle.

This work details the clean room wafer-level microfabrication of hybrid fluidic membranes (HFMs) that would be suitable working in quite severe conditions of temperature and pressure. The concept of HFMs consists of two thin RTV silicone based membranes, which encapsulate an incompressible fluid. The development of such HFMs is to provide a technological solution for micro engines by replacing piston with HFMs. The latter will help to avoid friction losses and leaks due to the cylinder-piston gap which are detrimental to the engine operation.

For precise thermal control in satellites under varying internal heat dissipation and thermal boundary condition, we propose a high-fill factor MEMS radiator enhanced by the near-field effect. We have successfully fabricated a prototype with parylene shared springs. A fill factor as high as 89 % has been achieved. It is found that at the ON state,the diaphragm temperature is increased from 71.4 degrees Celsius to 93.8 degrees Celsius, showing up to 70 % enhancement in the radiation heat flux.

SESSION F8A: ENERGY HARVESTING III

A MEMS vibration energy harvester with gap-closing interdigitated electrodes is designed for and tested on HVAC air ducts. A two level stopper system is implemented which utilizes cantilever beams and a film of parylene deposited on the electrode sidewalls, defining the absolute minimum gap between the electrodes and providing electrical insulation. The device operates in impact mode when tested on the ducts with an RMS acceleration of 155 mgRMS. The peak power is 12nW (0.6 nW RMS) with a PSD of 6.9e-11 W/Hz at 240 Hz.

This paper reports the design, fabrication and testing of a novel vibro-impact type triboelectric energy harvester. Strong dynamic nonlinearities are measured for this vibro-impact system, and wideband frequency response under diverse structural parameters are analyzed. The proposed device is applied in two large amplitude scenarios, and generates maximal peak-to-peak voltage of 18V in foot swinging condition and 45V in arm swinging condition.

This paper reports the development of MEMS rotational electret energy harvester (EH) for human motion. With a large-scale proof-of-concept model, power output of 50 μW has been obtained at a very low rotational speed of 1 Hz. Optimal design of MEMS EH is also proposed, and a rotational structure with embedded ball bearing has been successfully developed using 1.5 mm-thick Si substrates. Experimental data of the prototype electret generator with asymmetric added-mass will be presented in the conference.

Pendulum structures are used for converting translational into rotational motion. This work investigates three different structures as well as their geometrical parameters with respect to their ability to couple human leg motion into a rotational inductive energy harvesting system. Multiple-mass setups are considered both in system simulations and experiments. An average output power larger than 20 mW was achieved under real-world conditions using a load resistance equal to the coil resistance.

SESSION F8B: FUEL CELLS

This work is aimed in the fabrication and operation of a paper-based membraneless nanofluidic fuel cell. The advantage of this device lies in the use of adhesive polyester as the support film and as the hook-and-loop tape, offering simplicity, easy to operate, and a significant decrease in cell dimensions. The enhancement of several aspect such as surface area, oxygen source, stream rate and distance between electrodes resulted in a current and power density of 600 mA cm-2 and 132 mW cm-2.

This paper reports the design, fabrication of a miniaturized PEM fuel cell combined microreactor with self regulated hydrogen mechanism. Miniaturized PEM fuel cell comprises of screen printed PEM fuel cell assembly and on board hydrogen storage medium; in order to extend the run time of the system hydrogen production microreactor is combined. Microreactor produces hydrogen based on catalytic hydrolysis of NaBH4; platinum catalyst used in this work is fabricated using pulsed electrodeposition and dealloying technique. Produced hydrogen from the microreactor is self regulated passively by hydrophobic surface based gas venting.

A nanofluidic fuel cell with flow through electrodes was used to investigate the role of pH in the cell performance using ethanol as fuel and two Pd nanoparticles, commercially available and synthesized using ionic liquids. The use of an ionic liquid as reaction medium allows to obtain nanoparticles by a clean pathway, which combined with the technology of fuel cells can be an attractive green solution to supply energy requirements of small devices.

Solid oxide fuel cells (SOFCs) are known as one of the possible next generation energy systems; however, lowering the operating temperature lower than 600C is indispensable to enhance their application fields. In order to solve this issue, we proposed a new SOFC structure using a thin film electrolyte to reduce its resistance at lower temperatures. In this study, we will present a recent progress on our SOFCs using a proton conductive thin film as an electrolyte.

