

# Thursday Morning, November 1, 2012

## Electronic Materials and Processing

Room: 14 - Session EM+SS+AS+NS-ThM

## Nanoelectronic Interfaces, Materials, and Devices

Moderator: M. Filler, Georgia Institute of Technology

8:00am **EM+SS+AS+NS-ThM1 Tensilely Strained Ge Nanomembranes for Applications in Group-IV Infrared Photonics, R. Paiella**, Boston University **INVITED**

Single-crystal semiconductor nanomembranes have emerged as a new materials platform offering unique opportunities for strain engineering, by virtue of their ultrasmall thicknesses that result in extremely high thresholds for plastic deformation under stress. This talk will review our recent work aimed at exploiting this property for the development of CMOS-compatible group-IV semiconductor light sources for the technologically important short-wave infrared spectral region. It is well known that Si, Ge, and related alloys are very inefficient light emitters and generally unsuitable for laser action, due to the indirect nature of their fundamental energy bandgap. A possible solution to this important drawback is provided by the ability of biaxial tensile strain in Ge to lower the conduction-band edge at the direct (G) point relative to the L-valley minima, until at a strain of about 1.9% the fundamental bandgap becomes direct. In our work, mechanically stressed Ge nanomembranes capable of accommodating the required strain levels have been developed, and used to demonstrate strong strain-enhanced photoluminescence. A maximum biaxial tensile strain of over 2% in a 24-nm-thick nanomembrane has been measured, above the accepted threshold for the formation of direct-bandgap Ge. A detailed theoretical model of the light-emission and optical gain properties of tensilely strained Ge has also been developed and applied to the measured luminescence spectra, providing evidence of population inversion at strain levels as low as about 1.4%. More recent work is focused on integrating optical cavities on these strained nanomembranes for the development of infrared photonic active devices.

8:40am **EM+SS+AS+NS-ThM3 Self-activating and Self-limiting Features of the Thermally Assisted Growth Mechanisms of Thin Oxide-, Nitride- and Carbide Films on Si Surfaces at Low Gas or Plasma Pressures, P. Morgen, J. Drews, R. Dhiman**, University of Southern Denmark, Z.S. Li, Aarhus University, Denmark

The thermally assisted growth of oxide-, nitride-, and carbide films on Si surfaces, in direct reactions, carried out with neutral gases or remote plasmas under ultrahigh vacuum background conditions, are self-limiting processes, reaching different thicknesses. The mechanisms have been studied using photoelectron spectroscopies with synchrotron radiation or conventional x-ray induced photoelectron spectroscopy (XS). For the oxidation with neutral oxygen molecules, or microwave-excited remote oxygen plasmas, and for the nitride formation reaction with microwave-excited remote nitrogen plasmas, the "kinetics" (uptake versus exposure plots) is well described with a Hill-function. For the nitrogen reaction, the variation of the temperature causes the Hill parameters to vary because this reaction has more latitude than the oxidation, in temperature range and final thickness, as well as in the resulting structure of the nitride, going from amorphous to crystalline at higher temperatures. One known instance of the "Hill reaction" is a self-activating enzymatic-like reaction, and such a mechanism is believed to be relevant also in our systems. The carbide reaction is different, due to defects in the growing film, which allow a relatively unhindered transport of Si to the surface, where it reacts with carbon species arriving at the surface, from remote microwave-excited plasmas of methane. Thus the limiting thickness of SiC/Si (111) is around 100 nm, while the thickness of oxide is 0.8 nm, and the nitrides between 1 and 3 nm.

9:00am **EM+SS+AS+NS-ThM4 Functional Conductive Polymer to Inexpensive and Portable Chemiresistive Biosensor, D. Bhattacharyya, K.K. Gleason**, Massachusetts Institute of Technology

Extensive research has focused on developing different types of biosensors for detecting bio-threat risks and the occurrence of toxins in the food supplies. However, these food screening processes involve many steps, have high labor costs, reagent costs and time delays of at least 2-3 days to obtain reliable data. Despite the current availability of various types of sensors, limitations of the current state-of-the-art biosensors for molecular recognition of biomolecules are well known. Among these limitations are the unacceptably long process times required for detection and user non-compliance as a result of the excessive weight of the sensor modules coupled with the inflexibility of the sensor platforms for routine uses.

Chemiresistive biosensors detect changes in resistance when analyte molecules specifically bind to the sensor surface. Chemiresistive biosensing technique is attractive because it is label-free and can be developed for faster detection of analytes. In this work, oxidative chemical vapor deposition (oCVD) technique is employed for deposition of functional conductive copolymer thin films on the electro-spun fiber mats. The dry oCVD process allowed us to deposit uniform and conformal conducting -OH functional copolymeric film on the electro-spun fiber mat in a single step. For the proof-of-concept of the biosensor application, avidin molecules were covalently immobilized to the -OH functional groups. Various concentrations of biotin solutions were employed as the analytes. The responses and the response times of the devices were significantly improved when the high surface area electro-spun mat were used as a substrate in contrast to a flat substrate.

