Nanometer-scale Science and Technology
Room 213D - Session NS-WeM

Nanoscale Patterning and Lithography

Moderator: D.W. Carr, Sandia National Laboratories

8:20am **NS-WeM1 Massive Self-Assembly for Integrated Carbon Nanotube Circuits*, S. Hong,*** Seoul National University, Korea, South Korea **INVITED**

Nanoscale electronic devices made of carbon nanotubes (e.g. transistors, sensors) can be much smaller and more versatile than any conventional microelectronic chips, while the lack of a mass-production method has been holding back their practical applications. Inspired by biomolecular self-assembly, we developed a novel self-assembly method for the wafer-scale fabrication of millions of carbon nanotube circuits with a single-nanotube-level precision. This method may enable industrial-level production of nanotube-based devices such as faster electronic circuits and high-density sensor arrays.

9:00am **NS-WeM3 Surface-Programmed Assembly of Carbon Nanotubes on Silicon Oxide Surfaces for Integrated Circuit Applications*, M. Lee,*** *J. Im, S. Hong,* Seoul National University, South Korea

As the microelectronics approaches its resolution limit, alternative electronic devices draw the attention of the scientific community. One strong candidate can be carbon nanotube (CNT)-based electronics. We developed a method to selectively assemble carbon nanotubes at a desired location with precise orientations on silicon oxide substrates. In this process, surface molecular patterns guide the assembly of CNTs onto desired locations. Importantly, we utilized only conventional microfabrication process such as photolithography for the entire process, which makes our method completely compatible with microfabrication techniques. This research can be utilized for fabrication of carbon nanotube-based electric circuits.

9:20am **NS-WeM4 Recent Lithography Results from the Digital E-Beam Array Lithography (DEAL) Concept*, W.L. Gardner,*** *L.R. Baylor,* Oak Ridge National Laboratory*; X. Yang,* University of Tennessee, Knoxville*; R.J. Kasica, D.K. Hensley,* Oak Ridge National Laboratory*; A.V. Melechko,* Univeristy of Tennessee, Knoxville*; D.C. Joy, P.D. Rack, B. Blalock, S. Islam,* University of Tennessee, Knoxville*; M.A. Guillorn,* Cornell Nanofabrication Facility*; M.L. Simpson,* Oak Ridge National Laboratory

The Digital E-beam Array Lithography (DEAL) concept is currently under development at Oak Ridge National Laboratory (ORNL).@footnote 1@ This concept incorporates a digitally addressable field emission array built into a logic and control integrated circuit to function as the write head for a massively parallel e-beam lithography tool. Each field emission device comprises three electrodes separated 1 µm from each other by SiO@sub 2@. The first electrode functions as the cathode and contains a single vertically aligned carbon nanofiber as the field emitter. The second is a 2-µm diameter extraction aperture formed using a self-aligning process. The third is a 4-µm diameter aperture functioning as an electrostatic focusing lens and created using standard photolithographic processing. Field emission and focusing tests on prototype devices demonstrated that the emission follows Fowler-Nordheim characteristics, the beams can be focused as anticipated from numerical simulations, and the extraction and focus apertures in well-aligned devices collect less than 1% of the emitter current. Preliminary lithographic results on PMMA coated substrates demonstrated that variations in linewidth measured as a function of the focus lens voltage are in good agreement with device modeling. Our current research objective is to demonstrate lithography using a full 3x3 array of operating devices. We will discuss our recent results in detail as well as ongoing work to achieve <100-nm linewidths and full array implementation. @FootnoteText@ @footnote 1@ ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract No. DE-AC05-00OR22725.