SESSION F9A: FLUID-BASED HARVESTERS

This paper presents a miniature radial-flow wind turbine that converts wind energy into electricity using piezoelectric transducers and magnetic excitation. It is the first realization of a piezoelectric radial-flow wind turbine considering compactness, reliability and the low start-up wind speed into the design. A 159 μW power output was obtained with a 270 kΩ load. The device starts working at 3.5 m/s and keeps operating down to 1.84 m/s after start-up.

The design, manufacturing, and performance characterization of a MEMS-scale turbine is reported. The turbine is designed for integration into a respiration harvester that can convert normal human breathing into electrical power through electromagnetic induction. The turbine is packaged and tested at respiration flow rates between 5-25 lpm. The highest rotational speed was measured to be 9.84 krpm at 25 lpm, resulting in 8.96 mbar pressure drop across the device and 370mW actuation power.

We present an in-shoe energy harvester converting foot-strike energy into electricity to power wearable or portable devices. A flexible air pump is employed to convert the vertical foot motion into airflow, and a miniature wind generator is developed to generate electricity at high frequencies. This design overcomes the difficulties of shoe energy harvesting, including the limited vertical distortion of shoes and the low human-motion frequency. A 6 mW power output was obtained with a 4.9 Ω load.

This paper reports the improved performance in both simulation and experimental results of the 4th generation microfluidic-based energy harvester where the power density has been increased by 6.89 times to achieve higher power density in comparison to the previous versions. Such improvement was achieved by optimizing device geometry (4 channels in series with 6 magnets per channel), resulting in one of the highest power densities among human-body-induced vibration based energy harvesters (PZ [2], EM [3], ES [4]). The fabricated device was tested by constructing a custom testing setup that mimics the periodic acceleration of human foot movements. The final device produced total power of 455.77mW from a volume of 20x3.74x0.75cm3, resulting in a power density of 8.13mW/cm3.

SESSION F9B: ENERGY STORAGE

In this study, new freestanding hierarchical carbon nanocomposite materials are evaluated as electrodes for energy storage. These electrodes consist of carbon nanotubes (CNTs) with a 1-20 nm tube diameter deposited on top of cellulose-derived carbon nanofibers (CNFs) with a 50-250 nm fiber diameter. CNF matrix has great mechanical and electrochemical stability along with valuable mesoporosity, while CNTs contribute to material surface area and electrical conductivity, which is beneficial for supercapacitor high energy performance.

We demonstrate the first liquid-activated textile battery which can achieve a voltage of 1.3 V. Details and experimental data on the design, fabrication and characterization of our Ag-Al textile battery are presented, which offers a unique platform for on-demand power generation for the detection of aqueous samples.

We report the fabrication and testing of silicon-integrated lithium ion secondary micro batteries with interdigitally arranged side-by-side electrodes. Cavities separated by narrow silicon spacers were etched into Si, passivated and provided with thin film current collectors. Slurries of the electrode materials, $Li_y(Ni_{1/2}Co_{1/5}Mn_{3/10})O_2$ as the cathode and $Li_4Ti_5O_{12}$ as the anode, were filled into the cavities by micro dispensing. The fabricated batteries were operated with 1M LiPF6 in EC:DMC as the electrolyte and feature a rate capability of > 10C and a linear capacity loss rate of <0.1 % per cycle over 30 full cycles.

This work presents an in situ operando approach that allows characterization of both stress and structural evolutions in Li-ion battery electrodes using a MEMS platform. New capabilities of our platform are also highlighted, allowing visual observation of crystal phase-dependent structural changes in the electrode, with an improved interference pattern monitoring method, yielding higher sensitivity compared to a previously reported technique. Simultaneous characterization of the stress and structural changes are achieved in a single experiment, showing excellent agreement with literature reports.

PLENARY PRESENTATION VI

Poster Presentations

SCIENCE AND ENGINEERING

Catalysis & Combustion

Porous silicon (PSi) is being investigated as an on-chip energetic material. When an oxidizer is added to PSi, a very energetic combustion reaction can be obtained. We have developed an electrochemical (galvanic) PSi etch process that will allow the integration of PSi with preexisting devices which may utilize the mechanical force, gases, light, or heat released by the PSi reaction. Proof-of-principle energy harvesting of the combustion reaction energy by an off-chip macroscale piezo cantilever has been demonstrated.

