Session 8: Sensors, MEMS, and BioMEMS– NEMS and Energy Harvesters
Monday, December 15, 1:30 p.m.
Imperial Ballroom B
Co-Chairs: Rainer Minixhofer, AMS
Kea-Tiong Tang, National Tsing Hua University

1:35 p.m.
8.1 Two-Dimensional Nanoelectromechanical Systems (2D NEMS) via Atomically-Thin Semiconducting Crystals Vibrating at Radio Frequencies, P. Feng, Z. Wang, J. Lee, R. Yang, X. Zheng, K. He and J. Shan, Case Western Reserve University

This paper reports on the exciting fundamentals and device engineering perspectives of a new type of two-dimensional nanoelectromechanical systems (2D NEMS) based on atomically-thin semiconducting crystals. 2D crystals, such as graphene and molybdenum disulfide (MoS_2), can be derived from layered materials consisting of are bonded through week van der Waals forces. Their outstanding mechanical properties (ultra-elastic, low areal mass density, high elastic modulus, and high intrinsic strength, etc.), coupled to their unique electronic properties, make them attractive candidates as building blocks for 2D NEMS. While graphene is the herald of 2D crystals, MoS_2 has been a forerunner among the transition metal dichalcogenides (TMDCs) and 2D semiconducting crystals beyond graphene. While graphene is a semi-metal, the semiconducting MoS_2 (and other TMDCs) has shown intriguing characteristics such as band structure dependence on number of layers and strain. This paper describes the initial explorations and recent rapid development of vibrating 2D NEMS beyond graphene. We introduce the basics on demonstrating the first 2D NEMS enabled by suspended MoS2 crystals. We then discuss key metrics such as dynamic range (DR) and nonlinearity in such 2D NEMS, showing that these robust 2D NEMS resonators can have very broad DR (up to ~110dB). We also demonstrate electrically tunable MoS_2 2D NEMS resonators, and through extensive measurements, showing the excellent electrical tunability. We further describe latest efforts in advancing these resonant 2D NEMS at radio frequencies for creating new functions and higher performance.

2:00 p.m.
8.2 Integrated On-Chip Energy Storage Using Porous-Silicon Electrochemical Capacitors, D.S. Gardner, C.W. Holzwarth, Y. Liu, S.B. Clendenning, W. Jin, B.K. Moon, C.L. Pint, Z. Chen, E. Hannah, R. Chen, C.P. Wang, C. Chen*, E. Mäkilä**, and J.L. Gustafson, Intel Corp., *Florida Int'l Univ., **University of Turku

Capacitors are favored over batteries for energy harvesting and certain energy storage applications. Electrochemical capacitors based on porous-silicon nano¬structures were synthesized and passivated using either ALD TiN or CVD carbon. Highly stable high density capacitances are achieved and are fabricated using silicon process methods with the potential of on-die integration.

2:25 p.m
8.3 Comprehensive Analysis of Deformation of Interfacial Micro-Nano Structure by Applied Force in Triboelectric Energy Harvester, M.-L. Seol, J.-W. Han*, J.-H. Woo, D.-I. Moon, J.-Y. Kim, and Y.-K. Choi, KAIST, *NASA Ames Research Center

The correlation between deformation of an interfacial micro-nano structure and applied force in a triboelectric energy harvester (TEH) is analyzed for the first time. Simulation, visualization experiment, modeling, and electrical measurements are conducted to clarify the effects of structural deformation according to the applied force, which governs triboelectric charge density at the interface.

2:50 p.m.
8.4 A High Efficiency Frequency Pre-defined Flow-driven Energy Harvester Dominated by On-chip Modified Helmholtz Resonating Cavity, X.J. Mu, C.L. Sun, H.M. Ji, L.Y. Siow, Q.X. Zhang, Y. Zhu, H.B. Yu, J.F. Tao, Y.D. Gu, and D.L. Kwong, A*STAR

We present a novel flow-driven energy harvester with its frequency dominated by on-chip modified Helmholtz Resonating Cavity (HRC). This device harvests pneumatic kinetic energy efficiently and demonstrates a power density of 117.6 $\mu W/cm^2$, peak to peak voltage of 5 V, and charging of a 1 μF capacitor in 200 ms.

3:15 p.m.

8.5 Fabrication of Integrated Micrometer Platform for Thermoelectric Measurements, M. Haras, V. Lacatena, F. Morini, J.-F. Robillard, S. Monfray*, T. Skotnicki*, and E. Dubois, Institut d'Électronique de Microélectronique et de Nanotechnologie, *STMicroelectrinics

Preliminary simulations of lateral thermo-generators showed that silicon's harvesting capabilities, through a significant thermal conductivity reduction, could compete with conventional thermoelectric materials, offering additional: CMOS compatibility; harmlessness and cost efficiency. We report the fabrication and characterization of integrated platforms showing a threefold reduction of thermal conductivity in 70nm thick membranes.

3:40 p.m.

8.6 Atomic Scale Engineering of Metal-Oxide-Semiconductor Photoelectrodes for Energy Harvesting Application Integrated with Graphene and Epitaxy $SrTiO_3$, L. Ji, M. McDaniel, L. Tao, X. Li, A. Posadas, Y.-F. Chang, A. Demkov, J. Ekerdt, D. Akinwande, R. Ruoff, J. Lee, and E. Yu, The University of Texas at Austin

Efficient and stable hydrogen production from water is demonstrated using a Si-based photocathode with an epitaxial oxide capping layer. A thin epitaxial strontium titanate, $SrTiO_3$, protection layer is grown directly on Si (001) by molecular beam epitaxy. By taking advantage of the conduction band alignment and lattice match between single crystalline $SrTiO_3$ and Si, the photogenerated electrons easily transport through the $SrTiO_3$ layer with minimized interface trap states and reduced recombination rate. Metal-insulator-semiconductor (MIS) photocathodes under broad-spectrum illumination at 100 mW/cm^2 exhibited a photocurrent density and photovoltage of 35 mA/cm^2 and 450 mV, respectively. There was no observable decrease in performance after 10 hr operation in 0.5M H2SO4. The efficiency and performance were highly dependent on the size and spacing of the structured metal catalyst. Using a nanosphere lithography lift-off process, 50 nm mesh-like Ti/Pt structures were created for the MIS photocathode and achieved an applied-bias-photon-to-current efficiency of 4.9%. Due the high mobility, graphene can also increase the fill factor.