9:40am **NS-WeM5 Monomer Based Thermally Curable Imprinting Lithography*, H. Lee,*** Korea University, Korea

Nanoimprint lithography is one of the most viable technologies for mass production of devices with nano-patterns such as optical components (polarizer and diffuser), bio and NEMS devices, photonic crystals and patterned magnetic media. With this technology, nano patterns are generated by duplicating the ruggedness of imprinting stamp onto polymer films on the substrate. However, high pressure (>800psi) and high temperature (>150C)operation is required to transfer nano patterns onto polymer film. In this study, a mixture of base monomer, vaporization inhibitor, anti-sticking agent and thermal initiator was used as an imprint resin. Viscosity of mixture was controlled by relative amount of vaporization inhibitor. Compared to the polymer based resin such as PMMA, monomer based resin has several advantages. Since the monomer based imprinting resin is in liquid phase without heating up to the decomposition temperature of thermal initiator, high quality pattern transfer with minimized residual layer can be done at much lower imprinting pressure. The decomposition temperature of thermal initiator is relatively lower than the glass temperature of polymer. Thus, imprinting can be done at lower temperature (below 100C). Thus, time consumption for heating and cooling can be reduced and higher throughput was obtained. In this study, whole 6 inch diameter wafers were patterned by single step imprinting with the same sized stamp.

10:00am **NS-WeM6 Charge Interactions in Ferroelectric Substrates: the Basis of Ferroelectric Nanolithography*, D.B. Li,*** *R. Shao, D.A. Bonnell,* The University of Pennsylvania

A new approach to directed assembly has recently been proposed that allows multiple nanostructures of diverse materials to be positioned in predefined locations. Ferroelectric Nanolithography has been demonstrated in the assembly of metal nanoparticle/functional organic molecule/oxide systems for a wide range of materials. The process is based on patterning ferroelectric domain orientation to control surface local electronic structure, which can be accomplished with exposure to electron beams and optical interference patterns. The underlying physics of these processes is not understood. This paper examines the effects of electron injection and electron-hole pair generation on surface ferroelectric polarization and charge compensation. The effects of dose, substrate thickness, and substrate morphology on pattern spatial resolution and stability are quantified for lead zirconate titanate and barium titanate films. For the case of electron-hole pair generation the mobile carriers compensate local atomic polarization at the surface. On high dose electron injection an electric field is established which reorients the polarization vectors. Both processes alter the local electronic structure by influencing surface band bending.

10:20am **NS-WeM7 Nanoscale Patterning in Application to Novel Materials and Device Structures*, N. Zhitenev,*** Bell Labs, Lucent Technologies **INVITED**

As the size of electronic devices shrinks down to atomic scale, device properties are increasingly dependent on physics and chemistry of interfaces or interfacial networks. The growth, the patterning and the characterization of such systems at nanometer scale present significant challenges and opportunities. Extremely small devices can display useful functionality based on new physical phenomena. On the other hand, direct lithography requiring deposition of resists, exposure to radiation and to wet/dry chemistry can strongly modify the device properties. Possible solutions are to perform the most invasive patterning before the growth or out of a potentially delicate device structure. We study such fabrication schemes in application to the patterning of self-assembled molecular monolayers between metal electrodes. The first approach uses pre-fabricated masks to confine the deposition of materials. The size of the features is controlled by shadow angle evaporation. Another method uses nanoimprinting to deliver patterned metal onto molecular layer. Metal-molecular layer-metal junctions are fabricated with the size down to ~10-100 nm. While certain electrical properties are fairly reproducible, these techniques provide only initial foothold toward the fabrication of nanoscale interfacial devices. The critical issues that determine the overall performance and require further research are control of the surface topography and the grain structure of metals, doping of the molecular layers by the contacts and formation of the chemical bonds at the interfaces.

11:00am **NS-WeM9 Fabrication of Nanopatterned Polymer Brushes by Scanning-Probe and Electron-Beam Lithography*, W.K. Lee,*** *M. Kaholek, S.J. Ahn, S. Zauscher,* Duke University

