Nanometer-Scale Science and Technology
Room 210 - Session NS2-MoM

Nanowires

Moderator: C.R. Marrian, IBM

8:20am **NS2-MoM1 Probing Growth Defects Inside Nanowires***, **J. Eriksson**, A. Mikkelsen, E. Lundgren,* Lund University, Sweden*; W. Hofer,* University of Liverpool, U.K.*; N. Skold, L. Samulesson, W. Seifert,* Lund University, Sweden

Free-standing semiconductor nanowires are perceived as future components in nanoelectronics and photonics. In fact, applications such as for example, bio/chemical sensors, n- p- type diode logic and single nanowire lasers have already been realized in the laboratory.@footnote 1@ Because of the extremely small dimensions of a nanowire, atomic scale structural features can have a significant impact on their properties. As a result, structural methods that address all these issues are highly desirable. Recently we have demonstrated a new method to image individual atoms inside III-V semiconductor nanowires using a combination of STM and a novel embedding scheme.@footnote 2@ In this way, we are able to image areas of the nanowire with atomic resolution both along the wire, and through the face of the wire. In this contribution we present a cross-sectional STM study of the structure and the electronic properties of stacking faults inside a GaAs nanowire containing an embedded GaInAs segment. The stacking faults are created due the formation of twins as the nanowire is grown. Spectroscopy measurements performed directly on a stacking fault are compared to density functional theory calculations, and the influence of the stacking fault on the electronic properties of the wire will be discussed. @FootnoteText@@footnote 1@L. Samuelson, Mater. Today 6 (2003) 22. @footnote 2@A. Mikkelsen et al, Nature Materials. 3 (2004) 519.

8:40am **NS2-MoM2 Optical Activation of Implanted Impurities in ZnS Nanowires***, D. Stichtenoth, D. Schwen, S. Mueller, C. Borchers, **C. Ronning**,* University of Goettingen, Germany

Nanostructures of zinc sulfide (ZnS), a II-VI compound semiconductors with a direct band-gap of 3.66 eV in the cubic phase and 3.74 eV in the wurtzite phase, show interesting optical properties, making it a promising candidate for optoelectronic devices. Single crystalline nanobelts and -wires were synthesized in a computer-controlled process according to the VLS mechanism. We investigated the morphology, structure and composition by scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD). The optical properties have been studied by temperature dependent photo- (PL) and cathodoluminescence (CL). The synthesized ZnS nanowires were implanted with nitrogen and boron as potential donor and acceptor, respectively. The implanted nanowires were investigated directly after ion implantation and showed a high quantity of defects resulting into non-luminescence material. Annealing procedures recovered the crystal structure and the optical properties, and we found varying and new PL-lines indicating the activation of the implanted impurities.

9:00am **NS2-MoM3 Metal, and Conducting Polymer Nanowires for Gas and Biomolecule Sensing***, **M. Yun**,* University of Pittsburgh*; C. Lee, R. Vasquez,* Jet Propulsion Laboratory*; N. Myung,* University of California at Riverside*; J. Wang, H. Monbouquette,* University of California at Los Angeles*; A. Mulchandani,* University of California at Riverside

Single Palladium (Pd), Polyaniline(PANI), and Polypyrrole(PPY) nanowires from 70 nm to 300 nm in diameter and up to 7 Âµ in length have been synthesized using e-beam lithography and electrodeposition. This fabrication method enables the use of various materials for single nanowire sensors, such as polymers, metal oxides, and semiconductors. These fabricated Pd nanowires are used to sense hydrogen gases and have achieved a sensitivity of 0.02% H2. In addition, we have observed that the resistance of the 200 nm wide avidin-functionalized PPY nanowires increased rapidly to a constant value upon addition of 1 nM of the biotin-DNA conjugate and the resistance increased with increasing concentrations up to 100 nM. At last, we will present that arrays of nanowires with controlled dimensions are fabricated on substrates, optionally as integral parts of multilayer structures, by means of a high-yield process based on ion milling on steps (IMOS). To demonstrate the utility of functionalized IMOS nanowires as sensors, we have successfully demonstrated Pt nanowire array and precisely assembled glucose oxide (GOx) on Pt nanowire array by co-deposition with electropolymerized PPY. A mixture of GOx and pyrrole is used in PBS solution for electrochemical polymer formation and GOx immobilization. It has been verified by measuring the current sensitivity of 0.3 nA/mM to the glucose with IMOS Pt nanowires.

