Friday Morning, November 17, 2006

Nanometer-scale Science and Technology
Room 2016 - Session NS-FrM

Nanowires

Moderator: S.E. Mohney, The Pennsylvania State University

8:20am **NS-FrM2 Double-Sided Epitaxy on Si Nanowire Ribbons*, *C.S. Ritz,*** *F.S. Flack,* University of Wisconsin, Madison*; Y. Zhang, F. Liu,* University of Utah*; M.G. Lagally,* University of Wisconsin, Madison

We study the ultrahigh-vacuum chemical vapor deposition growth of SiGe and Ge 3D islands on free-standing compliant Si nanowire ribbons. The Si template layer of a Si-on-insulator (SOI) sample with a thick buried oxide (BOX) is thinned down to the order of 20 nm via thermal oxidation and HF etching. This thin template layer can then be patterned into nanowire ribbons with widths less than 100nm along different crystallographic directions and connected at both ends. Reactive ion etching is used to remove the unwanted Si down to the BOX. Prior to SiGe growth a final HF dip is used to etch away this exposed oxide and undercut the Si ribbons, leaving them freestanding. CVD allows us to grow 3D islands on both the top and bottom surfaces of the Si ribbon.@footnote 1@ We observe a strong anticorrelation between islands grown on the top and bottom of the freestanding regions, as well as ordering of islands into rows along the ribbon edges. This latter ordering also exhibits additional dependence on the crystallographic orientation of the edge. Modeling suggests that this anticorrelation takes place to minimize the total strain energy and that growth on thinner ribbons induces and enhances correlation. In addition to the ordering of the dots, we also see global bending of the Si nanoribbon (because it is connected at both ends like a bridge) due to the elastic strain induced by the 3D islands. The islands affect the local electronic structure of the wire, which in concert with the ordering, makes double-sided epitaxy on nanowire ribbons a new approach to creating superlattice nanowires. @FootnoteText@ *Supported by DOE.@footnote 1@Clark S. Ritz, Frank S. Flack, Michelle M. Roberts, Donald E. Savage, Yu Zhang, Feng Liu, Max G. Lagally, Double-sided growth of ordered SiGe islands on ultra-thin Si, in preparation.

8:40am **NS-FrM3 Silicidation and Oxidation of Silicon Nanowires*, B.Z. Liu,*** *Y. Wang, S.M. Dilts, J.M. Redwing, T.S. Mayer, S.E. Mohney,* The Pennsylvania State University

Metallization and oxidation are two important processes in the fabrication of transistors on silicon wafers. Forming metal contacts and gate dielectrics is equally important when integrating silicon nanowires into functional devices, but the processes have not been studied as extensively to date. We have used transmission electron microscopy to investigate the silicidation of silicon nanowires using Pt, Pd, Fe, Co, and Ni. Metal films were deposited on the silicon nanowires and annealed between 200 and 750°C for 15 min to 15 h. Sections of the silicon nanowires were successfully converted uniformly into silicides by controlling the ratio of metal to Si, annealing temperature, and ambient. We have also investigated the kinetics of oxidation of undoped and doped silicon nanowires. Dry thermal oxidation of the as-grown silicon nanowires was carried out at temperatures between 700 and 900°C with trichloroethane flowing. Differences in the oxidation kinetics between the silicon nanowires and silicon wafers are discussed. The electrical properties of the thermally grown oxide shell were investigated as well. The thermally grown oxide shell on the silicon nanowires has been successfully utilized as a gate dielectric that improves the operational stability of silicon nanowire field effect transistors.

9:00am **NS-FrM4 Large Area, Dense Si Nanowire Array Chemical Sensors*, A.A. Talin,*** Sandia National Laboratories, 94550*; L.L. Hunter, B. Rokad, F. Leonard, B.A. Simmons,* Sandia National Laboratories

We present a simple top down approach based on nanoimprint lithography to create dense arrays of silicon nanowires over large areas. Metallic contacts to the nanowires and a bottom gate allow the operation of the array as a field-effect transistor with very large on/off ratios. The carrier mobility extracted from transconductance measurement exceed the values reported for chemically synthesized Si nanowires with similar dimensions. When exposed to ammonia gas or cyclohexane solutions containing nitrobenzene or phenol, the threshold voltage of the field-effect transistor is shifted, a signature of charge transfer between the analytes and the nanowires. The threshold voltage shift is proportional to the Hammett parameter and the concentration of the nitrobenzene and phenol analytes. For the liquid analytes considered, we find binding energies of 400 meV, indicating strong physisorption. Such values of the binding energies are ideal for stable and reusable sensors.