Here we present several lithographic approaches that we have adopted to fabricate nanopatterned polymer brushes. We demonstrate the use of nanoshaving, where an atomic force microscope (AFM) cantilever tip is employed as a nanomechanical tool to selectively remove a thiol resist. The freshly exposed gold surface in the resulting â?onano-trenchesâ?⍰ was immediately backfilled with a bromo-thiol initiator and enabled patterned surface initiated polymerization. In a complementary approach we prepared oxide nanopatterns on resist-coated silicon surfaces by applying an electric potential between the AFM cantilever tip and the silicon substrate. In this case the nanopatterns were backfilled with a silane initiator SAM. We show that the choice of silane SAM enables both, ring-opening metathesis and atom transfer radical polymerization. We also used lift-off (dissolution) e-beam lithography (EBL) to generate gold nanopatterns that could again be used to immobilize a thiol initiator. We demonstrate that by choosing an appropriate nanolithography technique and combining it with a suitable polymerization technique allows us to fabricate high-density polymer brush arrays with control over chemical functionality, feature dimension, shape, and interfeature spacing on the nanometer length scale. Furthermore we demonstrate that the spatially controlled immobilization of stimuli-responsive macromolecules on solid surfaces at the nanometer-length scale enables fabrication of â?osmartâ?⍰ â?"externally switchableâ?" polymer nanoarrays. Such nanostructures can provide sensing functionality within integrated nanoscale bioanalytical devices in which the transport, separation, and detection of biomolecules must be performed in aqueous solutions.

11:20am **NS-WeM10 Thermal Control in Dip Pen Nanolithography***, **P.E. Sheehan,*** Naval Research Laboratory*; W.P. King,* Georgia Tech*; L.J. Whitman,* Naval Research Laboratory

Although it has been widely assumed that Dip Pen Nanolithography (DPN) requires a water meniscus to tranfer ink from an AFM tip to a surface, we have shown that transfer can occur under xeric conditions@footnote 1@ , a method we call "dry deposition". Our recent studies of dry deposition have led to a number of insights into how DPN can be extended beyond "wet" inks. For example, deposition should be possible at high temperatures (i.e., above the boiling point of water) and, thus, temperature could be used to control deposition. We have utilized a heated atomic force microscope (AFM) cantilever tip to control the deposition of a solid organic ink. The ink, octadecylphosphonic acid (OPA), melts at 98°C and self-assembles on mica, the substrate. Evaporation was used to coat OPA onto a cantilever with integrated microheaters. When the cantilever temperature was below 98°C, no deposition was detected. At 98°C slow deposition was seen, but only after raising the temperature to 122° C was deposition robust. Thermal DPN (tDN) enhances traditional DPN in many ways. First, it allows exquisite control over writing--deposition may be turned on or off and the deposition rate changed without breaking contact with the surface. Secondly, the inks used have lower surface mobilities once cooled and so are able to achieve higher spatial resolution. Thirdly, imaging with a cool tip does not appear to contaminate the surface. This allows in situ confirmation of the deposited pattern without fear of contamination. Finally, tDPN expands the range of useable inks--current work with electronically active molecules that have high melting temperatures will be presented. @FootnoteText@ @footnote 1@ PRL 88, 156104 (2002).

11:40am **NS-WeM11 Chemomechanically Scribing Silicon with an AFM in a Read/Write Fashion***, M.V. Lee, K. Gertsch, **R.C. Davis**, M.R. Linford,* Brigham Young University

One of the most important problems in nanotechnology is the precise positioning of molecules on surfaces. One possible method for accomplishing such nanoscale patterning is the chemomechanical modification of silicon with an AFM tip. Using this method ca. 30 nm functionalized lines have been produced by i) wetting hydrogen-terminated silicon with a reactive compound, and ii) scribing with an AFM tip. Scribing activates the silicon so that it reacts with the liquid it is in contact with wherever the AFM tip is pushed against the surface. The width of the functionalized feature can be controlled by changing the force applied to the tip. In this talk we also report advances in chemomechanically depositing a monolayer on silicon using an AFM, and then chemomechanically replacing the monolayer in the scribed region by scribing over the functionalized region. Time-of-flight secondary ion mass spectrometry is used to confirm surface modifications and alterations. This new read-write capability should significantly increase the usefulness and power of the chemomechanical method at nanometer dimensions. @FootnoteText@ Wacaser, B.A.; Maughan, M.J.; Mowat, I.A.; Niederhauser, T.L.; Linford, M.R.; Davis, R.C. Chemomechanical surface patterning and functionalization of silicon surfaces using an atomic force microscope. Applied Physics Letters 2003, 82(5), 808-810.

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