Wednesday Morning, October 27, 1999

Nanometer-scale Science and Technology Division
Room 612 - Session NS-WeM

Nanopatterning

Moderator: C.R.K. Marrian, Naval Research Laboratory

8:20am **NS-WeM1 "MILLIPEDE" - A Highly Parallel, Very Dense AFM-Based Data Storage System**, ***P. Vettiger***, *M. Despont, U. Drechsler, U. Dürig, W. Häberle, M.I. Lutwyche, H. Rothuizen, R. Stutz, R. Widmer, G.K. Binnig,* IBM Research Division, Zurich Research Laboratory, Switzerland **INVITED**

We report on an alternative storage approach based on scanning probe techniques having areal density potential far beyond and data rates comparable to today's magnetic-recording techniques.@footnote 1,2@ Ultra-high areal density is achieved by thermomechanical writing/reading in very thin polymer films, and the high data rate by highly parallel operation of very large, 2D cantilever/tip arrays.@footnote 2@ Potential for ultra-high density was demonstrated by 40-nm bit indents and 40-nm bit pitch in 50-nm-thick polymers films (PMMA), resulting in 400 Gbit/sq inch.@footnote 3@ We also demonstrated, for the first time, large area thermal data erasing/rewriting in such polymer films. First functional 32x32 (1024) cantilever array chips were fabricated,@footnote 4@ which are among the densest VLSI-NanoEMS chips. The 32x32 array is fabricated on an 3x3 mm area of a 7x14-mm silicon chip. Four integrated approaching/leveling sensors in the four corners control the simultaneous approach of the entire chip. While the feedback control system keeps the chip leveled and the tips in contact with the media, the media is scanned in the X and Y directions. Writing/reading is controlled by a time-multiplexed row/column addressing scheme. Similar micromaching techniques were used to fabricate a silicon micromagnetic X/Y/Z scanner with integrated Cu coils.@footnote 5@ We present details on the MILLIPEDE storage concept, the thermomechanical write/read/erase processes/results as well as the VLSI-NEMS chip and micromagnetic X/Y/Z scanner fabrication. @FootnoteText@ @footnote 1@ H.J. Mamin et al., IBM J. Res. Develop. 39, 681 (1995). @footnote 2@ P. Vettiger et al., Proc. Int'l Conf. on Micro- and Nanoengineering 98, Leuven, Belgium, Sept. 1998, to appear in J. Microelectron. Eng. @footnote 3@ G. Binnig et al., Appl. Phys. Lett. 74, 1329 (1999). @footnote 4@ M. Despont et al., Technical Digest MEMS'99, p. 564 (IEEE, 1999). @footnote 5@ M. Lutwyche et al., Proc. 194th ECS Mtg., Boston, MA (in press).

9:00am **NS-WeM3 Scanning Probe Lithography of Silicon Nitride Thin Films**, ***F.S.-S. Chien***, National Chiao Tung University, Taiwan*; S.W. Lin,* National Tsing Hua University, Taiwan*; W.-F. Hsieh,* National Chiao Tung University, Taiwan*; Y.-C. Chou, T.-T. Chen,* National Tsing Hua University, Taiwan*; T.S. Chao,* National Nano Device Laboratory, Taiwan*; S. Gwo,* National Tsing Hua University, Taiwan

Silicon nitride has been extensively used as etch stops, diffusion barriers, oxidation masks, and gate dielectric layers in integrated circuit processing. A new method is proposed here to perform local oxidation and negative pattern transfer on silicon nitride thin films. A LPCVD silicon nitride film of 25 Å thickness grown on a p-type silicon wafer is locally oxidized by the probe of an atomic force microscope under positive biases of 5 V to 10 V. In this approach, nanometer-size oxidation patterns can be made on the silicon nitride film. By using the selective HF etching, the oxidized regions on the silicon nitride film can be removed. In a second step, the orientation dependent KOH etching, which has an extremely large selectivity between silicon and silicon nitride, can produce high-aspect-ratio trenched structures (pattern transfer of the original oxide mask) on the (110)-oriented silicon wafer. Such a new method of producing negative-resist pattern tranfer can greatly enhance the capabilities of scanning probe lithography for the future microelecronics and optoelectronics applications on the nanometer scale. @FootnoteText@ F. S.-S. Chien is also with Center for Measurement Standards, Hsinchu, Taiwan.