The combustion characteristics of non-premixed hydrogen micro-jet-flames with coflow air were studied numerically in present work with the emphasis on the interaction between flame and the solid tube. The variations of the maximum flame temperature and flame height with the Reynolds number in a range from 0.56 to 481 were obtained. The effect of the radiation heat loss on the combustion characteristics, and the effect of different coflow airs on the quenching velocities were also discussed.

Energy Conversion Physics & Devices

PA-03 PHOTONIC CRYSTAL ENABLED THERMOPHOTOVOLTAICS FOR A PORTABLE MICROGENERATOR pg. 312

W.R. Chan[1], V. Stelmakh[1], C.M. Waits[2], M. Soljačić[1], J.D. Joannopoulos[1], and I. Celanović[1]
[1] *Massachusetts Institute of Technology, USA and US Army Research Laboratory, USA*

This work presents the design and characterization of a first-of-a-kind millimeter-scale thermophotovoltaic (TPV) system using a metallic microburner, photonic crystal (PhC) emitter, and low-bandgap photovoltaic (PV) cells. We report on the integration of the microburner and PhC in a complete TPV system: we present measurements and simulations of electrical power generation of TPV systems with and without the PhC emitter.

PB-04 AUTOPARAMETRIC RESONANCE SYSTEMS FOR VIBRATION-BASED ENERGY HARVESTERS pg. 317

L. Kurmann[1], D. Hoffmann[2], B. Folkmer[2], Y. Manoli[3], P. Woias[3], and R. Anderegg[1]
[1] *University of Applied Sciences and Arts Northwestern Switzerland, SWITZERLAND,*
[2] *Hahn Schickard, GERMANY, and* [3] *University of Freiburg - IMTEK, GERMANY*

We model a new kind of vibration transducer with autoparametric capabilities for vibration-based energy harvesters. First a special class of 1D vibration transducers are introduced with strong nonlinear springs that show large resonances and capable for an effective energy transfer but not capable of autoparametric resonance. Then a new 2D class of vibration transducers are presented having strong nonlinear character and well suited for autoparametric resonance vibrations.

PA-05 MULTI-PHYSICS MODELING APPROACH FOR OSCILLATORY MICROENGINES: APPLICATION FOR A MICROSTIRLING GENERATOR DESIGN pg. 324

F. Formosa[1] and L.G. Fréchette[2]
[1] *Université Savoie Mont Blanc, FRANCE and* [2] *Université de Sherbrooke, CANADA*

An electrical circuit equivalent approach has been set up allowing elementary microengine components to be modeled. They cover gas channels/chambers thermodynamics, viscosity and thermal effects, mechanical structures and electromechanical transducers. We propose new developments taking into account scaling effects to establish models suitable for microengines. They are based on simplifications derived from the comparison of the hydraulic radius with respect to the viscous and thermal penetration depths respectively.

PB-06 POWER DENSITY IMPROVEMENT OF BI-CONDUCTIVE POLYMER MEMBRANE FUEL CELLS BY OPTIMIZATION OF ITS INTERNAL RESISTANCES pg. 329

S. Hamel and L.G. Fréchette
Université de Sherbrooke, CANADA

We develop a new set of equations that defines the internal resistances in bi-conductive membrane (BCPM) fuel cells and allows optimization of its critical dimensions and power density has been developed. Based on these equations, a design approach is proposed and fabrication steps that limit the power density of the final device are identified. To validate the model, the results from the developed equations are compared with the experimental results of Hamel et al.

PA-07 Not published

CHARACTERIZATION AND MODELLING OF POROUS SILICON SUPERCAPACITOR ELECTRODES FOR ON-CHIP ENERGY STORAGE

S. Muzi, K. Grigoras, J. Keskinen, L. Grönberg, J. Ahopelto, and M. Prunnila,
VTT Technical Research Centre of Finland, FINLAND

This paper reports the design, fabrication and characterization of porous silicon based super capacitor electrodes for hybrid and/or monolithic integration with energy harvesters. The supercapacitor technology reported here is based on hybrid nanomaterial utilizing ALD (atomic layer deposition) coated nano-porous silicon. Such electrodes exhibit excellent electrical properties and stability in different electrolytes - superior in comparison other Si-based approaches. The stability and volumetric densities of energy (1.3 mWh/cm3) and power (214 W/cm3) compare also favorably to those of carbon based approaches. Proof-of-concept on-chip integration is also demonstrated.