9:20am **NS2-MoM4 Determination of the Mechanical and Electromechanical Properties of 1D-nanostructures***, **A. Heidelberg**, B. Wu, J.G. Sheridan, J.J. Boland,* Trinity College Dublin, Ireland

Nanowires (NWs) have attracted considerable interest as nanoscale interconnects and as the active components of both electronic and electromechanical devices. Nanomechanical and nanoelectromechanical measurements are a challenge but remain key to the development and processing of novel NW-based devices. Here, we report a general method to measure the spectrum of NW mechanical properties based on NW bending under the lateral load from an atomic force microscope (AFM) tip.@footnote 1@ For electromechanical measurements bending experiments have been carried out with simultaneous measurement of the N@aa W@s conductivity. Mechanical measurements on Li@super +@(Mo@sub 3@Se@sub 3@)@super -@ NW bundles@footnote 2@ with a diameter range between 25 and 200 nm have been carried out using a SPM-nanomanipulator. In these experiments NWs were deposited out of solution across trenches on SiO@sub 2@. To prevent any slippage of the NWs during the manipulation, they were pinned down by E-beam induced deposition of Pt at the trench edges in a dual beam FIB/SEM system. Taking into account the wire shape and dimensions as well as the AFM cantilever dimensions, the Youngs modulus and the maximum bending strength of the NWs can be calculated from the force-displacement traces obtained by the lateral manipulations. The Youngs modulus for Li@super +@(Mo@sub 3@Se@sub 3@)@super -@ NWs shows a strong radius dependence. It increases exponentially with decreasing NW diameter which can be attributed to shear effects between the individual NWs in the NW bundles. For NWs with a radius of 30 nm a modulus of 1.22 TPa is found. The NWs show brittle failure and the bending strength increases with decreasing wire radius. Electromechanical properties of NW bundles were also measured and compared to data obtained on metallic (Au, Cu) and semiconducting (Si) NWs. @FootnoteText@ @footnote 1@B. Wu, A. Heidelberg, J. J. Boland, Nat. Mater. (accepted)@footnote 2@A. Heidelberg et al., Z. Phys. Chem. 217 (2003) 573.

9:40am **NS2-MoM5 Nanowires: From Biological Sensing to Computing and Much More!***, C.M. Lieber, **C. Yang**,* Harvard University **INVITED**

Nanotechnology offers the promise of producing revolutionary advances in many areas, extending from biology and medicine to electronics and computing, and thus may impact in a substantial way our future lives. This presentation will provide an overview to the bottom-up paradigm for nanotechnology enabled using nanowire building blocks. First, the growth of nanowires, with composition controlled down to the atomic scale, their fundamental electronic properties, and parallel assembly and interconnection will be described. Second, nanowire devices configured as electrically-based biosensors will be discussed with an emphasis on disease detection and ultimate sensitivity limits of these nanodevices, as well as the potential linkage to hybrid information processing systems. Third, studies of nanowire based electronic circuits and nanocomputing systems will be critically examined. Lastly, challenges that must be met to realize these and other nanotechnologies in the future will be summarized.

10:20am **NS2-MoM7 Direct Atomically Resolved Imaging of Nanowire Heterostructures and Nanowire Substrate Interaction***, **A. Mikkelsen**,* Lund Universty, Sweden*; J. Eriksson, L. Ouattara, E. Lundgren,* Lund University, Sweden*; T. Knaapen,* Eindhoven Technical University, The Netherlands*; N. Skold, W. Seifert, L. Samuelson,* Lund University, Sweden