9:20am **EM+SS+AS+NS-ThM5 Semiconductor Nanomembranes for Biomedical Applications, J.A. Rogers**, University of Illinois at Urbana Champaign **INVITED**

Biology is curved, soft and elastic; silicon wafers are not. Semiconductor technologies that can bridge this gap in form and mechanics will create new opportunities in devices that adopt biologically inspired designs or require intimate integration with the human body. This talk describes the development of ideas for electronics that offer the performance of state-of-the-art, wafer-based systems but with the mechanical properties of a rubber band. We explain the underlying materials science and mechanics of these approaches, and illustrate their use in bio-integrated, 'tissue-like' electronics with unique capabilities for mapping cardiac electrophysiology, in both endocardial and epicardial modes, and for performing electrocorticography. Demonstrations in live animal models illustrate the functionality offered by these technologies, and suggest several clinically relevant applications.

10:40am **EM+SS+AS+NS-ThM9 Structure, Dynamics and Mechanism of a Single-Molecule Electric Motor, C.J. Murphy, C.H. Sykes**, Tufts University

Future nano-electronic devices, such as fluid pumps, sensors and switches, will rely on rotating molecules bound to surfaces as key components. To operate these devices, it is important to understand and direct molecular rotation at this interface. We utilized a Low Temperature Scanning Tunneling Microscope (LT-STM) to both drive and measure the rotation of a single asymmetric thioether molecule bound to a copper (111) surface. Due to the hexagonal arrangement of the underlying Cu atoms the rotor molecule has six favorable orientations, with an asymmetrical barrier to rotation around the Cu-S bond. The symmetry of this barrier is dependent on the surface bound chirality. Rotation of the molecule can be driven by either thermal or electrical means. In thermally driven systems, there is no preferred direction of rotation. In order to measure the rate of anisotropic rotation, the system is cooled to 5 K, and a tunneling current is applied to periodically excite the molecule, resulting in a flashing ratchet like mechanism of molecular rotation. The progression of molecular orientations relative to the tip can be determined by the exponential dependence of tunneling current on distance. This allows evaluation of the rate, direction and magnitude of rotation between these orientations in real time. We aim to further interrogate this novel mechanism for electrically-driven motion by quantifying the lifetime of the rotor in each stable orientation and the transitions between these states as a function of tunneling current and voltage.

11:00am **EM+SS+AS+NS-ThM10 Semiconductor Nanostructures for Efficient Thermoelectric Energy Conversion, Z. Aksamija**, University of Wisconsin Madison

Thermoelectric (TE) refrigeration using semiconductor-based nanostructures, such as nanowires, nanoribbons, and superlattices, is an attractive approach for targeted cooling of local hotspots inside integrated circuits due to inherently no moving parts, ease of miniaturization and on-chip integration, and the nanostructures' enhanced TE conversion efficiency. In addition, thermoelectric power generation enables the reuse of waste heat in a variety of applications, from low-power and energy-efficient designs to internal combustion engines and solar cells. Thermoelectric efficiency, measured by the figure-of-merit ZT, is dictated by the ratio of electronic power factor  $S^2\sigma$  over the total thermal conductivity. Consequently, largest gains in TE conversion efficiency have come from the ability to reduce thermal conductivity. This is especially true in nanostructures, where small physical dimensions lead to reduced thermal transport due to the scattering of lattice waves, or phonons, with the boundaries of the nanostructure. The design of efficient semiconductor thermocouples requires a thorough understanding of both charge and heat

transport; therefore, thermoelectricity in semiconductor-based nanostructures requires that both electronic and thermal transport are treated on equal footing. SOI nano-membranes and membrane-based nanowires and ribbons show promise for application as efficient thermoelectrics, which requires both high electronic power factor and low thermal conductivity. I will present numerical simulation and modeling of both carrier and phonon transport in ultrathin silicon nanomembranes and gated nanoribbons. We show that the thermoelectric response of Si-membrane-based nanostructures can be improved by employing the anisotropy of the lattice thermal conductivity, revealed in ultrathin SOI nanostructures due to boundary scattering, or by using a gate to provide additional carrier confinement and enhance the thermoelectric power factor. Furthermore, we explore the consequences of nanostructuring on silicon/germanium and SiGe alloy superlattices, and show that the drastic reduction of thermal conductivity in these structures comes from the increased interaction of lattice waves with rough interfaces and boundaries. Finally we demonstrate reduced thermal conductivity in both suspended and supported graphene nanoribbons (GNRs), which exhibit strong anisotropy due to interaction of lattice waves with line edge roughness (LER) and the competition between LER and substrate scattering. The talk will conclude with an outlook for future nanostructured thermoelectric based on nanocrystalline and nanocomposite semiconductors, and nanopatterned graphene.

