Session 15: Sensors, MEMS, and BioMEMS– Graphene Devices, Biosensors and Photonics
Tuesday, December 16, 9:00 a.m.
Imperial Ballroom B
Co-Chairs: Debbie G. Senesky, Stanford University
Fengnian Xia, Yale University

9:05 a.m.
15.1 An Ultra-Sensitive Resistive Pressure Sensor Based on the V-Shaped Foam-like Structure of Laser-Scribed Graphene, H. Tian, Y. Shu, M.A. Mohammad, C. Li, Y. Yang and T.-L. Ren, Tsinghua University

We demonstrate a flexible, ultra-sensitive resistive pressure sensor based on the foam-like structure of laser-scribed graphene (LSG). Benefitting from the unique microstructure of the LSG, the sensitivity of the pressure sensor is as high as 0.96 kPa-1 in the low pressure range (0~50 kPa), which is the highest among all reported graphene-based pressure sensors. Moreover, the sensitivity in the high pressure range (50~113 kPa) is 0.005 kPa^{-1}. The response of the pressure sensor is highly stable up to 100 cycles with excellent performance. Our pressure sensor can meet the needs of specific applications, for example, high sensitivity for low-pressure applications and low sensitivity for high deformation applications. Moreover, the laser-scribing technology could enable large-scale production of the LSG pressure sensor with low cost in ~20 minutes. Our work indicates that laser scribed flexible graphene pressure sensors could be widely used for artificial electronic skin (e-skin), medical-sensing, bio-sensing and many other areas.

9:30 a.m.
15.2 Large-Scale Fabrication of Graphene-based Electronic and MEMS Devices, D. Wang, H. Tian, I. Martin-Fernandez, T.-L. Ren* and Y. Zhang, Lawrence Berkeley National Laboratory, *Tsinghua University, Chinese Academy of Sciences

Graphene has been demonstrated great potential in electronic and optoelectronic applications. However, the zero band gap of graphene leads to the low on/off ratio in field effect transistors and low optical wavelength selectivity in photo detectors. Moreover, the commonly used wet-transfer process for chemical vapor deposited (CVD) graphene could introduce contamination and defects that degrade the graphene device’s performance. These problems could be resolved if we found a graphene ribbon fabrication method that could precisely control the width, edge structure, as well as registries (location, orientation) on the substrates. In this talk, we will showcase our recent works on novel transfer-free and contaminant-free CVD methods for direct-growth of graphene nanoribbons and microribbons on dielectric substrates. By growing graphene nanoribbons (GNR) on well-designed nano-templates, we demonstrated the fabrication of die-scale GNR-FET array on SiO_2/Si substrate using simple photolithography tools[1]. The carrier mobility (3,000 /cm^2/V/s) is higher than those previously reported graphene nanoribbons fabricated on SiO2 substrates, thanks to our novel transfer-free and contaminant-free direct growth process. Because the GNR width in our method is defined by the metal-catalyst film thickness, which is not limited by the lithography resolution, it has the potential to be scaled down to sub-nanometer level. Direct GNR synthesis also avoids the problems of grain boundaries in conventional wafer-scale graphene film synthesis. For the case of graphene microribbons (GMR), by using fast annealing at a low temperature (750C for 2-5 minutes) and dewetting of Ni, continuous few-layer GMRs (2-10 µm in width, up to a few millimeters in length) grow directly on bare dielectric substrates through Ni assisted catalytic decomposition of hydrocarbon precursors [2]. These high quality GMRs exhibit low sheet resistance of ~700 Ω -2100 Ω, high on/off current ratio of ~3, and high carrier mobility of ~655 cm^2/V/s at room temperature. To demonstrate the temperature sensitivity of the CVD graphene devices, we measured the temperature dependence of the Raman G shift as well as the electrical resistance. Increasing temperature led to a red shift of the G mode peak of CVD graphene. A temperature coefficient of -0.025/cm/C can be extracted from the slope of Fig. 5, which is consistent with previous reports for single layer graphene flakes. The thermal conductivity can be therefore determined in the range of 3.10 x 10^3 to 3.39 x 10^3 W/mK, which is in the mid-range of multi-walled and single-walled carbon nanotubes. The electrical resistance dependence on temperature shows good agreement with theoretical prediction. For VG>20V above Diract point, resistance decreases with temperature due to the increase of intrinsic carriers. In contrary, while VG>20V below Diract point, resistance increases with temperature due to increase of phonon scattering. This bimodal metallic-semiconducting behavior shows great potential for CVD graphene as an intriguing material for future thermal sensing platform. Besides, CVD graphene is demonstrated as a fully transparent photodetector [3]. The fabrication process is shown in Fig. 7a. The device is fully transparent and flexible. The transparency is ~90%. The photo response is tested with good performance under flat and bend condition. Both of the GNR and GMR devices fabricated by the direct CVD growth methods have shown significant performance improvement over those made by conventional lithography methods. The new methods have overcome several limitations for the GNR and GMR patterning and are compatible with large-scale fabrication of graphene nano-devices. They can in principle fabricate graphene ribbons of any size and geometry, which is a feasible technology for the future integration with conventional semiconductor materials and the scalable production of graphene-based thermoelectric and optoelectronic devices.