Self-assembled semiconductor nanowires are a among the most interesting systems for doing low dimensional physics, as well as for realizing many future electronic and optoelectronic devices.@footnote 1@ Due to efficient strain relaxation a wide range of heterostructures, not possible in the bulk, can be grown in nanowires, and as a result, a multitude of complex nanowire based heterostructure devices has been realized in recent year. Very recently it has even been possible to grow optically active III-V structures on Silicon substrates.@footnote 2@ Because of the seeding type growth process of the wires, it is further possible to grow the wires by self-assembly in well defined positions for example on a chip. Using Scanning Tunneling Microscopy (STM), we address both the issue of heterostructure growth, the initial growth of the nanowire on the substrate and the influence of nanowire growth on the substrates - with atomic scale resolution. We apply our newly developed scheme to image individual atoms inside III-V semiconductor nanowires using a combination of STM and embedding.@footnote 3@ Using this method we have imaged GaInAs segments in GaAs wires with atomic resolution. We show that while the GaInAs segments are in principle perfectly defined on the atomic scale, an In distribution exists above the segment and also on the side facets of the wire. We further image GaAs nanowires at the GaAs(001) substrate interface, revealing intriguing details about both the initial growth of the nanowire along the surface, and the subsequent growth of the out-of-plane free standing wire. Finally we have investigated the influence of the nanowire growth, by Au seed particles, on the surrounding substrate - revealing that significant structural changes can occur. @FootnoteText@ @footnote 1@ L. Samuelson, Mater. Today 6 (2003) 22.@footnote 2@ T. Maartensson et al, Nano Lett 4 (2004) 1987@footnote 3@ A. Mikkelsen, et al, Nature Materials. 3 (2004) 519.

10:40am **NS2-MoM8 Near-field Scanning Photocurrent Microscopy of a Nanowire Photodetector***, **Y. Gu**, E.-S. Kwak, J.L. Lensch, J.E. Allen, T.W. Odom, L.J. Lauhon,* Northwestern University

One-dimensional nanomaterials such as semiconductor nanowires (NWs) are being considered for a variety of device technologies, including nanoscale photodetectors (PDs). The mechanisms of carrier photogeneration in nanoscale PDs have been addressed in a number of studies, but the charge transport and collection mechanisms have received comparatively little attention and are not well understood. In this regard, photoconductivity measurements with uniform illumination (spot size larger than the device) may be insufficient to establish the operational principles of NW devices because (1) the internal electric fields may be highly non-uniform, and (2) similarities between conventional and NW device characteristics may be fortuitous. To understand the global response and the ultimate potential of NW PDs, an understanding of the photoresponse on a smaller length-scale is desirable. We have developed a new technique, near-field scanning photocurrent microscopy (NSPM), to explore the local photoresponse of semiconductor NW devices. A near-field scanning optical microscope (NSOM) was used to image the photocurrent induced by local illumination (excitation spot size less than device size) along the length of a metal-semiconductor-metal (MSM) PD based on a single CdS NW. Under uniform monochromatic illumination, the MSM PDs exhibited photocurrents ~10@super 5@ larger than the dark current (< 2 pA). Under local illumination, the response of the devices was limited to regions near the M-S contact. Analysis of the spatial variation and bias dependence of the local photocurrent allowed the mechanisms of photocarrier transport and collection to be identified. The NSPM technique we describe can be readily extended to other NW-based devices with similar geometries, and provide insight into the operation principles of these devices. NSPM therefore has the potential to significantly advance the understanding and development of NW device technology.

11:00am **NS2-MoM9 Fabrication of Silicon Nanowires with Addressable Au-coated Si Islands***, **C. Wang**, K.S. Ma, M. Madou,* University of California, Irvine

