Thursday Afternoon, November 7, 2002

Nanometer Structures
Room: C-207 - Session NS-ThA

Nanowires
Moderator: D.A. Bonnell, University of Pennsylvania

2:00pm **NS-ThA1 Biofunctionalized Nanowires for Biosensing and Assembly**, ***C.D. Keating***, The Pennsylvania State University **INVITED**

This presentation will focus on the characterization, derivatization, and some applications of segmented metallic nanowires having stripes of different metals along their length. These particles are prepared by sequential electrodeposition of metals (e.g. Au, Ag, Pd, Pt, Co) within the pores of alumina or polycarbonate templates, and typically range from 30-300 microns in diameter and up to 10 microns in length. They can be released from the template and derivatized with proteins or nucleic acids for use in sensing or assembly. The metal segments can be used as an optical barcode to enable multiplexed bioanalysis or as a chemical pattern to spatially control (bio)chemical derivatization along the length of the particle. Both multiplexed bioanalytical applications and DNA-directed nanowire assembly will be discussed.

2:40pm **NS-ThA3 Aligned Dielectrophoretic and Electrophoretic Deposition of Single Wall Carbon Nanotubes**, ***P.E. Pehrsson***, Naval Research Laboratory, *J.W. Baldwin*, NRC/NRL Postdoctoral Fellow, Naval Research Laboratory

Carbon nanotubes offer real promise for a variety of nanotechnology applications such as resonator arrays for RF electronics, sensors, and other devices. We use dielectrophoresis (DEP) and electrophoresis (EP) to position nanotubes on surfaces and then measure their electrical conductivity. We vary the solution concentration and sonication procedures to control tube aggregation. We also use functionalized single-wall nanotubes (SWNTs), e.g. fluorinated, oxidized or with attached organosilanes. Functionalization can introduce potentially charged species such as carboxylic acid and may also change the nanotube's conductivity and permittivity, both of which may enhance its susceptibility to dielectrophoresis. The resistance across a gap spanned by a few tubes is typically above a MΩ, but resistance across the gap drops sharply (to 10-20 kΩ) at higher tube densities, possibly due to formation of a continuous percolation network. Tube purity is critical for good deposition. Contaminant particles in the suspension alter the deposition under specific deposition conditions. Some particles are unassociated with nanotubes and respond to the electric fields like other dielectric particles. Other particles (possibly leftover Ni nanocatalyst or amorphous carbon) are attached to the tubes and may pull them along in response to the fields. We are evaluating the interplay between surface chemistry on the nanotubes and at the electrode/liquid interface and the forces governing DEP and EP. DEP makes particles move in the direction of higher or lower electric field depending on the relative frequency-dependent conductivity and permittivity of the solvent and particle, and the particle size, shape, and surface chemistry. It could ultimately solve two of the biggest problems impeding the exploitation of carbon nanotubes; 1) separation of metallic and semiconducting nanotubes; and 2) removal of non-nanotube contaminants without the need for aggressive acid cleaning.

3:00pm **NS-ThA4 Functionalizing Molecular Lines on H-Si(100)**, ***P. Kruse***, *D.D.M. Wayner*, *R.A. Wolkow*, National Research Council of Canada

SPM-based lithography on H-terminated Si(100) and Si(111) surfaces has received considerable attention in recent years. It is based on stepwise controlled removal of H-atoms and subsequent reaction of molecules with the resulting Si-radicals (dangling bonds). Previously, we have reported the remarkable capacity of styrene to induce a chain reaction on these surfaces, resulting in self-directed line growth along dimer rows in the case of the Si(100) surface.[1] We have now examined a number of avenues for creating lines with built-in functionality. The incorporation of heteroatoms such as nitrogen in vinyl pyridine would be desirable, but the facile interaction of the lone electron pair of the nitrogen atom with the silicon dangling bonds prevents line growth. Aldehydes such as benzaldehyde are shown to undergo the same line growing mechanism as their vinyl compound analogues such as styrene. This offers the unique opportunity to create functionalized molecular lines by exposing the surface to dialdehydes. It is shown that in a rigid molecule such as terephthaldicarboxyaldehyde only one aldehyde group per molecule reacts with the surface whereas the other group is available for further reactions. This study seeks to open avenues for customizing molecular lines from self-directed growth for a wide variety of applications. Lines with preserved reactive groups or metal-complexing abilities can serve as devices or conducting wires on the surface and become building blocks of molecular electronics.