9:20am **NS-FrM5 Controlling the Width of Self Assembled Nanowires on the Si(001) Surface*, J. Nogami,*** *Y. Cui, J. Chung, D. Grozea,* University of Toronto, Canada*; C. Ohbuchi,* National Institute for Materials Science, Japan

Many low dimensional structures arise from self-assembly when depositing metals onto silicon surfaces, including both quantum dots and quantum wires. One class of these objects are rare earth silicide nanowires that grow on Si(001).@footnote 1@ In any self assembled nanostructure, one of the critical issues is control over feature size. In the case of metals deposited on the Si(111) surface, the 7x7 reconstruction has been used as a template to create clusters with a very narrow size distribution, where the metal atoms are confined to one half of the reconstruction unit cell.@footnote 2@ We present STM data that shows it is possible to use a metal induced 2x7 reconstruction of Si(001)@footnote 3@ to narrow the width distribution of Dy silicide nanowires. The interaction between the reconstruction and the nanowires is more complex than in the 7x7 case since nanowire growth induces local changes in the 2x7 periodicity. We will suggest possible mechanisms for the templating phenomenon. @FootnoteText@ @footnote 1@ J. Nogami et al, Phys. Rev. B 63 (2001) 233305.@footnote 2@ J. Jia et al, Appl. Phys. Lett 80 (2002) 3186.@footnote 3@ B.Z. Liu and J. Nogami, Surf. Sci. 540 (2003) 136.

9:40am **NS-FrM6 Synthesis and Characterization of Aligned III-Nitride Nanowire and Heterostructure Nanowire Arrays*, G.T. Wang,*** Sandia National Laboratories*; A.A. Talin,* Sandia National Laboratories, 94550*; J.R. Creighton,* Sandia National Laboratories*; D. Werder,* Los Alamos National Laboratory*; E. Lai, P.P. Provencio,* Sandia National Laboratories

Nanowires based on the direct bandgap semiconductor Group III nitride (AlGaInN) materials system have attracted attention as potential building blocks in nanophotonics, nanoelectronics, and sensing. We have employed a metal-organic chemical vapor deposition process to synthesize highly aligned arrays of single-crystalline GaN nanowires in a standard cold-wall rotating disk reactor on 2-inch diameter sapphire and GaN substrates without the use of a template. SEM and TEM analysis indicate that the nanowires share a common growth direction and have aligned facets. Interestingly, the majority of the nanowires do not have a catalyst droplet at the tip, suggesting the growth may differ from the standard vapor-liquid-solid process. Building on this technique, we have also been able to synthesize radial heterostructure nanowire arrays consisting of a GaN cores and various III-nitride shell materials, including AlN, InN, and AlGaN, and InGaN. The GaN and heterostructure nanowires were probed using a Sandia-developed platform which allows us to correlate the morphological, optical, and electrical properties of a statistically relevant number of nanowires. Results from 3D STEM tomography and spatially resolved photoluminescence and cathodoluminescence studies will also be presented. We have found that the growth conditions, particularly temperature, have a strong effect on the structural, optoelectronic, and electrical properties of the nanowires. Additionally, the choice of substrate and the catalyst preparation play critical roles in the density, uniformity, and alignment of the nanowire arrays. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

10:00am **NS-FrM7 Epitaxially Grown III-V Nanowires for Quantum Device Applications*, L. Samuelson,*** Lund University, Sweden **INVITED**

In this talk I will survey progress during the last couple of years in the controlled growth of epitaxially nucleated nanowire structures, obtained via local catalytic activation of growth. From an application point of view, progress in the technologies which allow control of geometrical dimensions and positioning of nanowire structures and devices is of great importance, as is the recently demonstrated ideal formation of III-V nanowires epitaxially grown on silicon substrates. From the perspective of designing and realizing complex device structures, by which quantum phenomena can be utilized, the formation of axial as well as radial heterostructures within a nanowire is of special interest and I will give different examples of how this has been achieved. Finally, I will present a couple of quantum device families that we have been working on in the last year, such as wrap-gate field-effect transistors and multiple-barrier storage devices.

10:40am **NS-FrM9 Electrical Characterization of Nanowires with the LEEPS Microscope**, ***D.H. Weber***, *A. Beyer, A. Gölzhäuser,* University of Bielefeld, Germany

We introduce the LEEPS microscope as a tool for the electrical characterization of nanowires. We have contacted single nanowires in the LEEPS electrically and have measured the conductivity. In addition the LEEPS image itself represents the electrical properties. The LEEPS (Low Energy Electron Point Source) microscope is a transmission electron microscope with electron energies from 20 eV to 200 eV. These electrons are emitted by a field emission tip with a radius in the atomic range. Because the electrons have a high spatial coherence the resulting detector image is an interference pattern which includes structural as well as electrical and magnetic information of the object. The LEEPS image includes features which are very typical for either conductive or nonconductive nanowires. The interference pattern of conductive nanowires appears much brighter referring to the image background as the interference pattern of a nonconductive nanowire. With a sharp manipulation tip as a movable electrode a single nanowire can be contacted electrically and the I/U curve is measured. Contacting and measurement can be observed with the LEEPS microscope subsequently. To take the contact resistance into account, length dependent measurements have been performed. We present I/U curves of single nanowires (i.e. ZnO) as well as a comparison of LEEPS images of conductive and nonconductive wires (i.e. ZnO, Cu, Bi and Al@sub 2@O@sub 3@, polymers).