PB-08 FLEXIBLE SOLID-STATE FABRIC BASED SUPERCAPACITOR pg. 334

S. Yong, J.R. Owen, M.J. Tudor, and S.P. Beeby
University of Southampton, UK

This paper reports the design, fabrication and characterization of a flexible fabric solid-state electrical double layer supercapacitor. The proposed device was fabricated using a spray coated fabric substrate to impregnate the textile with carbon particles to form the supercapacitor electrodes. These were combined with a non-hazardous gel electrolyte and achieved high capacitance.

This paper reports multiphysics simulations (COMSOL) of relatively low conductive cathode oxide materials in nanoarchitectures that operate within the appropriate potential range (cut-off voltage 2.5 V) at 3 times the C-rate of micron scale thin film materials while still accessing 90% of material. This paper also reports a novel anode fabrication of Germanium sputtered on a Cu nanotube current collector for lithium-ion batteries. Germanium on Cu nanotubes is shown to alleviate the effect of volume expansion, enhancing mechanical stability at the nanoscale and improved the electronic characteristics for increased rate capabilities.

Engineered & Nanostructured Materials for Energy Conversion

We develop c-axis tilted AlN films on Si(100) substrates in the aim of high output power vibration energy harvesters (VEHs). Tilted c-axis AlN film is predicted that show higher electrical electromechanical coupling (k31) than normal c-axis AlN, leading to higher output power. The tilted-angle of c-axis was controlled by substrate temperature.

In this study, we succeeded in improving surface potential of electret based on inorganic-organic nanocomposite by using fluoropolymer named "CYTOP" and silica nanoparticles. The silica nanoparticles were mixed in the CYTOP before curing or stacked between two CYTOP layers. The surface potentials of CYTOP mixed or stacked with silica nanoparticles were higher than those of a control electret made of pure CYTOP. Comparing two types of electrets, the performance of stack-typed electret is better than that of mix-typed electret.

Herein we describe the fabrication and characterization of piezoelectric composites consisting of BaTiO3 nanoparticles, double wall carbon nanotubes (DWCNT's) and PDMS. By the careful addition and mixing of arc discharge grown DWCNT's into a BaTiO3/PDMS mixture we investigate the effect that varying amounts of DWCNT's will have on the piezoelectric D33 constant on composite films. Piezoelectric constants are measured using a Berlincourt type piezoelectric measurement tool. Final composite structure is verified via scanning electron microscopy.

In the present work, we report the synthesis and evaluation of a methanol tolerant PtAg/C bimetallic catalyst for the oxygen reduction reaction. Electrodeposits of Pt and Ag were carried out by chronoamperometry technique. The PtAg particles synthesized exhibit properties of tolerance to methanol up to 5 M. This cathode is intended to be used in a high-load methanol microfluidic fuel cell or even in a single stream fuel cell.

We report the design, fabrication, and characterization of 2D photonic crystal (PhC) thermal emitters for a millimeter-scale hydrocarbon TPV microgenerator as a possible replacement for batteries in portable microelectronics, robotics, etc. In our TPV system, combustion heats a PhC emitter to incandescence and the resulting radiation is converted by a low-bandgap TPV cell. The PhC tailors the photonic density of states to produce spectrally confined thermal emission that matches the bandgap of the TPV cell, enabling high heat-to-electricity conversion efficiency. The work builds on a previously developed fabrication process to produce a square array of cylindrical cavities in a metal substrate. We present ongoing incremental improvements in the optical and thermo-mechanical properties, the fabrication process, and the system integration, as recently combined with fabrication using novel materials, such as sputtered coatings, to enable a monolithic system.

Fabrication for Energy Systems

This paper reports the fabrication of a rotary MEMS bearing structure for examining the properties of Carbon Nanotube (CNT)-based rotating bearings. Applications of the device are explored.

Textile-based sensor and piezoelectric contributed recently to smart textile development especially focused on medical applications. In this work, the development of a textile-based piezoelectric material has been addressed based on a method compatible with large area manufacturing at low-cost. We first report on the actuation of paper cantilevers using pure crystals demonstrating the efficient and well-known piezoelectric character of the pure material: Rochelle salt. Then the fabrication of the composite material is described. Finally, the converse piezoelectric effect of the composite material is demonstrated.

