Electronic Materials and Processing
Room: 210E - Session EM-TuM

Beyond CMOS: Materials and Devices for a Post CMOS Era
Moderator: Christopher Hinkle, University of Texas at Dallas, Suzanne Mohney, Penn State University

8:00am **EM-TuM1 Secret Ingredients in Thin-TFET: A 2D Material-based Transistor**, ***Grace Huili Xing***, Cornell University **INVITED**

Thin-TFET stands for Two-dimensional Heterojunction INterlayer Tunnel Field Effect Transistor [1]. This name was coined by my student, Mingda Oscar Li, based on one of the device concepts we submitted in the LEAST center proposal. The rationale behind this device concept was derived from our earlier work on III-V based TFETs, in particular, TFETs with tunneling aligned with the gate field [2] and our investigations on the impact of band alignment (straddling [3], staggered and broken-gap [4]) on TFET. In the recent benchmarking exercise [5,6], a few more intriguing features were discovered in this 2D embodiment of the TFET with tunneling aligned with the gate field, in additional to being the ultimate scaled TFET down to the atomic thickness. [1] M. Li et al, JAP, 074508 (2014). [2] Y. Lu et al. EDL, 655 (2012). [3] G. Zhou et al. EDL, 782 (2012); G. Zhou et al. EDL, 1516 (2011). [4] G. Zhou et al. DRC (2011); G. Zhou et al. IEDM (2012). [5] M. Li et al. J-EDS, 200 (2015); [6] D. Nikonov et al., J. Exploratory Solid-State Computational Devices and Circuits, 10.1109/JXCDC.2015.2418033 (2015).

8:40am **EM-TuM3 Application of Thermodynamics to Processing Transition Metal Dichalcogenides**, ***Suzanne Mohney****, A.C. Domask, T.N. Walter, R.L. Gurunathan, Y. Zeng*, Penn State University

We have applied thermodynamics to guide us in processing transition metal dichalcogenides for ohmic contact formation, oxidation, and etching. Annealing has been reported by a number of researchers to reduce the resistance of electrical contacts to transition metal dichalcogenides. To better understand the effect of annealing and guide our ongoing experiments, we have surveyed the condensed phase equilibria in the transition metal-Mo-S systems. The phase diagrams we have calculated or found in the literature fall into three categories: the metal is in thermodynamic equilibrium with MoS2, there is a driving force for the metal to reduce MoS2, or there is a stable solid solution or ternary phase that dominates the phase diagram. We have performed a similar analysis of the metal-W-Se systems, although there is less thermodynamic data available for the transition metal selenides than the transition metal sulfides. In this presentation, we will first compare materials characterization of annealed contacts to MoS_2 and WSe_2 to our predictions. Then, we will turn our attention to oxidation and etching. Introducing transition metal dichalcogenides to an oxidizing environment can have different effects on the material, depending on the temperature and partial pressure of the oxidizing agent. Using O_2, we find from our thermodynamic calculations that a solid product of oxidation forms on MoS_2 and WSe_2 at mildly elevated temperatures, whereas at higher temperatures we can use O_2 as a vapor phase etchant due to the volatility of the oxygen-bearing reaction products. We have found good agreement between our predictions and characterization of processed samples using light microscopy, atomic force microscopy, scanning electron microscopy, and scanning Auger microscopy.

9:00am **EM-TuM4 Stress-Directed Compositional Patterning of SiGe Substrates for Lateral Quantum Barrier Manipulation**, *S. Ghosh*, University of New Mexico, *D. Kaiser*, University of Pennsylvania, *J. Bonilla*, University of New Mexico, *T. Sinno*, University of Pennsylvania, ***Sang M. Han***, University of New Mexico

For large-scale manufacturing of single-electron transistors, the capability to form an addressable 2D array of quantum dots would prove useful. While vertical stacking of quantum well and dot structures is well established in heteroepitaxial semiconductor materials, however, manipulation of quantum barriers in the lateral direction in a uniform array poses a significant engineering challenge. Here, we demonstrate lateral quantum barrier manipulation in a crystalline SiGe alloy, using structured mechanical fields to drive compositional redistribution. To apply stress, we make use of a nano-indenter array that is pressed against a $Si_{0.8}Ge_{0.2}$ wafer in a custom-made mechanical press. The entire assembly is then annealed at high temperatures, during which the larger Ge atoms are selectively driven away from areas of compressive stress. Compositional analysis of the SiGe substrates reveals that this approach leads to a transfer of the indenter array pattern to the near-surface elemental composition, resulting in near 100% Si regions underneath each indenter and a natural pathway to quantum barrier modulation. The process is studied in detail using multiscale computer simulations that demonstrate its robustness across a wide range of applied stresses and annealing temperatures. We computationally explore a carefully chosen set of indenter arrangements to show that Ge atoms can be focused into dots. We expect that this "stress transfer" method can be applied to other crystalline alloys in a scalable way.