9:20am **NS-WeM4 Nanolithography and Pattern Transfer of (110)-oriented Silicon Using Scanning Probe Lithography and Anisotropic Wet Etching**, ***C.-L. Wu***, National Tsing Hua University, Taiwan*; S.-S. Chien, W.-F. Hsieh,* National Chiao Tung University, Taiwan*; T.-T. Chen, Y.-C. Chou, S. Gwo,* National Tsing Hua University, Taiwan

Recently, scanning probe lithography has became an emerging technology capable of fabricating sub-micron structures. We have demonstrated that silicon nanostructures (~60 nm lateral dimension) with high aspect ratios and large structural heights (~400 nm) may be fabricated by scanning probe lithography and aqueous KOH orientation-depentent etching on the H-passivated (110)Si wafer. The High spatial resolution of fabricated features is achieved by atomic force microscope based nano-oxidation process in ambient and anisotropic selective wet etching. Combining the large (110)/(111) anisotropic ratio of etch rate and large Si/SiO@sub2@ etch selectivity of aqueous KOH etching at an optimal concentration and a relatively low etching temperature, structural ridges of high-aspect-ratio and excellent parallelism as well as a hexagonal pit structure determined by the terminal etch geometry can be obtained. This method is potentially useful for simple and reliable high-packing-density and high-aspect-ratio micromachining on the nanometer scale.

9:40am **NS-WeM5 Patterning of Silicon Surfaces With a Non-Contact Atomic Force Microscope: Attomol Chemistry and Nanofabrication**, ***R. Garcia***, *M. Calleja,* Consejo Superior Investigaciones Cientificas, Spain*; H. Rohrer,* Switzerland

Nanometer-size water bridges have been used to confine the anodic oxidation of silicon surfaces with a non-contact atomic force microscope. The formation of a water bridge between two surfaces separated by a gap of a few nanometers is driven by the application of an external electrical field. Once a liquid bridge is formed, its length and neck diameter can be modified by changing the tip-sample separation. The liquid bridge provides the ionic species and the spatial confinement to oxidize Si(100) surfaces.@footnote 1,2@ The very small number of active ionic species within the bridge, a few attomoles, allows a precise control of the lateral and vertical size of the oxide. Above results are applied to develop a highly reproducible method to nanofabricate two types of patterns: (i) arrays of 5000 dots with a periodicity of 40 nm and an average width of 10 nm and (ii) lines 10 micron long and 10 nm wide. @FootnoteText@ @footnote 1@R. Garcia, M. Calleja and F. Perez-Murano, Appl. Phys. Lett. 72, 2295 (1998). @footnote 2@R. Garcia, M. Calleja and H. Rohrer, J. Appl. Phys. (in press).

10:00am **NS-WeM6 Fabrication of Nanoscale Metal Wires on the Si(001) Surface Using Scanning Tunneling Microscopy**, ***T. Mitsui***, *E. Hill, R. Curtis, E. Ganz,* University of Minnesota

Nanoscale wires are fabricated on the Si(001)-(2x1) surface using an atomic hydrogen resist process.@footnote 1@ The patterning is achieved by removing small areas of the hydrogen passivation layer with a scanning tunneling microscope. Pattern transfer is performed by chemical vapor deposition (CVD) or physical vapor deposition (PVD). CVD provides higher selectivity than PVD. However, Ti selective CVD growth from TiCl@sub 4@ is self limiting by Cl passivation. Growth can be resumed by removing the Cl passivation locally using the STM. Al selective CVD produces 3 nm wires although the wires appear to be granular and sequential growth roughens the pattern. To improve the wire quality, we are now using selective Pd silicide growth by PVD. @FootnoteText@ @footnote 1@T-C. Shen, C. Wang, G. C. Abeln, J. R. Tucker, J. W. Lyding, Ph. Avouris, and R. E. Walkup, Science 268, 1590 (1995).