This paper reports the design, fabrication, and testing of an electromagnetic energy harvester fabricated by using the mature and low-cost rigid-flex printed circuit board (PCB) technology. The rigid boards are used for mechanical frames and coil winding whereas the flexible polyimide is used for mechanical springs and shuttle mass platform on which a permanent magnet is attached. The harvester showed a strong nonlinearity due to the spring hardening effect, thus increasing its operation bandwidth.

A cost effective bottom-up process for the fabrication of micro thermoelectric generators (µTEGs) was developed. It is based on a novel fabrication method involving two selectively dissolvable photoresists and galvano-static electrodeposition of thermoelectric materials. The characterization of a 71 thermocouples µTEG will be presented accompanied with some data from simulations.

In this paper we present a piezoelectric based vibrational energy harvesting device (PEH) which could be integrated into a biocompatible package to power implantable sensor or therapeutic medical devices. The presented architecture is a serial bimorph laminated with ultra-thinned (ranging from 15µm to 100µm) outer PZT "skins" that could operate at a "very low frequency", below 25Hz typically. The core process flow is disclosed (see Figure 1) and detailed with regards to cost and reliability.

We present the fabrication and evaluation of integrated on chip micro-scale supercapacitors. The cells strings to be ultimately attractive and viable for electronic applications must demonstrate the performance uniformity for the individual micro-EDLCs. One of the important aspect of this issue is the reproducibility and yield of the micro-EDLCs fabricated in a one process flow.To address this issue, we performed few characterizations techniques among them: electrochemical Cyclic voltammetry (CV) and impedance spectroscopy (IS).

Power Electronics

This paper presents design and simulation of a power management circuit for MEMS electrostatic energy harvesters with significantly small capacitances in order to make it applicable to highly miniaturized generators. The interface circuitry is based on a flyback technique and automatically detects the switching instants for optimal power transfer through the flyback path without using any external control signals. The need to power the circuitry by extracted power only and the limited available power makes low power consumption of the circuit a main design driver.

Heat & Mass Transfer in Energy Systems

We fabricated in-plane thermoelectric micro-generator on a free-standing Silicon nitride thin film substrate, and evaluated the performance of the generator. The measured temperature difference in the generator was 22.3 K at 373K due to its high thermal resistance of the structure. The calculated exergy of the thermoelectric device is up to 7 %. The efficiency is much higher than that of a conventional type thermoelectric module. It is possible to get higher performance by the thermal design, which is a more simple way than an improvement of ZT.

Tribology

This paper reports a comprehensive analysis of the performance for gas-lubricated bearing-rotor system in silicon microengine. The generalized lubrication model and dynamics model are developed and the effects of micro fabrication defects, viscous friction force and temperature on both steady-state and dynamic characteristics of bearing system are investigated. The results can serve as a useful tool for the design of silicon microbearing-rotor systems.

APPLICATION

Energy Harvesting Devices & Systems

This paper demonstrates an entirely new, parallel-beam architecture for passively-switched energy harvesting and tailors the beams' interaction to vary performance. The harvester's volume is 5 times smaller than previous version; however, it generates power over the entire range from 0.2 g to 2 g and from 5 Hz to 20 Hz.

We designed and fabricated a new vibrational energy harvester that can convert low frequency vibrations to electrical energy over a wide frequency band. To realize the vibrational energy harvester, we proposed to use a remarkable phenomenon called stochastic resonance, which makes amplitude of bi-stable oscillators increase. Then, we modeled a vibrational energy harvester that has double well potential system and numerical simulations were implemented. In accordance with simulation results, an energy harvester was designed and fabricated.

This paper focuses on a dynamic study of a thermal energy harvester . We propose here a dynamic model of the device, simulations results and experimental validation by using a complete set of bimetallic strips characterized mechanically.

This paper presents the electrical characterization of a novel concept of micro thermal energy harvesters based on thermally activated bilayer buckling structures. A piezoelectric layer is directly integrated into the bistable structure. The buckling is first induced mechanically by a tip to avoid the eventual pyroelectric charges. Then the thermal bucking is characterized and the output power of different geometries is measured.

The improvement of output energy from the electret type vibration energy harvester is demonstrated. By using high-density doubled number of electrodes and optimizing the electrode width and pitch, the output power of 26 uW was obtained at constant vibration with 400 ump-p, 350 Hz from the numerical calculation, which is as five times large as previous work.