[1] G.P. Lopinski, D.D.M. Wayner, and R.A. Wolkow, Nature 406, 48 (2000).

3:20pm **NS-ThA5 Growth, Properties and Applications of Semiconductor Nanowires**[1], ***L. Samuelson***, Lund University, Sweden **INVITED**

One-dimensional (1D) semiconductors, or nanowires, have interesting physical properties and may offer possibilities to realize ultra-small electronic and photonic devices[2] as well as new kinds of circuitry.[3] Well defined nanowires (or nanowhiskers) can be formed using size selected catalytic nanoparticles to induce growth. By locating individual nanoparticles on predefined locations on a substrate also the position of the nucleation of individual nanowires may be controlled.[4] It was recently shown that not only homogeneous nanowires, but also multi-heterostructures with good electronic properties may be formed within a nanowire, even for combinations of materials having large differences in their lattice constants.[5] I will describe results from our studies of the electronic properties of heterostructures and will present examples of 1D heterostructure nanoelectronic devices created in nanowire systems.

@super 1@ I want to ackhowledge contributions from a number of students and colleagues (see author lists in refs. 5 and 6), especially Jonas Ohlsson on whisker growth, Mikael Bj@um o@rk on physics investigations and Prof. Reine Wallenberg on transmission el ectron microscopy.

@super 2@ K. Hiruma et al., "GaAs p-n junction formed in quantum wire crystals", Appl. Phys. Lett. 60, 745 (1992)

@super 3@ Y. Huang et al., "Directed assembly of one-dimensiona l n anostructures into functional networ ks", Science 291, 630 (2001)

@super 4@ B. J. Ohlsson et al., "Size-, shape-, and position-controlled GaAs nano-whiskers", Appl. Phys. Lett. 79, 3335 (2001)

@super 5@ M. T. Bj@um o@rk et al., "One-dimensional steeplechase for electrons realized", Nano Lett. 2, 87 (2002).

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4:00pm **NS-ThA7 Metal-Catalyzed Nanowires for Integrated Devices and Interconnections**, ***T.I. Kamins***, *X. Li*, *T. Ha*, *R.S. Williams*, Hewlett-Packard Laboratories

As integrated-circuit technology progresses, interconnections between active devices become more important in determining overall circuit and system density and performance. Without special circuit techniques, interconnection delays can degrade circuit performance even if the device speed improves. Defining multiple levels of fine wires by conventional lithography becomes increasingly difficult as dimensions decrease, and defining wires by advanced techniques becomes attractive. Wires can be formed at the nanoscale by nanoimprint lithography or by self-assembly techniques such as anisotropic lattice-mismatched epitaxy or metal-catalyzed nanowire growth. The latter is especially attractive because the surfaces are formed by growth, rather than by etching, which can cause crystal damage. The catalyzing nanoparticles can be in the liquid phase or possibly in the solid phase during growth. Nanowires formed by self assembly can be used as interconnections between devices, and devices can also be formed within the nanowires, allowing close integration of the nanowires and devices. If the nanowire is uniformly doped, tradeoffs must be made between the series resistance in the interconnection and the ability to deplete the wire in the device region, limiting performance. Requiring the maximum depletion region to be at least half the wire diameter limits the conductance of the interconnection, and therefore the charging time of the device, to possibly unacceptable values. If portions of the wire can be selectively doped, the interconnecting region and the device can be separately optimized.