10:20am **NS-WeM7 Growth and Characterisation of Submicrometer Regular Arrays of Pillars and Helices**, ***M. Malac***, *R.F. Egerton, M.J. Brett,* University of Alberta, Canada

The fabrication of photonic bandgap structures presents one of the current challenges in microfabrication. Submicron periodic structures with a high aspect ratio are necessary to create a structure with a photonic bandgap in the visible or near infrared region. We have fabricated arrays of pillars and helices with lattice parameter down to 300nm and aspect ratio as high as 25. We utilize oblique-angle deposition onto a rotating substrate (GLAD technique) to grow our films. A square array with lattice parameter between 300 nm and 1 micrometer was patterned onto the substrate prior to film growth. The array was made using electron beam lithography based on PMMA resist followed by lift-off. The array provides preferential sites for shadowed film growth when the film is deposited onto a substrate which is oblique with respect to the arriving species. This method provides a high degree of process control and sufficient number of degrees of freedom to allow for the growth of a wide range of structures. Our microstructures were made of titanium or bismuth, chosen for the large difference in their melting points. All films were deposited onto a room-temperature substrate, implying a low adatom diffusion length for titanium (due to a low ratio of substrate temperature and melting point) but a large adatom diffusion length for bismuth (where bulk diffusion may play a significant role). The titanium pillar structures appear to be uniform along their length, the crystallite size being smaller than the pillar diameter. Regular arrays of titanium helices exhibited bifurcation within each helix, whereas bifurcation was strongly suppressed in both helices and pillars

made of bismuth. The delibrate introduction of a defect into the patterned array did not have a radical effect on film growth.

10:40am **NS-WeM8 Plasma Polymerization as a Novel Means of Preparing Concentric-Tubular Composite Microstructures**, ***E.R. Fisher***, *M.L. Steen, J.R.D. Peers,* Colorado State University

Template synthesis has been shown to be a general method for preparing micro- and nanostructured materials. This method entails synthesizing a desired material in the pores of microporous filtration membranes. Concentric-composite micro- and nanostructures have also been prepared by the template method. Such concentric-tubular structures consist of an outer tubule of one material surrounding inner tubules of different materials. Synthetic methodologies for preparing concentric-tubular micro- and nanostructures include electroless deposition of Au, electropolymerization of metals and semiconductors, carbonization of polymer precursors, chemical-vapor deposition and sol-gel synthesis. Thus, these methodologies are used to prepare composite micro- and nanostructures composed of metals, semiconductors, carbon, polymers and Li@super +@-intercalation materials. We propose an alternative synthetic methodology to preparing concentric-tubular micro- and nanostructures of this type. This method employs plasma polymerization to deposit polymeric conformal coatings on Au micro- and nanotubules synthesized by the template method. There are several experimental advantages to using plasma polymerization. Polymer-formation occurs from almost all volatile organic molecules, even those lacking vinyl and aromatic groups necessary for other polymerization schemes. The chemical composition of the deposited films can be controlled by adjusting plasma parameters, such as applied rf power, monomer flow rate, and pulsed vs. CW conditions. An extensive parameter study of several plasma systems has been examined. We have prepared several Au-insulating and Au-conducting polymer concentric-composite micro- and nanostructures by plasma polymerization. For example, polystyrene-coated Au microstructures are obtained from a pulsed benzene plasma. Results from scanning electron microscopy and electrochemical characterization will be discussed.

11:00am **NS-WeM9 Fabrication of Bismuth Nanowires with a Silver Nanocrystal Shadowmask**, ***S. Choi***, *K. Wang,* University of California, Los Angeles*; M. Leung, G. Stupian, N. Presser, B. Morgan, R. Robertson, E. King, M. Tueling,* Aerospace Corporation*; S. Chung, J. Heath,* University of California, Los Angeles*; S. Cho, J. Ketterson,* Northwestern University

There has been much interest in arrays of bismuth (Bi) nanowires for both fundamental understanding and device application because of many interesting properties such as long mean free path of the carriers and the small effectiveness and the semimetal-semiconductor transition. In this abstract, we describe a method of using silver (Ag) nanocrystal wires as a shadowmask to produce nanometer-size Bi wire patterns and discuss transport properties of Bi nanowires. In our technique, organically functionalized Ag nanocrystals (2-100nm) can assemble into lamella (wire-like) phases. The width of the wires could be controlled from 20 to 300nm. The wire patterns can be transferred as Langmuir-Scheffer (horizontal lift-off) films to the polymethyl methacrylate (PMMA) coated Bi/CdTe substrates. Bi epilayers were grown by molecular-beam epitaxy (MBE) on CdTe (111) B substrates. X-ray diffraction showed only sharp (00.l) peaks were present, which implied c-axis growth of Bi perpendicular to the substrates. Cleanness of surface of Bi films was also confirmed by the Time-Of-Flight Secondary Ion Mass Spectroscopy (TOFSIMS) using high energy Gallium ions. The wire patterns were transferred to the PMMA films by spatially selective electron beam exposure on the Ag nanocrystal wire shadowmask. 50 nm and 70 nm wide Bi wire patterns were formed by a subsequent anisotropic reactive ion etching (RIE) process. The metal contacts on the Bi nanowires were prepared by in-situ Focused Ion Beam (FIB) deposition for temperature dependent resistance measurement. In zero magnetic field, the temperature dependent resistance measurements on the Bi nanowires with widths of 50 nm and 70 nm showed the resistance increased with decreasing temperature, which was characteristic for semiconductor and insulators.