We propose an energy harvester using ferrofluid droplets that deform in an oscillating magnetic field. The proposed device consists of top and bottom plates with a conducting electrode coated with a hydrophobic layer and water-based ferrofluid droplet. The contact area between the ferrofluid and the solid surface is changed according to the magnetic field applied by a magnet, which generates AC output power. We demonstrate that the modulation of ferrofluid droplets can be easily and effectively controlled by remote actuation from external magnetic field.

This paper presents an experimental verification of a self-excitation control of a resonance-type vibration energy harvester with a Duffing-type nonlinearity which is designed to perform effectively in a wide frequency range. An experimental prototype harvester was designed and fabricated to conduct validation tests. It was shown that the numerical and experimental results agreed very well, and the highest-energy solutions were successfully stabilized globally.

We have developed scalable indoor lighting energy harvester for IoT application which especially using for agricultural environmental sensing. Optical harvester device fabrication processes were using MEMS and printing hybrid manufacturing process for low cost and for scalable characteristics. We have evaluated input power and output power scalability under several environmental conditions.

This work reports the design and optimization of a novel combined vibration energy harvester based on the use of electrodynamic and magnetoelctric principle for reliable and powerful system within a challenging size. Finite element analysis for the combined device is developed to evaluate the convertor. The system consists on the use of magnetoelctric transducer placed between two magnets and surrounded with a coil. Rectangular geometry for the magnetoelctric transducer is selected.

This work reports the design and optimization of a novel combined vibration energy harvester based on the use of electrodynamic and magnetoelectric principle for reliable and powerful system within a challenging size. Finite element analysis for the combined device is developed to evaluate the convertor. The system consists on the use of magnetoelectric transducer placed between two magnets and surrounded with a coil. Rectangular geometry for the magnetoelectric transducer is selected.

We have designed special suspended microplatforms as a part of Silicon compatible planar thermoelectric microgenerators. Bottom-up grown silicon nanowires will bridge such platforms to the surrounding silicon bulk rim acting as thermoelectric material. In order to maximize the temperature developed between both areas, any other support bridging structures (usually auxiliary silicon beams) are rethought as low conductance thin film membranes with a sieve-like design that allows fabricating them with a short additional wet anisotropic etch step.

This paper reports on the theory and experimental verification underpinning optimization of the active electrode area of a cantilevered piezoelectric vibration energy harvester in order to maximize output power. The results show that increasing active area does not always increase output power; on the other hand, output power may be reduced if the region corresponding to low mechanical strain is covered.

This work presents the design, fabrication and characterization of a nonlinear MEMS Electromagnetic Vibrational Energy Harvester (VEH) with wide operational bandwidth. The nonlinearity is introduced in the proposed device through the stretching strain of the specially designed fixed-fixed beam arms, which gives rise to the wider bandwidth of 57 Hz at 1g. The device is characterized at different level of integration to report a comparative study. This work also discusses an electrical actuation mechanism to overcome the fundamental limitation of multi-stability of nonlinear VEH at micro-scale.

PB-50 **MEMS NARROW GAP ELECTROMAGNETIC HARVESTER WITH MITIGATION OF CURVATURE DISTORTION** **pg. 536**

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

The narrowing air-gap of electromagnetic energy harvester is one of the most important parameter to improve the generated energy. In this paper we demonstrate a compensation method for residual stress on the NdFeB sputtered magnetic film on Si wafer. By using both-side sputtering method, we successfully reduced the residual stress from 144 MPa to 9.40 MPa.

PA-51 **Not published**

MICRO ELECTROMAGNETIC VIBRATION ENERGY HARVESTER BASED ON COMBINED FREE/RIGID IMPACT MOTION FOR LOW FREQUENCY - LARGE AMPLITUDE OPERATION

A. Haroun[1,2], I. Yamada[1], and S. Warisawa[1]
[1]University of Tokyo, JAPAN and [2]Cairo University, EGYPT

We present a micro electromagnetic vibration energy harvester (FIMG) that can work effectively at low frequencies with analytical and experimental study. It simply consists of a permanent magnet mass that allowed to move freely inside a tube carrying an electrical coil directly connected to the vibration source and closed at both ends with two hard end stops. The proposed harvester shows a significant output power at low frequency - large amplitude vibration. A prototype of D9L12 cylindrical size can generate 91.3 μW at 2.5Hz and 9.87 ms^{-2}. In addition, it has a simple construction that allows size minimization.