4:20pm **NS-ThA8 Gadolinium Silicide on Si(100)**, ***B.C. Harrison***, *J.J. Boland*, University of North Carolina at Chapel Hill

The fabrication and characterization of nanoscale structures is motivated by the desire to produce materials and devices with novel optical, structural, and electronic properties. A large part of this effort involves discovering ways to replace current microelectronic technology with faster and cheaper nanostructures. One system of current interest is lanthanide silicide nanowires that spontaneously self-assemble on the Si(100) surface.[1,2,3] The high aspect ratio, large mechanical strength, micrometer length scales, and metallic character[3] suggest applications as nanoscale interconnects. However, these wires cannot be successfully used in electronic circuits until the morphology and placement is controlled and their electrical properties are well characterized. This study focuses on the morphology and electrical properties of Gadolinium silicide since this silicide has the smallest lattice constant mismatch in the wire growth direction of any of the available lanthanide silicides. Scanning Tunneling Microscopy (STM) is used to study the atomic structure of the nanowires and the wetting layer that grows

by a Stranski-Krastanov mechanism while the local electrical properties of these structures are probed by STS.

[1]Chen, Y.; Ohlberg, D. A. A.; Williams, S. J. Appl. Phys. 2002, 91, 3213.
[2]Chen, Y.; Ohlberg, D. A. A.; Medeiros-Riberio, G.; Chang, Y. A.; Williams, S. Appl. Phys. Lett. 2000, 76, 4004.
[3]Nogami, J.; Liu, B. Z.; Katkov, M. V.; Ohbuchi, C.; Birge, N. O. Phys. Rev. B 2001, 63, 233305-1. .

4:40pm **NS-ThA9 Atomic Structure and Electronic Properties of Rare Earth Silicide Epitaxial Nanowires on Si(001)**, ***J. Nogami***, Michigan State University

Several groups have recently reported growing nanowires of rare earth (RE) metal silicides on the Si(001) surface.[1,2,3] These nanowires grow by self assembly during the deposition of the RE metal on the Si(001) surface. They have many desirable properties such as crystalline structure, metallic conduction, and micron scale length. Recent STM and STS results on Dy and Ho silicide nanowires will be shown. Metal coverage, growth temperature, substrate step density, and post growth annealing duration all have strong effects on the nanowire morphology and surface density. Macroscopic transport measurements on nanowire networks will also be discussed.

[1] C. Preisenberger et al, J. Phys. D 31,L43 (1998)
[2] Y. Chen et al, Appl. Phys. Lett. 76, 4004 (2000)
[3] J. Nogami et al, Phys. Rev. B 63, 233305 (2001).

5:00pm **NS-ThA10 Fabrication of Low-dimensional Nanostructured Substrates**, ***M. Yoshimura***, Toyota Technological Institute, Japan, *K. Ojima*, NIMS, Japan, *K. Ueda*, Toyota Technological Institute, Japan

A clean Si(110) surface is reconstructed into so-called "16x2" superstructure, where pentagonal silicon clusters (hereafter, "pentagons") form one-dimensional up-and-down terrace structure with monatomic layer (0.2 nm) in height and about 5 nm in periodicity. This structure is expected to be a novel template for low-dimensional nanostructures. Since high step-density in this surface is due to relaxation of surface stress caused by formation of pentagons, it is possible to control the terrace width by modifying surface stress intentionally. Recently we succeeded in increasing terrace width by about 50% in Sn/Si(110) system. In this surface, Sn atoms form trimers, which are inserted into the pentagons. Then the spacing between pentagons is increased, giving lower surface stress and lower density of steps. Thus the arrangement of pentagons dominates surface structure in Si(110). However, the atomistic processes of rearrangement have not yet been clear. Here we first demonstrate the control of dimensionality of Si(110)-16x2 surface, namely, single or double domain, by using tilted wafers. We found that the epitaxial growth of metals on these surfaces was completely different from each other. Secondly, we examined adsorption of other metals on Si(110) to see how the pentagons change their positions and how the surface stress is relaxed. In contrast to Sn/Si(110), the up-and-down terraces immediately annihilate on Ag/Si(110) system. Lastly we compare the case of Ge(110), which forms a similar 16x2 structure, and discuss the mechanism of stress relaxation in (110) surface based on above results.

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