With the increasing interest in various aspects of nano devices, it is becoming apparent that controlled growth is the key to manufacturing. The ability to control the growth of materials on the nanometer scale is important since it determines the device applications. Within many various material, Si nanowires (SiNWs) have attracted intensively research efforts in the synthesis and characterizations. The vapor-liquid-solid mechanism is the rife technique to growth SiNWs. The SiNWs were grown by decomposition of SiH4 as the Si atom sources. Most recently, the other approach, e.g. the solid-liquid-solid, has been developed. In this, the bulk Si wafers were used as either the substrates or Si sources. A thin Au layer was deposited on the substrate as catalyst. In this method, the SiNWs were directly deposited onto the conducting substrate. The post-growth processes are needed to employ those SiNWs as building blocks for the electronics. Herein, we report an alternative method to fabricate the SiNWs by adopting SLS mechanism. The addressable Au-coated Si islands were fabricated by lithography with lift-off on the SiO2 pre-coated substrate. The substrates were then heated to 900 ÂºC in N2/H2 gas. By this isolated Si islands technique, the grown SiNWs were settled down on the insulated substrate. By e-beam or optical lithography, the conducting electrodes can be fabricated on the wires. The islands are the starting point of the growth which can be served as the marker to localize the positions of SiNWs. By engineering design the size and position of the islands, the post-growth fabrication will be much easy instead of using alignment technique under the microscopes. We demonstrated a convenient technique to fabricate SiNWs of controllable position using SLS mechanism. The synthesized SiNWs were deposited on the non-conducting substrates. The widths of the wires are in the tens of nanometer range. The characterizations of synthesized SiNWs were carried out.

11:20am **NS2-MoM10 Mechanical and Electromechanical Properties of Metallic Nanowires***, **B. Wu**, A. Heidelberg, J.J. Boland,* Trinity College Dublin, Ireland

Here, we present a general method to measure the full spectrum of nanowire (NW) mechanical properties: ranging from Youngs modulus E, yield strength, plastic deformation and failure. This method is based on NW bending under the lateral load from an atomic force microscope tip, and involves the manipulation of NWs after they have been mechanically pinned at the edge of a trench using a focused ion-beam. We find that for Au and Cu NWs the Youngs modulus (E) is essentially independent of diameter, while the yield strength is largest for the smallest diameter wires, with strengths up to 100 times that of bulk materials and substantially larger than that reported for bulk nanocrystalline metals (BNMs). In contrast to BNMs, NW plasticity is characterized by strain-hardening demonstrating that dislocation motion and pile up is still operative down to diameters of 40 nm. Possible origins for the different mechanical properties of NWs and BNMs are discussed. The application of this method has also been extended to electrical measurement of NW systems under mechanical strain. For metallic and conducting polymer NWs, the resistance was monitored when NWs were subjected to loads by AFM tip. The potential applications will be discussed.

11:40am **NS2-MoM11 In Situ Resistance Measurement of Epitaxial Silicide Nanowires***, H. Okino, R. Hobara, Y. Hosomura, I. Matsuda, S. Hasegawa,* University of Tokyo, Japan*; **P.A. Bennett**,* Arizona State University

We present in situ resistance measurements for CoSi2 nanowires (NWs) on Si(110), using a custom-built multi-tip UHV-STM. We have shown elsewhere that self-assembled epitaxial silicide NWs can be formed with a variety of transition metals (Co, Ni, Fe, Ti, Pd, Dy) on Si(100), Si(111) or Si(110) surfaces, in various combinations (Phys. Rev. Lett v93, 2004, p256102). In most cases, these form via a new "endotaxial" growth mechanism, in which the silicide grows into the substrate along inclined Si{111} planes, breaking the symmetry of the surface and leading to the long, thin island shape. These NWs are metallic, single-crystal structures with potential applications as interconnects, nano-electrodes or as functional elements for nano-electronic devices. Four independent STM tips can be positioned to contact a single NW. Each tip is pushed ~ 10nm beyond the point of tunneling to make good electrical contact with the NW. Four-point measurements on a single NW yield typical values of 600 @ohm@ and 60 @ohm@ for the NW and contact resistance, respectively, for a NW with dimensions 60 nm wide, 40 nm high and 2 microns long. Similar values are obtained from a 2-point configuration by measuring the resistance vs. tip separation. The corresponding resistivity is @rho@ = 20-30 µ@ohm@cm, which is similar to that for high-quality epitaxial films of CoSi2 at 300K. This indicates that defect- and/or surface-scattering is small for these structures. We also find that the NWs are isolated from the substrate by a Schottky barrier with zero-bias resistance of ~ 10@super 7@ @ohm@. The good isolation results from a surface depletion layer near the NWs.

Author Index

Bold page numbers indicate presenter