11:20am **EM+SS+AS+NS-ThM11 UV Ozone Irradiation Induced Defect Formation in Graphene/PZT Devices**, C.X. Zhang, D.M. Fleetwood, M.L. Alles, R.D. Schrimpf, Vanderbilt University, E.B. Song, S. Kim, K. Galatsis, K.L. Wang, University of California at Los Angeles, E.X. Zhang, Vanderbilt University

Graphene based materials are promising candidates for integration into future integrated circuit technologies. Initial studies of the effects of electron-beam and proton irradiation have been performed on graphene materials, but there remain significant questions about the nature of the conductivity and the defects that influence its material and electronic properties. We have found that low-energy x-ray irradiation can lead to significant shifts in the charge neutral point and increases in resistance of suspended graphene layers and graphene layers on SiO<sub>2</sub>. For graphene-on-SiO<sub>2</sub> structures, the reaction oxygen atoms may be supplied either by ozone in the ambient air, or by the adjacent SiO<sub>2</sub> substrate. Similar reactions may be observed for hydrogen, for devices exposed to x-ray and/or UV ozone (UVO) irradiation. Moreover, we also have found that graphene/PZT ferroelectric field-effect transistors (FFETs) are sensitive to UVO irradiation. The conducting channel in these devices is a single graphene layer. The device functions as a nonvolatile memory with reverse hysteresis, where charge trapping and detrapping in the PZT layer leads to a large memory window that is robust to x-ray irradiation and/or memory state cycling. When these devices are exposed to UVO irradiation, the memory window of the device decreases slightly with exposure time. In addition, an increase is observed in the slope of the I-V curves, along with a small positive shift in current-voltage characteristics. These results are consistent with the formation of negatively charged surface states on the graphene layer during the UVO exposure, which are most likely associated with adsorbed oxygen. The degradation in the I-V characteristics recovers somewhat with room temperature annealing. At the AVS meeting, the detailed electrical response will be described, and a physical model will be presented for the UVO degradation and recovery mechanisms.

11:40am **EM+SS+AS+NS-ThM12 Switching Molecular Kondo Effect by Chemical Reactions**, H. Kim, ISSP, University of Tokyo, Japan, Y.H. Chang, KAIST, Korea, M.H. Chang, Korea University, Y.-H. Kim, KAIST, Korea, S.-J. Kahng, Korea University

Motivated by spintronics applications, the methods to control Kondo effect have been actively studied in magnetic adsorbates on metal surfaces using scanning tunneling microscopy, but they were limited to the processes that required external energy supply from scanning tunneling microscope tip. We report new methods to control molecular Kondo effect by using bimolecular chemical reactions. A chemical binding between diatomic molecules and Co-porphyrin was exploited to switch off, or reset the molecular Kondo effect. The Kondo effect was switched back on using scanning tunneling microscope manipulation as well as thermal desorption. These methods rely on the hybridized pairing of unpaired spins in d<sub>2</sub> and π\* orbitals of Co-porphyrin and diatomic molecules, respectively, as supported by our density functional theory calculation results. Our study opens up ways to control the molecular Kondo effect using an enormous variety of bimolecular chemical reactions.

12:00pm **EM+SS+AS+NS-ThM13 Quantifying the Local Seebeck Coefficient using Scanning Thermoelectric Microscopy (SThEM)**, J.C. Walrath, Y.H. Lin, K.P. Pipe, R.S. Goldman, University of Michigan

Thermoelectric (TE) devices allow reliable solid-state conversion of heat to electricity. The efficiency of a TE device is determined by the figure of

merit, ZT, which is sensitive to the Seebeck coefficient, S. Traditional S measurements are used to quantify thermally-induced electron transport on a macroscopic scale. A promising alternative method for nanoscale measurements of S is scanning thermoelectric microscopy (SThEM). In SThEM, an unheated scanning tunneling microscopy (STM) tip acts as a high-resolution voltmeter to measure the thermally-induced voltage, V, induced by a temperature gradient in a heated sample. SThEM has been utilized to measure V across a GaAs p-n junction [1], with the spatial profile of S determined through a comparison of the measured V with a simulation of a network of resistors and voltage sources, based upon a theoretical S-value [2]. Although this approach is useful for predicting the measured V, it does not provide a method for direct conversion of the measured V to a local S. We have developed a Fourier heat conduction model to calculate a temperature profile matrix, thereby enabling direct conversion between the measured V and the local S. According to our model, SThEM can be optimized by fine-tuning several parameters, including the cone angle of the STM tip and the relative thermal conductivity of the tip and sample. We applied our model to SThEM data across a GaAs p-n junction [1] and improved the agreement between the measured and theoretical S by 40%. Our progress towards SThEM measurements of CoSb<sub>3</sub> and InAs quantum dots will also be discussed. This material is based upon work supported by the Department of Energy under Award Number DE-PI0000012. Y.H. Lin and R.S. Goldman are supported in part by DOE under contract No. DE-FG02-06ER46339.

[1] H.K. Lyeo, A.A. Khajetoorians, L. Shi, K.P. Pipe, R.J. Ram, A. Shakouri, and C. K. Shih, *Science* **303**, 816 (2004).

[2] Z. Bian, A. Shakouri, L. Shi, H.K. Lyeo and C.K. Shih, *Appl. Phys. Lett.* **87**, 053115 (2005)

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