11:00am **NS-FrM10 Germanium Nanocrystals and Nanowires: Morphological Control, Surface Characterization, and Applications**, ***H. Gerung***, *L.J. Tribby,* University of New Mexico*; T.N. Lambert,* Sandia National Laboratories*; N. Andrews,* University of New Mexico*; T.J. Boyle,* Sandia National Laboratories*; C.J. Brinker, J.M. Oliver, S.M. Han,* University of New Mexico

The use of Ge@sup 0@ nanocrystals (NCs) and nanowires (NWs) for advanced materials applications are of great interest; however, complex synthetic routes have hindered their use and development. We have recently developed a simple route to produce Ge@sup 0@ NCs and NWs from the reduction of Ge@sup +2@ precursors at 300°C and 1 atm Ar without using metal catalysts and without producing salt byproducts. Taking a molecular design approach, we tailor the Ge-ligand bond and the ligand steric hindrances to control Ge@sup +2@ precursors' reactivity. More reactive Ge@sup +2@ precursors yield Ge@sup 0@ NCs, while less reactive alkoxide precursors yield Ge@sup 0@ NWs. X-ray diffraction and transmission electron microscopy show that both NCs and NWs are in cubic phase. The surface of these Ge@sup 0@ NCs and NWs can be further functionalized to prevent spontaneous oxidation, which is useful for both optical and biological applications. The resultant Ge@sup 0@ NCs are optically active, as demonstrated by the presence of photoluminescence in both visible (around 450 nm) and infrared region (around 1300 nm). Ge@sup 0@ NCs also display highly nonlinear optical behavior; the experimentally measured two photon absorption coefficient ranges from 1190 to 1940 cm/GW. We also demonstrate that water-soluble Ge@sup 0@ NCs are stable for months. Preliminary investigations on the use of Ge@sup 0@ NCs as a biological probe reveal that dinitrophenol (DNP)-decorated Ge@sup 0@ nanocrystals readily bind to anti-DNP IgE receptors on mast cells, while maintaining high cell viability comparable to the control cells. The details of synthesis, optical properties, and biofunctionalization will be presented. The authors acknowledge generous support from NSF CAREER (DMR-0094145). Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

11:20am **NS-FrM11 Fabrication of Tin Oxide Nanowires Based Nano-Micro Sensor for Room Temperature Hydrogen Detection**, ***S. Deshpande***, *A. Karakoti, G. Londe, H.J. Cho, S. Seal,* University of Central Florida

Randomly oriented tin oxide nanowires, with diameters on the order of 100 nm, were grown on Si substrate using thermal evaporation technique. The thermodynamic and kinetic factors leading to the evolution of tin oxide nanowires from vapor solid transformation during the process is evaluated. These nanowires were successfully incorporated into micro-electro-mechanical (MEMS) device. Hydrogen (H2) at ppm-level has been successfully detected at room temperature using the present 1-dimensional tin oxide based MEMS sensor. The device showed rapid and reversible resistance changes upon periodic exposure to hydrogen gas (less than 900ppm concentration). The one dimensional geometry of tin oxide is responsible for the device response. Effect of aspect ratio of the nanowires on diffusion of hydrogen molecules in the tin oxide nanowires, effect of catalyst adsorption on nanowire surface and corresponding effect on sensor properties has been studied in detail.

11:40am **NS-FrM12 Atomic Level Analysis of Carbon Nanotubes and Graphite Nanofibers by the Scanning Atom Probe**, ***O. Nishikawa***, *M. Taniguchi,* Kanazawa Institute of Technology, Japan

Utilizing the unique capability of the scanning atom probe (SAP) carbon nanotubes (CNT) and graphite nanofibers (GNF) are mass analyzed detecting individual field evaporated ions. The analyzed CNTs are the mixture of single and multiple wall nanotubes (SWCNT and MWCNT). A minute lump of densely intertwined CNT was mounted at the apex of a tungsten tip with silver paste. The GNFs are grown on a nickel substrate. The mass analysis of the CNT and GNF by the SAP was conducted by applying DC and pulsed voltages to the specimen at room temperature. The mass resolution of the SAP is better than 1000. It has been reported that most CNTs and graphite contain a significant amount of hydrogen and oxygen. In this study we focused at the correlation between the C-C binding and the local concentration of hydrogen and oxygen in CNTs and GNFs. Field evaporation of metal proceeds atom-by-atom base because the metallic binding is uniform and non-directional. On the other hand the covalent bonds are directional and non-uniform. Accordingly, non-metallic specimens are mostly field evaporated as cluster ions. Furthermore, strongly bound clusters are field evaporated as multiply charged ions. An interesting finding is the detection of many large carbon cluster ions. The number of carbon atoms is not random but quite characteristic such as 11, 17, 19 and so on. The mass peaks of doubly and triply charged ions are very sharp without a tail indicating strong C-H bonds. On the other hand the mass peaks of singly charged cluster ions have a tail. This implies that the C-H bonds are weak and the C-H cluster are dissociated before entering the ion detector. Detection of the large cluster may imply that the CNT is field evaporated as a nano-size graphene sheet and not as a carbon chain. The electronic state of the specimens and the correlation between the size of cluster and the ratio of the number of carbon atoms to that of hydrogen atoms will be discussed.

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