Tuesday Afternoon, November 3, 1998

Nanometer-scale Science and Technology Division
Room 321/322/323 - Session NS-TuA

Quantum Wires and Quantum Dots

Moderator: Ph. Avouris, IBM T.J. Watson Research Center

2:00pm **NS-TuA1 Self-organized Ge Quantum Wires on Si (111) Substrate**, ***G. Jin***, *Y.S. Tang, J.L. Liu, K.L. Wang,* University of California, Los Angeles

Self-organized nanostructures have been of considerable interest recently due to the fact that self-organization provides a possible way to realize nanostructures without process-induced damage as frequently seen in those defined by electron beam lithography and reactive ion etching. However, very few work has been reported on self-organized quantum wires. In this work, self-organized Ge quantum wires on Si (111) substrate grown by MBE have been realized and studied. Regular surface steps were formed on cleaned Si (111) substrate after annealing at 870°C in a UHV MBE system, then selforganized Ge quantum wires were formed on the substrate after growing 300 nm Si buffer layer. Atomic force microscopy (AFM) studies showed that regular surface steps were formed along [11 -2] direction and the terrace width was about 120 nm and the step height was about 0.6 nm. The self-organized Ge quantum wires with the width of about 65 nm and the height of about 5.5 nm were parallel to the direction of [11 -2] with the pitch close to the terrace width, or about 120 nm. The uniformity of the quantum wires was found to be reasonably good. Raman studies indicated that the peak of Ge-Ge mode shifted to a higher energy. This suggests that the Ge quantum wires are tensilely strained on the edge sites of the steps. The result of polarized Raman studies confirmed the existence of the wires and the wire orientation which is consistent with the AFM result. The size distribution and the optical properties of the Ge quantum wires are also under study. @FootnoteText@ The work was supported in past by National Science Foundation (DMR-9520893)

2:20pm **NS-TuA2 Formation and Characterization of Metal Atom Nanostructures on Si(112) Facet Surfaces**, ***S.M. Prokes***, *O.J. Glembocki,* Naval Research Laboratory

Facet semiconductor surfaces have been suggested for use as templates in the formation of ordered dots and lines. A bulk-terminated Si(112) surface is of particular interest since it consists of distinguishable (111) terraces and (001) steps which can serve as a template for the formation of well-ordered nanostructures, such as metallic wires or dots, with the aim of producing electron gratings and magnetic nanostructures. We have studied the formation of Ga, Al and Sc nanostructures on facet Si(112) surfaces, which were investigated using LEED, Auger spectroscopy and Reflectance Difference Anisotropy (RDA). Although the clean Si(112) surface exhibits (1x2) reconstruction, we found that the deposition of Ga or Al above 300°C removes this reconstruction and leads to a periodic stepped structure of alternating (111) terraces and (001) steps. Ga or Al chains then form by a self-limiting process, which we can track from the rapid change of the (2x1) Si(112) reconstruction under sub-critical coverage, to chain formation leading to a 5x1 reconstruction followed by a 6x1 reconstruction, using RDA. Furthermore, AES and RDA results show the replacement of Ga atoms by Al atoms at the step edges during sequential deposition of Ga and Al, indicating a stronger Al-Si bond. Using RDA, we have also observed that depositions at lower temperatures can lead to the formation of Ga metallic wires on the Si(111) terraces. For Sc, we find that its higher surface energy precludes the formation of wires but leads to the formation of nanometer-size Sc islands, which may exhibit enhanced magnetic moments. Using Monte Carlo techniques to model the time evolution of the deposition at various temperatures, we are also able to extract highly accurate values for the surface kinetic parameters involved in the formation of these nanostructures.

2:40pm **NS-TuA3 Nanotubes and Nanowires: Physics, Chemistry and Applications**, ***C.M. Lieber***, Harvard University **INVITED**

One-dimensional nanostructures, nanowires and nanotubes, represent an exciting and intellectually challenging area of research that crosses the borders between many areas of the physical sciences and engineering. Interest in these structures has been driven by fascinating issues in chemistry and physics, and the potential to impact science and technology. For example, it remains a great challenge to understand the intrinsic and potentially unique properties of nanowires and nanotubes, and thereby define new applications. This presentation will focus on addressing these critical issues. First, STM studies of the atomic structure and tunneling density of states of single-wall carbon nanotubes (SWNTs) will be described. Measurements show that SWNTs exhibit semiconducting and metallic behavior that depends predictably on helicity and diameter, and also exhibit well-defined 1D van Hove singularities. These results are compared and contrasted with theoretical calculations, and their implications discussed. Second, atomic force microscopy studies of the bending and stretching of individual nanowires and nanotubes will be discussed. The implications of these results on potential structural applications will be discussed. Lastly, the application of nanowires and nanotubes as molecular resolution, functionally-sensitive probes for chemistry and biology will be described.

