Tuesday Afternoon, October 16, 2007

Nanomanufacturing Topical Conference

Room: 615 - Session NM+TF-TuA

Nanomanufacturing of Materials

Moderator: M. Tuominen, University of Massachusetts, Amherst

1:40pm **NM+TF-TuA1 Nanoscale Patterning with S-layer Proteins and Area Selective Atomic Layer Deposition**, ***J.R. Liu***, *C.M. Tanner, E. Lan, B.S. Dunn, J.P. Chang*, University of California at Los Angeles

Nano-sized crystalline bacterial cell surface layer (S-layer) proteins have the intrinsic property to reassemble into two-dimensional arrays with ordered pores of identical size onto solid supports,[1] ideal as a template for nanoscale patterning. In this work, we demonstrated that, when combined with area selective atomic layer deposition (ALD), the reassembled S-layer proteins can be effective nanotemplates to pattern nano-sized dielectrics. S-layer proteins were reassembled on Si wafer from the solution containing protein units and $CaCl_2$. Atomic force microscopy (AFM) and transition electron microscopy (TEM) images showed that the protein unit size and the pore diameter are about 10 nm and 5 nm, respectively. Octadecyltricholorosilane (ODTS) was used to modify the more hydrophilic protein surface since ODTS has been demonstrated to be an effective monolayer resist on a hydrophilic SiO_2 surface toward ALD of HfO_2.[2] High-k oxides were only deposited in the pores built by the protein units by an area selective ALD after the S-layer nano-template was modified by ODTS. Attenuated total reflection-fourier transform infrared spectroscopy (ATR-FTIR), contact angle measurement, and x-ray photoelectron spectroscopy (XPS) were employed to analyze the reassembling, modification, and removing process of S-layer proteins. FTIR analysis of the reassembled S-layer proteins before and after ODTS treatment revealed NH (3297 cm^{-1}), CH_3 (2968 and 2866 cm^{-1}), CH_2 (2922 cm^{-1}), CO (1645 cm^{-1}), and CN (1525 cm^{-1}) from S-layer proteins, while the intensity of CH_2 increased after modified by ODTS, due to the 17 CH_2 groups in ODTS. The ODTS treated S-layer proteins surface became more hydrophobic, evident by a contact angle change from 59° to 84° for 2h and 101° for 40h. After cleaning, the peaks of NH (3297 cm^{-1}), CH_3 (2968 and 2866 cm^{-1}), CH_2 (2922 cm^{-1}), CO (1645 cm^{-1}), and CN (1525 cm^{-1}) from S-layer proteins disappeared, confirming that S-layer proteins have been removed completely. The current-voltage (I-V) of oxide nanopatterns is characterized by a conductive AFM.

[1] U. B. Sleytr, P. Messner, D. Pum, and M. Sara, Angew. Chem. Int. Ed., 1034-1054, 38, 1999.
[2] R. Chen, H. Kim, P. C. McIntyre, and S. F. Bent, Appl. Phys. Lett., 4017-4019, 84, 2004.

2:00pm **NM+TF-TuA2 Plasmonic Nanoparticle Complexes for Diagnostics and Therapeutics**, ***N.J. Halas***, Rice University **INVITED**

The combination of metallic nanostructures and molecular adsorbates provides a broadly adaptable route to the development of optically addressible, functional nanocomplexes. In particular, nanostructures based on this approach can be designed to sample, and, via Raman scattered light, report on specific aspects of their chemical environment. Combining this sensing functionality with photothermal heating of the local environment of the nanocomplex provides an important strategy for functional therapeutics for cancer and beyond.

2:40pm **NM+TF-TuA4 Conduction Nature of Nanochannels of Track Etched Polymeric Membranes**, ***K. Awasthi***, University of Rajasthan, India

The nanopores are developed by using one side etching of swift heavy ion irradiated polymeric membrane. In an electrolytic cell, the chemical solution serves as well as etchant and as an electrolyte. In the moment breakthrough of a track the beginning and increasing electrical current supplies information of the birth and growing of the track. The membranes used can be seen as model systems acting as interconnects between two separate liquids. There is a significant difference in the electrical conduction behavior of the electrolytes having common anion. It is clear from the voltage current characteristics that electrical conduction through the etched membrane of polycarbonate is dependent on size of cation.