PB-52 **MULTILAYER FERROELECTRET-BASED ENERGY HARVESTING INSOLE** **pg. 541**

Z. Luo[1], D. Zhu[1,2], and S.P. Beeby[1]
University of Southampton, UK and [2]Coventry University, UK

This paper reports a flexible energy harvesting insole made of multilayer ferroelectrets, and demonstrates that this insole can sufficiently power wireless transmission. The insole can produce more than 100 μJ of energy from every step of walking. For every 3 to 4 footsteps, the transmitter gains energy from the insole and is able to send an 8-bit wireless signal to its receiver, which is 6 to 8 meters away from the source.

PA-53 **PASSIVELY-SWITCHED, NON-CONTACT ENERGY HARVESTER FOR BROAD OPERATIONAL RANGE AND ENHANCED DURABILITY** **pg. 546**

W.Z. Zhu and C. Livermore
Northeastern University, USA

This paper presents the first simulation and demonstration of passively-switched dynamics in a multi-element harvester in which the beams interact by non-contact (magnetic) means rather than by mechanical impact.

PB-54 **PIEZO-MAGNETIC ENERGY HARVESTING FROM MOVEMENT OF THE HEAD** **pg. 551**

A. Delnavaz and J. Voix
École de Technologie Supérieure, CANADA

We design, optimize and test the piezo-magnetic energy harvester that is capable of converting non-harmonic movements of the human head into electricity. The device is composed of a doubly-clamped piezoelectric fiber composite (PFC) beam and two permanent magnets. The PFC beam comprises unidirectionally aligned piezoceramic micro-fibers with interdigitated electrodes. The device can operate with the small-amplitude and low-frequency movements of the head for which other energy harvesting solutions are rarely efficient. Also, the proposed energy harvester can inconspicuously be integrated with the glasses.

PA-55 **PIEZOELECTRIC ENERGY HARVESTING FROM HEARTBEAT VIBRATIONS FOR LEADLESS PACEMAKERS** **pg. 556**

M.H. Ansari and M.A. Karami
University at Buffalo, USA

In this research, we study energy harvesting from heartbeat vibrations using fan-folded piezoelectric beams. The generated energy from the heartbeat can be used to power a leadless pacemaker. The proposed device does not incorporate magnets and is thus Magnetic resonance imaging (MRI) compatible. The required power for a pacemaker is about 1 μW. It is shown that our proposed device generates an order of magnitude more power than the nominal power needed for a leadless pacemaker. The small size of the energy harvester and sufficient output power of the device are the advantages of this new design. The size of the device is $2\,cm \times 0.5\,cm \times 1\,cm$ (1 cc in volume).

This paper answers the often asked, and until now inadequately answered, question of which MEMS compatible transducer type achieves the best power density in an energy harvesting system. The results presented allow an engineer to choose an optimal transduction mechanism as a function of harvesting operating frequency, acceleration and device size.

Fuel Cells, Reactors, Combustors & Heat Engines

We investigate the kinetics, catalytic activity and mass-transport of a layer of porous electrode that consists of external hierarchical nanostructures through 2D COMSOL simulations of an anode of a direct methanol fuel cell (DMFC). Investigations include the influence of nanostructures morphology on total catalytic activity and specific activity based on pore accessibility as well as catalytic efficiency of nanostructures. Additionally, Thiele modulus equation was applied inside the simulations to support and provide a well understanding of the results.

Recently, enzymatic biofuel cells that use glucose in a human body to produce electricity have been of special interest. In this study, we fabricated of a glucose biofuel cell with flexible and stretchable electrodes using MWCNT on a PDMS substrate. The maximum power of 0.46 μW at 96.5 mV that corresponds with the power density of 1.52 μW/cm2 was realized by introducing a glucose solution of 100 mM at room temperature.

We develop a membraneless enzymatic microfluidic fuel cell, which operates using ethanol as fuel. Alcohol dehydrogenase (DH) enzyme was selected as catalyst, and altogether with aldehyde DH, were used as bioanodes to enhance the ethanol electro-oxidation reaction. The study of the enzymatic array (combined, vertically and horizontally separated) resulted in the highest cell performance to date reported corresponding to the combined enzymatic electrode: 7.01 mW cm-2.

