## Processing at the Nanoscale/NANO 6
## Room 302 - Session NS+NANO6-WeA

### Nanoscale Modification of Materials

**Moderator:** R.E. Palmer, The University of Birmingham, U.K.

2:00pm **NS+NANO6-WeA1 Selective-Area Chemical Vapor Deposition Using AFM-Patterned Silicon Nitride Growth Mask**, ***S. Gwo***, *S.-W. Lin, Y.-C. Chou, T.T. Chen,* National Tsing-Hua University, Taiwan*; T. Yasuda, S. Yamasaki,* Joint Research Center for Atom Technology (JRCAT), Japan*; T.-S. Chao,* National Nano Device Laboratory, Taiwan

Silicon nitride (Si@sub 3@N@sub 4@) is a very robust material against oxidation and etching and is typically used as an oxidation mask. Here we report atomic force microscope (AFM)-based local oxidation of Si@sub 3@N@sub 4@ and its applications in nanofabrication. Owing to very large etch and growth selectivities among Si@sub 3@N@sub 4@, SiO@sub 2@, and Si, AFM nanolithography using Si@sub 3@N@sub 4@-mask could be used to both "subtractive" (selective-area anisotropic etching of underlying substrate) and "additive" (selective-area chemical vapor deposition) fabrication processes of nanostructures through the openings on the Si@sub 3@N@sub 4@ resist mask. Using this AFM-patterning method combined with a novel design of bilayer growth mask, which is entirely compatible with the existing microelectronic processes, synthesis of ultrahigh packing density and ordered nanostructure becomes readily achievable.

2:20pm **NS+NANO6-WeA2 Fabrication of Nanoscale Templates by Chemical Lithography**, ***A. Gölzhäuser***, *W. Geyer, V. Stadler, W. Eck, M. Grunze,* Universität Heidelberg, Germany*; T. Weimann, P. Hinze,* Physikalisch Technische Bundesanstalt, Germany*; K. Edinger,* University of Maryland

Nanostructure fabrication requires precise lithographic tools and smart materials that can be modified in a controlled manor. Recently, we discovered that self-assembled monolayers of biphenylthiols are crosslinked by electrons and can be utilized as negative resists.@footnote 1@ Crosslinked biphenyls can also be applied as stabilizing spacer groups during modifications via chemical lithography, specifically the conversion of NO@sub 2@ to NH@sub 2@ end groups.@footnote 2@ Based on these findings, we fabricated templates by high resolution electron beam lithography. We used a Leica LION LV 1 system at a beam energy of 2.5 keV and doses between 10 and 50 mC/cm@super 2@. We also applied a simple and versatile projection technique using FIB structured stencil masks and low energy (50eV) electrons. The templates were characterized by contact and lateral force AFM. The finest structures have lateral dimensions of ~20nm. We show that they can be used for a laterally controlled molecular deposition. @FootnoteText@ @footnote 1@ W. Geyer, V. Stadler, W. Eck, M. Zharnikov, A. Gölzhäuser, M. Grunze, Appl. Phys. Lett. 75, 2401 (1999). @footnote 2@ W. Eck, V. Stadler, W. Geyer, M. Zharnikov, A. Gölzhäuser, M. Grunze, Adv. Materials, in press.

2:40pm **NS+NANO6-WeA3 National Nanotechnology Initiative: Overview**, ***M. Roco***[1], The National Science Foundation **INVITED**

PLEASE SEND US AN ABSTRACT. Thank you.

3:20pm **NS+NANO6-WeA5 Electronic Conductivity and Thermoelectric Measurements of Bismuth Nanoline Structures**, ***K. Miki***, *A. Yamamoto, K. Sakamoto,* Electrotechnical Laboratory, Japan