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3:00pm **NM+TF-TuA5 Laser Sintering of Nano-Silver coated Polyetheretherketone Powder**, ***D. Pohle***, *C. Damm*, University Erlangen-Nuremberg, Germany, *T. Rechtenwald*, BLZ, Bavarian Laser Center gGmbH, Germany, *A. Rösch, H. Münstedt*, University Erlangen-Nuremberg, Germany

The effectiveness of silver as oligodynamic bactericide is proven and well investigated. The silver ions inhibit vital activities of the bacteria, such as breathing and metabolism. Elemental silver particles provide a large reservoir of antimicrobial silver ions, as in contact with water and dissolved oxygen they release small amounts of silver ions, only. The oxidation occurs on the surface of the particles. Accordingly the ion concentration and the rate of silver ion release are dependent on the surface to volume ratio of the elemental silver particles. The polymer matrix used in this investigation is polyetheretherketone. PEEK is a high performance thermoplastic with melting temperature of 345°C, very good mechanical properties and outstanding stability against chemicals and radiation. Its water uptake is below 0.5%. Because of this an antimicrobial equipment of the bulk material by use of silver is difficult. Silver nanoparticles were generated. Polyvinyl alcohol was dissolved in distilled water and silver nitrate was added. Sodium borohydride was used as reduction agent. Formation of elemental silver nanoparticles occurred, which were stabilized by the PVA. PEEK powder (PEEK 150 PF, Victrex, UK) was coated with silver nanoparticles by giving the polymer powder into the silver dispersion for 24h. The coated PEEK powder was used in a laser sintering (LS) process to generate antimicrobially equipped polymer specimens. LS of PEEK is a challenge because of its very high melting temperature and the irregular shape of the polymer particles. A modified laser sintering machine (EOSINT P 380, EOS, Germany) was used to obtain powder bed temperatures up to 350°C. After a pre-treatment of the polymer powder, including sieving and adding a small amount of carbon black to increase the flow ability, it was possible to manufacture discs with a diameter of 10mm and a height of 3mm. By use of LS specimens with open porosity are generated, so water can easily infiltrate the polymer parts. Stripping voltammetry showed that the sintered specimens released much more silver ions than hot pressed dense PEEK specimens. The silver release as function of time plot indicates that the release is governed by diffusion. To investigate the antimicrobial efficacy of the polymer specimens Escherichia coli was used. The antimicrobial tests were made by use of a solid agar plate method. As expected by the silver ion release test the specimens are active against E. coli.

4:00pm **NM+TF-TuA8 TEM-Based Metrology and Structural Characterization of HfO_2 ALD Films Formed in Anodic Aluminum Oxide Templates**, ***I. Perez***, *E. Robertson, L. Henn-Lecordier, P. Banerjee, S.J. Son, S.B. Lee, G.W. Rubloff*, University of Maryland, College Park

A broad variety of nanotechnology applications are poised to exploit the self-assembly that occurs in forming anodic aluminum oxide (AAO) films, which can be structured to comprise cylindrical nanopores with uniform dimensions (15-300nm diameters) spaced closely and regularly in AAO films microns in thickness. Such AAO films comprise templates for manufacturing of energy devices (capacitors, batteries, solar cells), electrochromic displays, or – if released by AAO dissolution - nanoparticle systems for targeted, imageable drug delivery, in which ultrathin highly conformal layers are formed in the nanopores by atomic layer deposition (ALD) or electrochemical deposition (ECD). Nanomanufacturing of such structures relies on the availability of fairly rapid metrologies and material characterization techniques which are precise at the nanoscale. We have achieved this goal based on transmission electron microscopy (TEM) methods, demonstrated here for ALD HfO_2 nanotubes formed in AAO templates. The HfO_2 nanotubes are first released by dissolution of the surrounding AAO template, then captured on standard TEM grids for observation in the TEM, whose high spatial resolution readily allows determination of nanotube diameters and wall thicknesses as a function of distance along the nanotube. We have developed image analysis codes to extract this metrology information in semi-automated fashion, so that ALD deposition profiles can be readily compared with ALD and AAO process parameters to optimize nanostructure manufacturing and to validate further models for process conformality. Furthermore, we have used HRTEM to identify HfO_2 crystal phases at different locations along the nanotubes upon annealing, carried out on nanotubes either while embedded in the AAO template or after release. For annealing at 650°C for 30 minutes, we find the expected monoclinic phase of HfO_2 is formed. These results demonstrate that the ability to release nanotubes from the AAO template, coupled with rapid HRTEM characterization and metrology, comprises an effective means to support AAO-based nanodevice manufacturing.