9:20am **EM-TuM5 Interlayer Tunnel FETs**, ***Sanjay Banerjee***, Microelectronics Research Center, University of Texas at Austin **INVITED**

The scaling limits of conventional silicon based Complementary Metal Oxide Semiconductor (CMOS) devices has triggered a wide range of research in search of potential candidates for beyond CMOS logic devices. We will discuss the operation of vertical interlayer tunnel field effect transistors (ITFETs) using a stacked double bilayer graphene (BLG) and hexagonal boron nitride (hBN) heterostructure as one such potential candidate. The device is fabricated with a sequential pickup transfer method with the edges of the top and bottom BLG flakes being rotationally aligned to roughly 60° for alignment of the K points in the Brillouin zone of the two graphene layers, and using the hBN as the top, interlayer and substrate dielectric. The device shows multiple negative differential resistance (NDR) peaks which can be adjusted through the gate bias. Temperature dependent measurements show that the peak width of the differential conductance slightly broadens and the height somewhat lowered when the temperature is increased, but overall the temperature dependence is weak enough to be indicative of resonant tunneling being the primary mechanism. Through electrostatic calculations, it is shown that the multiple peaks occur when the two conduction bands at the K-point of the top and bottom bilayer graphene become aligned at certain bias conditions. It is also shown that by adjusting the rotational alignment of the bands of the top and bottom BLG through an in-plane magnetic field, the conductance peaks can be broadened or sharpened. As an example of a potential application, by utilizing the NDR characteristic of the device, a one-transistor latch or SRAM operation is demonstrated which operation margin can be adjusted through the gate bias.

11:00am **EM-TuM10 Graphene and TMD for Electronic Devices**, ***Seongjun Park****, J. Lee, J. Heo, K. Lee, E. Lee, S. Lee, S. Jung*, Samsung Advanced Institute of Technology, Republic of Korea **INVITED**

Two dimensional (2D) materials including Graphene and Transition Metal Dichalcogenide (TMD) have been considered as potential materials for post Si technology. They are atomically thin and have exceptional electronic and optoelectronic properties, such as high electron mobility and high reponsivity. In addition, they have unique mechanical properties as inorganic semiconductors, such as flexibility and even some stretchabilities due to their atomic thin nature.

TMS's have band gaps and TMD based device can have high on/off ratio. Thus, they have been considered as channel materials for atomically thin nano devices. There are various TMD materials with various band gaps and this is somewhat advantages for TMD's since they can be considered many different applications depending on their band gaps.

Unlike TMD, graphene has no band gap and it is difficult to achieve high on/off ratio. We propsed and demonstrated a new device structure, Barristor, based on one of the unique properties of graphene, work function tunability. The key feature of the device is the modulation of Schottky barrier height between graphene and semiconductor through the gate voltage modulation. This new device shows high on/off ratio of 1,000,000 or higher can be achieved. In addition, Barristor is fully compatible with curent Si technology and we were able to fabricate the devices with 6" wafer scale with CVD (Chemical Vapor Deposition) grown graphene.

In this presentation, we will cover some of our recent developments of TMD based devices. We investigated various TMD's and we will present the summary of their performances. Also we will discuss about the details od Barristor including vertical tunneling devices. In addition, we will dIscuss the issues on wafer scale developments and some of the process related issues of TMD devices and Graphene Barristor and their potential applications.

11:40am **EM-TuM12 On Smart Textiles and Vacuum: The Joys of Innovation and Discovery on Quality of Life**, ***Sundaresan Jayaraman***, Georgia Institute of Technology **INVITED**

The discovery of vacuum has had a transformational impact on the quality of life of individuals. Until recently, the term "wearable" referred to a garment that is worn by individuals. However, the invention of the wearable motherboard or smart textiles has given new meaning to the term "wearables" and it goes beyond the traditional definition of clothing. Rather, it refers to an accessory that enables *personalized mobile information processing*.

We present the the concept of the wearable motherboard integrating electronics and textiles. We discuss the role of textiles as a "meta-wearable," and how it has transformed a multitude of disciplines ranging from sports to healthcare. Finally, we the discuss the future of smart textiles as a key enabler in the context of "big data," and its impact on the quality of life of individuals.

Authors Index

Bold page numbers indicate the presenter