Using the newly discovered characteristic structure of Bi perfect lines in Si(001) terraces, we have fabricated two new nanostructures of bismuth in silicon epitaxial layers and measured both their electronic and thermoelectric properties. Atomically perfect bismuth lines form in flat Si(001) surfaces around the temperature at which most of the bismuth desorbs from bismuth epitaxial layers. The lines are 1 nm wide and can be hundreds of nm long without kinks or other defects. In order to form multiple layers containing lines, segregation of the bismuth during subsequent silicon deposition was suppressed by further deposition of bismuth. In this way we fabricated three layers of Bi lines with undoped Si spacer layers 62 nm thick on an SOI (silicon on insulator) substrate, then capped it with 20 ML of silicon. We also fabricated a Bi delta doped structure: we intentionally destroyed most of the whole line structure by incompletely covering the surface with Bi and then heating the sample around 1100 degree C for 20 minutes. In this way we made five delta doped layers, separated by undoped Si spacer layers 20 nm thick. The layered structures were patterned into 1 micron x 100 micron bar-shaped devices through reactive ion etching, and metal contacts were made for transport measurements. By isolating the device on silicon oxide we eliminated electric leakage. The electronic measurements show that the delta doped structure is n type whereas the buried Bi line structure has metallic conductivity. We applied a temperature gradient to the buried Bi line structure along sample length of 100 micrometres, and observed a thermoelectric voltage linearly proportional to the temperature difference, of the order of 100 microvolts.

3:40pm **NS+NANO6-WeA6 Quantum-wire Arrays Fabricated by a High-pressure High-temperature Injection Process**, ***T.E. Huber***, Howard University*; M.J. Graf,* Boston College*; C.A. Foss Jr.,* Georgetown University

Three-dimensional arrays of metals and semiconductor ultrafine wires can be synthesized by injecting its liquid melt into a porous anodic aluminium oxide (PAAO) template. This is a highly effective technique with a resolution that exceeds 10 nm in many cases. Nanowire arrays are attracting a great deal of attention because of their potential applications in electronics and optics and promise for studying quantum confinement effects. The semimetal Bi is unique because, due to its extremely small effective mass, its Fermi wavelength is long, 25 nm. Therefore, quantum confinement effects should be readily observed in nanowires whose diameter are below ca. 25 nm. Large area (2 mm x 2 mm) arrays of parallel wires of Bi with diameter as small as 20 nm, lengths of 30 - 50 mm, and packing density as high as 10@super 11@ cm@super -2@ have been fabricated. The nanowires are essentially single crystalline and oriented. We have found a resistivity enhancement and a very large positive magnetoresistance. For small diameter wires a resistance maximum is observed. The nanowires contact resistance and doping effects are discussed. The experimental results are discussed in terms of the semimetal-to-semiconductor transition, classical size effects and mesoscopic phenomena. Bulk Bi and Bi-Sb alloys are the best thermoelectric materials at 77 K; the nanowire array composites, especially the 1D Bi quantum wire systems, are expected to show improved properties.

4:00pm **NS+NANO6-WeA7 Transport Study of Single Bismuth Nanowire Fabricated by Silver and Silicon Nanowire Shadowmask**, ***S. Choi***, *M. Leung, G. Stupian, N. Presser,* The Aerospace Corporation*; S. Chung, J. Heath, A. Khitun,* University of California, Los Angeles*; A. Balandin,* University of California, Riverside

We have carried out measurements of the electrical conductivity of a single bismuth nanowire fabricated by low energy electron beam lithography using silver/silicon nanowire shadowmasks. The nanowires examined have characteristic dimensions slightly below the critical diameter (about 50nm) at which a semimetal to semiconductor phase transition was predicted to occur. Our results reveal a semiconductor-like temperature dependence of the electrical conductivity of a bismuth nanowire which is strikingly different from the bulk dependence. We have also developed a theoretical model which adequately describes the dependence of the electrical conductivity and energy band gap on the diameter of bismuth nanowires and other parameters. The experimental data presented may be crucial for suggested thermoelectric application of bismuth nanowires.

4:20pm **NS+NANO6-WeA8 Conductance Anisotropy in a Mesoscopic Array of Atomic Wires: Ga/Si(112)@footnote 1@**, ***K.J. Yoo***, *S. Tang,* University of Tennessee*; P.T. Sprunger,* Louisiana State University*; H.H. Weitering,* University of Tennessee