We develop air-breathing μ-DMFCs with different anode flow fields to improve the cell performances. From the results obtained in this work, it can be concluded that the single-serpentine flow field structure parameters demonstrated in the μ-DMFC is also applicable to the greater DMFCs or the PEMFCs running on the anode.

Energy Management, System Integration & Energy Aware Systems

In this work an integrated CMOS circuit is presented which automatically maximizes the charging current for rechargeable chip integrated micro fuel cell accumulator arrays. These accumulators comprise a fuel cell for delivering energy to systems and a hydrolysis cell for recharging the integrated hydrogen storage. The charging current supplied by small solar cells which are projected to be part of the chip package is continuously monitored and an interface circuit is adjusted in order to maximize the charging current.

This paper reports the design, fabrication, and characterization of novel conductometric humidity sensors that employ an ultrathin film of graphene oxide (GO) nanoflakes as transducing element. The GO film is deposited at atmospheric pressure and at a temperature slightly above room temperature using a home-built electrospray printer. In dynamic humidity tests conducted at atmospheric pressure, the sensor tracks the response of a commercial sensor and reacts to changes in humidity in less than 500 ms. There is a quadratic dependence of the relative humidity on the sensor resistance for the studied relative humidity range between 3% and 63%, with more than a three-fold change in resistance over the range. The power consumption of the sensor is less than 30 μW while drawing 7 μA, and less than 15 μW while drawing 5 μA. Our devices are promising candidates for deployment in a distributed sensor network due to their low cost, small size, and low power consumption.

RF Energy Conversion

This paper describes the high level design of an IPT (Inductive Power Transfer) system for bodyworn electronics, and in doing so investigates the challenges for an IPT system that arise specifically inthis scenario. Principally, these are: highly variable coil coupling through time-varying miss-alignmentand coil separation; a requirement that one or both of the coils must be wearable and thus flexible andwashable; and proximity to the human body introducing limits on the maximum EM field.

This paper investigates performance of a near field wireless power transfer system that uses curved relay resonator coils to extend transfer distance. Near field wireless power transfer can transfer energy over a relatively short distance which is on the same order of dimensions of the coupled coils. Previous work has shown that the energy transfer distance can be increased using flat relay resonators. This research focuses on using the curved relay coils to extend energy transfer distance. The concept can be used in e-textiles applications.

Thrusters & Propulsion Systems

Since combustion is a simple way to achieve large quantities of energy from a small volume, we develop a MEMS based solid propellant microthruster array for small spacecraft and micro-air-vehicle applications. A large range of thrust force is obtained by varying chamber and nozzle geometry parameters in one step of DRIE. The use of polysilicon initiator deposited on thin membrane ensures a better heat transfer to the propellant and thus a short response time and low energy consumption. Experimental tests of ignition and combustion employing home made propellants are reported and discussed.

ADDITIONAL

Fluidic

Low pumping loss working spaces were developed for a novel planar free-piston Stirling microengine. The complexity of its flow geometry and its expected high operating frequency (kHz) are difficult to analyze. Thus, experimental research was favored. We describe the design process used to shape the exchangers and how static pressure was measured along a steady unidirectional flow and analytically treated to determine pumping loss. It was surmised to be an efficient way of immediately depicting pumping loss issues in both directions for what would be a transient pulsating flow.

Magnetic

We design, model and test a new concept of electret-based energy harvester for use on nearby an electrical conductor carrying an AC current. The experimental results of an energy harvester, using external bias voltage, verify the working principle of the harvester. The RMS output voltage sharply increase when the current amplitude gets 36 A - 40 A and continuously increase when the bias voltage varying from 5V-67V.

We report the influence of film thickness on the material properties of electroplated CoPt permanent magnets. It was observed that the magnetic properties decrease substantially for films below 2 μm. This effect was determined to be a consequence of metal-silicide reactions at the substrate interface. Subsequently, a TiN diffusion-barrier layer was shown to inhibit the silicide reaction and thereby maintain strong properties in micron-thick layers.

Piezoelectric

We present a new computational technique which is aimed at obtaining fast and accurate simulations of piezoelectric beams, used in inertial energy harvesting MEMS.A refined, yet simple, model is proposed with reference to the multi-physics problem of piezoelectric energy harvesting by means of laminate cantilevers. The main objective is to retain a simple structural model (Euler-Bernoulli beam), with the inclusion of effects connected to the actual three-dimensional shape of the device.