11:20am **NS-WeM10 Fabrication of Metal Nano-wires using Carbon Nanotube Masks**, ***W.S. Yun***, Seoul National University, Republic of Korea*; K.-H. Park, J.S. Ha, K. Park,* ETRI, Republic of Korea*; J. Kim,* KRISS, Republic of Korea*; S.K. Kim,* Seoul National University, Republic of Korea*; J.-P. Salvetat, L. Forró,* EPFL, Switzerland

Circumventing problems lying in the conventional lithographic techniques, we devised a new method for the fabrication of nanometer scale metal wires using the unique characteristics of carbon nanotubes (CNTs). Since carbon nanotubes could act as masks when CNT-coated thin Au/Ti layer on a SiO@sub 2@ surface was physically etched by low energy argon ion bombardment (ion milling), Au/Ti nano-wires were successfully formed just below the CNTs exactly duplicating their lateral shapes. Cross-sectional analysis by transmission electron microscopy revealed that the edge of the metal wire was very sharply developed indicating great difference in the milling rates between the CNTs and the metal layer as well as the good directionality of the ion milling. We could easily find a few nanometer-wide Au/Ti wires among the wires of various widths. After the formation of nano-wires, the CNTs could be pushed away from the metal nano-wire by atomic force microscopy. The lateral force for the removal of the CNTs is dependent upon the width and shape of the wires. Resistance of the metal nano-wires without the CNTs was also measured through the micro-contacts defined by electron beam lithography. Since this CNT-based lithographic technique is, in principle, applicable to any kinds of materials, it can be very useful in exploring the fields of nano-science and technology, especially when it is combined with the CNT manipulation techniques.

11:40am **NS-WeM11 Strain Effects on the Growth Modes at Stepped Surfaces**, ***D.Y. Petrovykh***, *J.-L. Lin, J. Viernow, A. Kirakosian, A. Li, F. Liu, M.G. Lagally, F.J. Himpsel,* University of Wisconsin, Madison

Strain and atomic steps have been used previously to control size, spacing and alignment of self-assembled nanostructures. In this study we utilize high quality Si(111) stepped surfaces as templates for growth of CaF@sub 2@ nanostructures.@footnote 1@ The growth modes in this system in the submonolayer coverage regime are strongly influenced by strain. The step flow mode is expected for deposition rates and substrate temperatures used in our experiments. Instead the growth results in strings of islands attached to step edges. Only for coverage around 0.5 monolayer and above we observe continuous stripes characteristic of the step flow mode. The above two regimes may be beneficial for self-assembly of quantum dot and wire arrays respectively. It has been recently suggested@footnote 2@ that the misfit strain is responsible for the initial roughening of the growth front and formation of islands. Beyond a critical coverage the roughening is suppressed by the interaction between islands on adjacent terraces and continuous stripes become more favorable. A quantitative comparison of experimental results with theory is presented. @FootnoteText@ @footnote 1@ J. Viernow, J.-L. Lin, D.Y. Petrovykh, F.M. Leibsle, F.K. Men, F.J. Himpsel, Appl. Phys. Lett. 72, 948 (1998); J. Viernow, D.Y. Petrovykh, F.K. Men, A. Kirakosian, J.-L. Lin, and F.J. Himpsel, Appl. Phys. Lett. 74, 2125 (1999); D.Y. Petrovykh, J. Viernow, J.-L. Lin, F.M. Leibsle, F.K. Men, A. Kirakosian, F.J. Himpsel, J. Vac. Sci. Technol. A17, July/August (1999). @footnote 2@ Adam Li, Feng Liu, D.Y. Petrovykh, J.-L. Lin, J. Viernow, F.J. Himpsel, M.G. Lagally (to be published).

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