3:20pm **NS-TuA5 Self-Assembled Nanostripes on Silicon**, ***D.Y. Petrovykh***, University of Wisconsin, Madison; *J. Viernow,* Universität Hannover, Germany; *J.-L. Lin,* University of Wisconsin, Madison; *F.M. Leibsle,* University of Missouri, Kansas City; *F.-K. Men,* National Chung Cheng University,Taiwan, R.O.C., Republic of China; *A. Kirakosian, F.J. Himpsel,* University of Wisconsin, Madison

We report on the successful fabrication of one-dimensional structures on silicon with sizes of a few nanometers. As templates we use stepped Si(111)7x7 surfaces, which can be prepared with high precision (only one kink in 20,000 edge sites).@footnote 1@ On top of such a template, CaF@sub 2@ stripes are produced by step flow growth. They play the role of a photoresist in nanolithography. Various growth modes of CaF@sub 2@ are found by chemically-sensitive scanning tunneling microscopy, including a regime at 600-650@super o@C where regular, 10 nm wide stripes are formed and a second regime at 700-750@super o@C where the stripes break apart spontaneously into strings of 10 nm diameter dots. Chemical sensitivity to CaF@sub 2@ is achieved in STM via current images at a bias voltage where electrons from the tip tunnel into the band gap of CaF@sub 2@. After producing passivating CaF@sub 2@ stripes, metallic wires are to be deposited on the remaining reactive silicon, e.g., by selective CVD, electroplating or evaporation and diffusion off the CaF@sub 2@. Test experiments on these processes will be reported. @FootnoteText@ @footnote 1@J. Viernow, J.-L. Lin, D. Y. Petrovykh, F. M. Leibsle, F. K. Men, and F.J. Himpsel, Appl. Phys. Lett. 72, 948 (1998) @footnote 2@J.-L. Lin, D. Y. Petrovykh, J. Viernow, F. K. Men, D. J. Seo, and F.J. Himpsel, J. Appl. Phys. 84, July 1 (1998)

3:40pm **NS-TuA6 Fabrication of Metallic Nanowires via UHV-STM Lithography and Thermal CVD**, ***M.C. Hersam***, *G.C. Abeln, D.S. Thompson, J.S. Moore, H. Choi, S.-T. Hwang, J.W. Lyding,* University of Illinois, Urbana-Champaign

The selective removal of hydrogen from a passivated Si(100) surface with an ultrahigh vacuum (UHV) scanning tunneling microscope (STM) allows nanometer-sized "templates" of clean Si(100) to be defined on an otherwise unreactive surface. By delivering chemically reactive species to the surface in the gas phase, different materials can be selectively deposited on the unpassivated Si(100) areas. In particular, nanopatterned metallization is achieved through selective thermal chemical vapor deposition (CVD) of organometallic precursor molecules. This paper systematically analyzes such precursor molecules to determine their suitability for selective CVD of metal on Si(100) in UHV. Initially, a novel aminoalane precursor was employed for CVD of aluminum at ~200°C. STM images of the surface after exposure to this precursor suggest monolayer coverage and evidence of a 2X2 reconstruction. However, variation of the dose and deposition conditions did not lead to the growth of a thicker film. Hence, in an effort to produce a more receptive surface for the growth of metallic thin films, CVD of nucleating agents (e.g., TiCl@sub 4@) was also studied. XPS and STM data show the selective deposition of Ti on clean versus H-passivated Si(100) after TiCl@sub 4@ exposure at room temperature. In an effort to grow TiN, the TiCl@sub 4@ experiments were repeated on an ammonia coated Si(100) surface. Again, XPS and STM data show the selective deposition of Ti. Finally, multiple precursor molecules were integrated for the growth of multi-layer structures. As a footnote, our efforts for interfacing these STM patterned nanowires with macroscopic external electronics will be updated.