4:20pm **NM+TF-TuA9 Nano-Manufacturing of Materials at Oak Ridge National Laboratory's NanoApplications Center**, ***S.M. Robinson***, Oak Ridge National Laboratory

The NanoApplications Center (http://nanotech.ornl.gov/) at Oak Ridge National Laboratory (ORNL) employs state-of-the-art facilities and multidisciplinary R&D capabilities to transition the discoveries of nanoscience to innovative technologies for energy environment, and economic competitiveness. It fosters innovation of new energy-related nanotechnologies and helps transform industry by enabling the responsible development of processes for mass production and application of nano-scale materials, structures, devices, and systems that provide unprecedented energy, cost, and productivity benefits. Capabilities within the NanoApplications Center include 1) materials processing and fabrication, 2) characterization, and 3) responsible nanomanufacturing, and 4) rapid prototyping for development and deployment. This paper describes example nano-manufacturing projects for materials processing and real-time measurements for process control. These include investigation of infrared-based processing for high temperature processing of metals to enhance metallurgical and mechanical properties by controlling grain size and development of coating processes that infuse alloys several hundred nanometers deep into the surface of a metal to create enhanced durability. To better enable nanomanufacturing, researchers at ORNL have developed and applied novel real-time characterization techniques to process monitoring and control. A commercial differential mobility analyzer is being used to sample and characterize nanoparticles in real time.

4:40pm **NM+TF-TuA10 Nanometrology: A Key Element for Successful Nanomanufacturing**, ***M.T. Postek***, National Institute of Standards and Technology **INVITED**

Nanomanufacturing is the essential bridge between the discoveries of nanoscience and real world nanotech products - it is the vehicle by which this Nation will realize the promise of major technological innovation across a spectrum of products that will affect virtually every industrial sector. For nanotech products to achieve the broad impacts envisioned, they must be manufactured in market-appropriate quantities using reliable, repeatable, and commercially viable manufacturing processes. In addition, they must be manufactured so that environmental and human health concerns are met, worker safety issues are appropriately assessed and handled, and liability issues are addressed. Critical to this realization of robust nanomanufacturing is the development of the necessary instrumentation, metrology, and standards. This will allow the physical dimensions, properties, functionality, and purity of the materials, processes, tools, systems, products, and emissions that will constitute nanomanufacturing to be measured and characterized. This will in turn enable production to be scaleable, controllable, predictable, and repeatable to meet market needs. If a product cannot be measured it cannot be manufactured. This presentation will discuss some of the challenges confronting the effective development of the nanometrology needed for the success of nanomanufacturing.

Nanomanufacturing Topical Conference

Room: 615 - Session NM-WeM

Nanomanufacturing for Information Technologies

Moderator: J. Murday, University of Southern California

8:00am **NM-WeM1 Emerging Materials for Nanomanufacturing**, ***D. Herr***, Semiconductor Research Corporation **INVITED**

