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Faculty of Mechanical Engineering הפקולטה להנדסת מכונות

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A Novel Synergy between Sensing and Energy Scavenging

Emad Iranmanesh, PhD
Mechanical Engineering and Robotics Program, Guangdong Technion-Israel Institute of Technology, Shantou, Guangdong, P. R. China
e-mail: emad.iranmanesh@gtiit.edu.cn

Hosted by: Em. Professor Michael Shapiro

Sensors for forces, pressures and vibrations play an important role in many IoT applications. Traditionally, MEMS piezoelectric sensors have been designed to convert mechanical energy to electrical signals. However, MEMS are difficult to integrate with complementary metal-oxide semiconductor (CMOS) peripheral electronics for a system on a chip. Despite advances in mechatronics, miniaturization, and advanced manufacturing technologies in producing compact and wearable sensing devices in various applications (human motion analysis, activity recognition, and health monitoring), these units yet require energy to run CMOS-based circuitry. Piezoelectric Energy Harvesters (PEHs) can be sometimes employed in MEMS sensors to convert mechanical vibrations into electrical energy to provide an external source of power for sensing systems. However, integration of both elements into a single compact device is problematic. Moreover, due to energy losses, efficiency of these devices is yet low. Sensing and energy harvesting have never been co-designed at both device and circuit level. Therefore, a synergy design between energy scavenging and sensing offers a possibility to create a system for simultaneous energy harvesting and sensing, where a single piece of hardware acts both as a harvester and a sensor without need for batteries. As such, there is a clear need for a compact bi-functional mechanically-driven device fully compatible with electrical element which converts mechanical energy directly to a signal is attractive from mechanical side. An integration of both ultra-low power amplifier and rectifier is also highly-favorable from electrical perspective.

An ideal route to address a bi-functional device is to implement a synergy between sensing and energy harvesting, where an event-trigger sensor is used to avoid frequent sampling and reduce power consumption, and an energy harvesting mechanism is in place for energy recycling. In such a configuration, the signal from the sensing unit is the same as the one registered in the energy harvesting system. A tradeoff between energy harvesting and sensing exists in that the output signal extracted for sensing in the form of voltage or current, needs to be amplified; whereas the harvesting function requires a power to drive the system. This seminar focuses on a novel flexible two-terminal hybrid piezotronic (coupling semi-conductivity and piezoelectricity) n-p-n bipolar junction transistor (PBJT) acting as a highly-sensitive, current/voltage-mediated pressure sensor which implements the desired synergy between sensing and energy harvesting. Vertically-stacked n-p-n structure compromised of a p-type polymer (base) sandwiched by two n-type piezoelectric semiconductor layers (emitter and collector). The PBJT bridges between energy harvesting and sensing, so that transformation of mechanical vibration into electrical energy is utilized as a source of power to bias an electrical element with least energy loss and no mismatch. Moreover, the PBJT offers simultaneous signal amplification and regulation which are always arduous in sensory/harvesting systems. Based on device physics an analytical model along with small-signal equivalent electrical circuit which approve high-sensitivity of device and the sensing-harvesting synergy have been developed. A single-pixel device has also been fabricated and experimentally analyzed. The PBJT shows high-record sensitivity of 139.7 kPa-1 (current-based) and 88.66 kPa-1 (voltage-based). Optimization of device performance in both sensing and harvesting will be of future interest where emitter, collector doping (Aluminum-and Indium-doped Zinc Oxide), replacement of current piezoelectric semiconductor bulk layers at emitter and collector with easy-synthesized nanotubes/nanorods, and variation in base thickness along with its doping (Lithium bis (trifluoromethane) sulfonimide-LiTFSI, Phenyl-C61-Butyric Acid Methyl Ester-PCBM) are proposed. Last but not least, characterization of the source of mechanical vibration, material selectivity to introduce a novel ultrasonic device (PBJT acts as a low-frequency detector) in harvesting ultrasonic energy (proposed to run an image-guided endoscopic capsule robot), and introduction of yarn-based PBJT as a fiber being sewed in wearables which opens new windows to smart textile technology, will also be of high interest as future work.

Seminars Coordinator: Assoc. Prof. Matthew Suss.

Bio: Emad Iranmanesh is currently working as a Research Associate in Mechanical Engineering and Robotics Program, Guangdong Technion-Israel Institute of Technology. Prior to this, he was a postdoc fellow of Peking University where he got the award of young talented scientist of Guangdong Province, China. He got his PhD from Sun Yat-sen University-Carnegie Mellon University, Joint Institute of Engineering. His research mostly focuses on: microelectronics, piezotronics, wearables, sensors, and CMOS-based devices. He is the active member of IEEE Electron Device Society and his research lead to 6 patents and high impact publications published and considered for publication in Nature Microsystems & Nanoengineering, IEEE Electron Device Letters, IEEE Transactions on Electron Devices, IEEE Electron Device Meeting (IEDM), Nanoscale Advances, RSC Advances, and Sensors.

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