4:00pm **NS-TuA7 STM/AFM Nanofabrication Process on Atomically Flat Substrate for Single Electron Device**, ***K. Matsumoto***, Electrotechnical Laboratory, Japan **INVITED**

Planar type single electron transistor(SET) and SET memory are proposed and realized on the atomically flat @alpha@-Al@sub 2@O@sub 3@ substrate using a STM/AFM nanofabrication process. Using STM tip/AFM cantilever as a cathode, the surface of the titanium(Ti) metal which was on an atomically flat @alpha@-Al@sub 2@O@sub 3@ substrate is selectively oxidized to form a few tens of nanometer wide oxidized titanium(TiO@sub

x@) line just under the tip. The surface roughness of the 2.5nm thick Ti metal is less than 0.15nm and retains the atomically flat condition. The surface roughness of TiO@sub x@ is also less than 0.15nm. The TiO@sub x@ works as an energy barrier for an electron, and the barrier height between Ti and TiO@sub x@ is 468meV. Therefore, the narrow TiO@sub x@ line could be used for the tunneling junction for SET. The size of the SET island is 8nm x 26nm square. The width, the thickness, and the length of the two tunnel junctions are 19nm, 2nm, and 26nm, respectively. The tunnel junction capacitance calculated from these structure parameters is C@sub t@=0.12aF. The gate electrode is set 964nm away from the island. The SET operates even at room temperature and shows the Coulomb oscillation with the periods of ~1.8V at the drain bias of -0.3V. At the different drain bias from -0.2V to -0.7V, the drain current shows the same oscillation periods of ~1.8V against the gate bias change. From this periods of Coulomb oscillation, the gate capacitance is estimated to be C@sub G@=0.1aF. Owing to the atomically flat @alpha@-Al@sub 2@O@sub 3@ substrate, the uniformity and reproducibility of the TiO@sub x@ line improves drastically, and it makes possible to fabricate the SET memory with complicated multi-tunnel junction structure.

4:40pm **NS-TuA9 Raman Scattering Studies of Multiple Ge Dots on Si (100) By Solid Source Molecular Beam Epitaxy**, ***J.L. Liu***, *Y.S. Tang, G. Jin, K.L. Wang,* University of California, Los Angeles

Recently, the growth of Ge dots on Si substrate has attracted much attention due to its potential applications in Si-based optoelectronics and its possible contribution to the scaling-down devices. The optical properties of these dots are particular interest in the investigation. In this work, we report the Raman scattering studies of multiple Ge dots on Si (100) substrate grown by solid source molecular beam epitaxy. The sample contains 20 periods of boron-doped Ge dots with 6 nm Si as barriers. The cross-sectional transmission electron microscopic observations illustrate that the size and height uniformities of the Ge dots are not worse that 7 percent. Raman spectrum shows the upper shift of Si-Ge mode and downward shift of Ge-Ge mode which are attributed to the alloying of the wetting layers and the phonon confinement in the Ge dots, respectively. From the polarization dependence Raman spectrum, we find the possibility of the strong intersubband absorption in the dots.

5:00pm **NS-TuA10 Surface Oxidation of Germanium Quantum Dots Produced by a Laser Vaporization-Controlled Condensation Technique**, ***S. Li***, *S. Wen, M. Wiess, J.A. Carlisle, M.S. El-Shall,* Virginia Commonwealth University

Weblike aggregates of coalesced Ge quantum dots are produced by a laser vaporization-controlled condensation technique. The surface oxidation of Ge quantum dots is studied with Fourier-Transform Infrared Spectroscopy (FTIR), core-level X-ray photoelectron spectroscopy (XPS), and x-ray diffraction (XRD). The freshly prepared Ge particles possess the bulk Ge crystal lattice. After the particles are removed from the reaction chamber for 10 min, the surface of the particles becomes oxidized as seen by XPS and FTIR. However, the FTIR peaks are very weak. Further oxidation of the Ge core, by exposure of the Ge quantum dots to air, results in the epitaxial growth of surface oxidation layers, as confirmed from XRD and XPS. After the particles are stored in air for two months, sharp features corresponding to crystalline GeO@sub 2@ are observed in the XRD spectrum. The surface-oxidized Ge quantum dots do not show photoluminescence from the core Ge particles, but rather show the emission characteristics of GeO@sub 2@, with photoluminescence lifetimes less than 20 ns. The photoluminescence is thus attributed to defect states in GeO@sub 2@.

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