The emerging nanomaterials era offers novel tool sets that exhibit the potential for addressing the ITRS's concurrent vision for enhancing functional density and driving new waves of market opportunities. Though significant materials challenges remain, new generations of smart patterning materials and assembly methods likely will enable the continued scaling of extreme CMOS, the integration of heterogeneous nanomaterials onto silicon platforms, and functional diversification. However, it remains to be seen whether potential material solutions are identified and matured in time to impact key insertion windows. One key challenge is the extensibility of optical patterning. At the November 1992 Semiconductor Technology Workshop, the demise of optical patterning was projected to occur in 2001, after the 180 nm technology node. This corresponded to nine years or three technology nodes, n+3, out from the then current 500 nm technology node, n. The 1994 and 1997 National Technology Roadmaps for Semiconductors (NTRS) conveyed similar messages that optical lithography would end after the 130 nm and 100 nm generations, respectively, or n+3 nodes out from the current technology nodes. The 1999 and 2003 International Technology Roadmaps for Semiconductors (ITRS) also predicted lithography's end n+3 technology nodes out from the current 180 nm and 90 nm nodes, respectively. The 2003 and 2006 ITRS potential solutions roadmaps for exposure tool technologies suggested that optical lithography would not be viable beyond the 32 nm and 22 nm nodes, respectively. Only the 2001 update of the ITRS conveyed a more near term, n+2, transition to a non-optical lithography technology, after the 65 nm node. Over the last forty years, considerable attention was focused on the exposure tool and mask infrastructure. Cumulative investments in developing exposure tool and mask related technologies are on the order of $10B and $1B, respectively. During this same period, relatively modest investments were made in the development of imaging materials, such as photo resists. However, line edge roughness (LER) and line width roughness (LWR) increasingly challenge our ability to achieve uniform electrical properties in the deep nanometer transistor domain. Additionally, the discussion about the interdependence between LER and dopant nano-roughness and their impact on device properties is just beginning to happen. This talk will consider the limitations of current families of lithographic materials and suggest emerging patterning materials that may satisfy projected nanofabrication requirements, including LER, long range dimensional control, resolution, and functionality. The materials science needed to develop these new generations of robust imaging materials for future information processing technologies represents a relatively unexplored and untapped frontier. Today's convergence difficult nanofabrication challenges, emerging market drivers, and recent breakthroughs in materials technology offers a rare opportunity for chemists, chemical engineers, materials scientists, and others to develop breakthrough material and process insertion options will impact future nanofabrication technology. This research area exhibits the potential for keeping the demise of optical patterning n+3 generations away from current technology, for nodes to come.

8:40am **NM-WeM3 Defect Engineering for Ultrashallow Junctions using Surfaces**, ***E.G. Seebauer***, *C.T.Z. Kwok, R Vaidyanathan,* University of Illinois, Urbana-Champaign, *S.H. Yeong, M.P. Srinivasan,* National University of Singapore, *B. Colombeau, L. Chan*, Chartered Semiconductor Manufacturing, Singapore

Formation of extremely shallow pn junctions with very low electrical resistance is a major stumbling block to the continued down scaling of microelectronic devices. Recent work in our laboratory has shown that the behavior of defects within silicon can be changed significantly by controlling the chemical state at the surface. Certain chemical treatments of the surface induce it to act as an active 'sink' for point defects that removes Si interstitials selectively over impurity interstitials, leading to less dopant diffusion and better electrical activation. The present work demonstrates such effects experimentally for several dopants such as boron, arsenic and phosphorous in both crystalline and Ge pre-amorphized silicon wafers. Moreover, such active surfaces dramatically reduce the number of end-of-range defects observed after annealing. In the case of boron, a continuum model for boron diffusion and activation has been developed to quantify the surface effects under a wide range of annealing protocols ranging from hours to milliseconds in duration. Two-dimensional simulations based on this model indicate that the beneficial effects of active surfaces in the source-drain region extend laterally to the surface toward the channel region of a device as well as perpendicularly to the surface into the bulk. In a separate but parallel mechanism, fixed charges created at surfaces or interfaces can interact with charged defects in the bulk. Simulations suggest that this electrostatic mechanism results in a deeper junction and dopant pile-up near the surface/ interface. The work also discusses possibilities for creating such active surfaces in real RTP conditions.

9:00am **NM-WeM4 Formation of Parallel- and Latticed-Nanostructures by Surface-Patterning Technique**, ***H.J. Kim***, *Y.H. Roh, B. Hong*, Sungkyunkwan University, Korea

Nanowires, semiconducting nanowire, carbon nanotube (CNT) and deoxyribonucleic acid (DNA), have been extensively investigated to obtain highly ordered electronic components for nanocircutitry and/or nanodevices. However, there are difficulties to apply them to nanodevices because of and aligning them with uniform interval on specific location and high contact resistance between metal electrodes and nanowire. We report a new method to carefully control the interval of DNA-templated gold nanowires (AuNWs) using surface-patterning techniques. In this technique, a process to form parallel- and latticed-nanostructures involves three steps: (1) nano-road was generated on oxide surface, chemically treated with (aminopropyl)triethoxysilane (APS) which has a NH3+ terminal group, patterned by electron beam lithography (2) ?-DNA molecules were stretched and aligned on chemical nano-road by tilting techniques. (3) AuNWs were formed by the electrostatic interaction between DNA and gold nanoparticles. By the combination of a tilting technique and surface-patterning technique, we could selectively align ?-DNA molecules and AuNWs by chemical nano-roads of 500 nm interval on Si substrate. We used atomic force microscopy (AFM) to analyze the configuration of AuNWs.