In recent years, researchers at the Naval Research Laboratory have used the Si(112) surface as a template for the fabrication of a mesoscopic array of single-atom-wide gallium wires or quantum wires.@footnote 2@ The structural uniformity of the wire array appears far superior to those created by nanolithographic methods. We have characterized this Ga/Si(112) hetero-structure with Scanning Tunneling Microscopy, Angle-Resolved Photoelectron Spectroscopy (ARPES), and Si 2p core-level spectroscopy. The electrical conductivity of the wire-array was measured as a function of temperature in ultrahigh vacuum using the four-point-probe technique parallel and perpendicular to the quantum wires. The parallel conductivity has a temperature-dependence characteristic of a semiconductor. In contrast, the conductivity perpendicular to the wires appears metallic. This unexpected result can be understood on the basis of first-principles calculations by Flores and coworkers in Madrid @footnote 3@, which indicate that the band effective mass in the perpendicular direction is close to the free electron mass (m*=1.3 m@sub e@) whereas the effective mass in the parallel direction is very large (m*> 5.5 m@sub

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e@). The main features of the theoretical surface-state band structure have been confirmed with ARPES. Contributions to the electrical conductivity by the space charge layer beneath the surface have been calculated based on core level measurements of band bending. These contributions were subtracted to determine the electrical conductance solely through the quantum wires. @FootnoteText@ @footnote 1@Work supported by National Science Foundation(DMR-9705246). @footnote 2@A. A. Baski, S. C. Erwin, and L. J. Whitman, J. Vac. Sci., B14(2), 992(1996). @footnote 3@F. Flores, in private communication.

4:40pm **NS+NANO6-WeA9 Time Evolution of Ag Nanowires Grown on Ag/GaAs(110) Surfaces**, ***H.-B. Yu***, *C.-S. Jiang, X.-D. Wang, C.-K. Shih,* University of Texas at Austin

We have studied an unusual 'shrink-expand' behavior of Ag nanowires grown on Ag films using scanning tunneling microscope (STM). Ag films were prepared using low temperature deposition onto UHV in-situ cleaved GaAs(110) surfaces, followed by room temperature annealing. The film thus formed, below or around 6 ML, are atomically flat with voids distributed in the film. After the film becomes smooth, atoms inside the voids continue to transfer to the top Ag surface and form nanowires. Some of the nanowires have aspect ratios greater than 100:1. The nanowire length growth was monitored with STM, showing linear growth rate with time, while keeping the same width. After growing to certain length, the wires start to shrink, and at the same time, their widths expand by about 1.4 nm. After this shrinking process, the Ag wires continue to grow linearly in time before it takes on another 'shrink-expand' process. This 'shrink-expand' behavior can be observed on nanowires with no voids surrounded, but also on wires that are approaching the existing void edge, which indicating the repulsive interaction of nanowires with the edge of the voids. Detailed mechanism of this nanowire shape transition will be discussed.

5:00pm **NS+NANO6-WeA10 Ion Implanted Contacts to Nanostructures and Metallic Monolayers on Clean Surfaces**, ***J.W. Nolan***, *B.N. Cotier, M.J. Butcher, P.H. Beton, P. Moriarty, M.R.C. Hunt, A. Neumann,* University of Nottingham, UK*; V.R. Dhanak,* Daresbury Laboratory, UK*; A. Gundlach,* Edinburgh University, UK*; S. Thoms,* University of Glasgow, UK

Ion implanted (As) contact tracks with separations of order 200nm and depths ~20nm are formed in p-Si/SiO2 wafers. These tracks are investigated using scanning tunnelling microscopy (STM) in an ultra-high vacuum environment following removal of the SiO2 layer using a combination of wet etching and high temperature vacuum annealing in the range 600-1000oC. The ion implanted regions are activated by this anneal and are slightly depressed (by ~5nm) as compared with the surrounding surface but co-exist with the Si(100)-2x1 and Si(111)-7x7 surface. Core level photoemission studies of control samples which have been uniformly implanted show that As desorbs from the near surface region for temperatures >900oC, the temperature at which the oxide layer is thermally desorbed, but this leads to an insignificant change in resistance of the tracks. The ion implanted regions form high impedance reverse biased p/n junctions with a p-type substrate and adjacent implanted tracks may be shorted by the deposition of thin metallic films. The shorting resistance of these structures has been measured using an in-situ electrical prober and results are correlated with the morphology of the metallic layer. For samples annealed below 900oC the oxide layer is not desorbed and a shorting resistance ~20kOhms is observed for a Ag film of thickness 0.5nm. At higher annealing temperatures this shorting resistance is much higher due in part to As desorption and in part the island morphology of the Ag film. The process is compatible with H termination and de-passivation and we report results on metallic adsorption on depassivated wires ~1-5nm wide.

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