9:55 a.m.
15.3 Flexible, Transparent Single-Layer Graphene Earphone, H. Tian, C. Li, M.A. Mohammad, Y. Yang and T.-L. Ren, Tsinghua University

We demonstrate a novel flexible and transparent earphone based on single-layer graphene (SLG) for the first time. The SLG earphone operates in the frequency range of 20 Hz to 200 kHz and has a highest sound pressure level (SPL) of 70 dB with a 1 W input power. The SPL emitted from one to six layers of stacked SLG are compared. It is observed that the SPL decreases with an increasing number of stacked layers. The SLG earphone is packaged into a commercial earphone casing and can play music. Compared with a conventional earphone, the SLG earphone has a broader frequency response and a lower fluctuation. Testing results in both time- and frequency-domains show a frequency doubling effect, which indicates that the working principle is based on the electro-thermoacoustic (ETA) effect. As the SLG earphone operates in both the audible and ultrasonic frequency range, it can be used for a wide variety of applications, including for interspecies communication.

10:20 a.m.
15.4 A Semiconductor Bio-electrical Platform with Addressable Thermal Control for Accelerated Bioassay Development, T.-T. Chen, C.-H. Wen, J.-C. Huang, Y.-C. Peng, S. Liu, S.-H. Su, L.-H. Cheng, H.-C. Lai, T.-C. Liao, F.-L. Lai, C.-W. Cheng, C.-K. Yang, J.-H. Yang, Y.-J. Hsieh, E. Salm, B. Reddy*, F. Tsui, Y.-S. Liu, R. Bashir* and M. Chen, Taiwan Semiconductor Manufacturing Company, *University of Illinois at Urbana-Champaign

In this work, we introduce a bioelectrical platform consisting of field effect transistor (FET) bio-sensors, temperature sensors, heaters, peripheral analog amplifiers and digital controllers, fabricated by a 0.18μm SOI-CMOS process technology. The bio-sensor, formed by a sub-micron FET with a high-k dielectric sensing film, exhibits near-Nernst sensitivity (56-59 mV/pH) for ionic detection. There were also 128x128 arrays tested by monitoring changes in enzyme reactions and DNA hybridization. The electrical current changes correlated to changes in pH reaching -1.387μA/pH with 0.32μA standard variation. The detection of urine level via an enzyme(urease)-catalyzed reaction has been demonstrated to a 99.9% linearity with 0.1μL sample volume. And the detection of HBV DNA was also conducted to a 400mV equivalent surface potential change between 1 μM matched and mismatched DNA. As a proof of concept, we demonstrated the capabilities of the device in terms of detections of enzymatic reaction and immobilization of bio-entities. The proposed highly integrated devices have the potential to largely expand its applications to all the heat-mediated bioassays, particularly with 1-2 order faster thermal response within only 0.5% thermal coupling and smaller volume samples. This work presents an array device consisting of multiple cutting-edge semiconductor components to assist the development of electrical bio assays for medical applications.

10:45 a.m.
15.5 Label-Free Optical Biochemical Sensor Realized by a Novel Low-Cost Bulk-Silicon based CMOS Compatible 3-Dimensional Optoelectronic IC (OEIC) Platform, J. Song, X. Luo, J. S. Kee, C. Li and G. Lo, A*STAR

We demonstrate label-free optical biochemical sensor realized by a low-cost bulk-silicon based 3D-OEIC technology. Novel Ge-photodetector is enhanced with integrated mirrors. Critical components of Grating coupler, tunable filter and label-free optical biochemical sensor are integrated in CMOS BEOL process. This work facilitates further development of cost-effective portable point-of-care diagnostic tool.

11:10 a.m.
15.6 MEMS Tunable Laser Using Photonic Integrated Circuits, M. Ren, H. Cai*, Y. D. Gu*, D. L. Kwong* and A. Q. Liu, Nanyang Technological University, A*STAR,

This paper reports a monolithic MEMS tunable laser using silicon photonic integrated circuit, formed in a ring cavity. In particular, all the necessary optical functions in a ring laser system, including beam splitting/combining, isolating, coupling, are realized using the planar passive waveguide structures. Benefited from the high light-confinement capability of silicon waveguides, this design avoids beam divergence in free-space medium as suffered by conventional MEMS tunable lasers, and thus guarantees superior performance. The proposed laser demonstrates large tuning range (55.5 nm), excellent single-mode properties (50 dB side-mode-suppression ratio (SMSR) and 130 kHz linewdith), compact size (3 mm × 2mm), and single-chip integration without other separated optical elements.