9:20am **NM-WeM5 The Challenges and Rewards of Building a Better Biosensor System: The NRL cBASS®**, ***L.J. Whitman***, Naval Research Laboratory **INVITED**

On December 5, 1995 David Baselt, at the time a postdoctoral researcher at NRL working on a cantilever-based biosensor using magnetic particle labels, wrote in his lab notebook, "Did some reading on magnetoresistive sensors. It may be possible to use these rather than piezolevers to detect magnetic particles." Over the past dozen years, a dynamic team of researchers at NRL has developed this idea into the compact Bead Array Sensor System (cBASS®), a prototype biosensor system that integrates a suite of patented and patent-pending technologies for magnetic labeling and biomolecular detection, biomolecular assay methods, surface chemistry, and microfluidics.[1-9] The current system is capable of multiplexed detection of biomolecules at attomolar concentrations in complex matrices in <20 min with little or no sample preparation. The technology has been licensed for a variety of applications, including food and water testing, environmental analysis, veterinary diagnostics, and biodefense. I will describe the development history of this project, the challenges of moving an idea from concept to advanced development within a government laboratory, and some of the lessons learned along the way.

[1]Baselt et al., Biosens. Bioelectron. 13, 731 (1998).
[2]U.S. Patent 5,981,297.
[3]Edelstein et al., Biosens. Bioelectron. 14, 805 (2000).
[4]Tamanaha et al., J. Micromech. Microeng. 12, N7 (2002).
[5]Sheehan et al., Biosens. Bioelectron. 18, 1455 (2003)
[6]Rife et al., Sensors Actuat. A 107, 209 (2003).
[7]Sheehan and Whitman, Nano Lett. 5, 803 (2005).
[8]Stine et al., Langmuir 23, 4400 (2007).
[9]Mulvaney et al., Biosens. Bioelectron., in press.

10:40am **NM-WeM9 Patterned Medium Substrates for Magnetic Recording Fabricated Using Ion Beam Proximity Lithography**, ***V. Parekh***, *A. Ruiz, Ch. E, P. Ruchhoeft, D. Litvinov*, University of Houston

We describe the fabrication of patterned medium substrates consisting of 50nm diameter Co/Pd multilayer pillars in a densely packed array with 100nm pitch using ion beam proximity lithography (IBPL) to pattern a resist followed by argon ion milling to transfer the pattern into the magnetic stack. These pattern medium samples serve as test structures to develop a fundamental understanding of the switching behavior of isolated magnetic islands and as a test-bed for developing next-generation magnetic recording media. In our fabrication approach, substrates are first coated with a Ta buffer layer, followed by deposition of alternating Co (0.3nm) and Pd (0.7nm) layers (repeated 10 times). Hydrogen silsesquioxane, a negative

tone, ion sensitive resist, is deposited onto the multilayer structure and patterned using IBPL, in which an energetic helium ion beam irradiates a stencil mask, placed in front of the resist-coated sample, and ions passing through the stencil openings damage the resist and copy, in a single exposure, the entire mask pattern. After developing the resist, the HSQ pillars are transferred into the multilayers by argon ion milling. In developing this process, we have concentrated on the uniformity of the lithographically defined bits to improve the switching field distribution of the magnetic medium. To this end, we have developed stencil masks fabricated from 250nm thick, $1cm^2$ area, free standing silicon nitride membranes. The blank membranes are coated with palladium, silicon dioxide and resist. Electron beam lithography is used to define 100nm circular openings on a 200nm pitch in the resist, which are then transferred into the membrane using a series of reactive ion etching and ion milling steps. A conformal gold coating allows for further reduction of the mask features without significantly increasing the feature size variation. Measurements using scanning electron microscopy reveal a 3nm standard deviation in the sizes of the mask openings over a $1mm^2$ area. The standard deviation of the island structures that are formed using this mask have a similar standard deviation in size (4.5nm), indicating that our printing process is primarily limited by our ability to fabricate masks. A six-fold increase in the coercivity of the multilayer samples (from 900Oe for continuous samples to 6kOe for the patterned samples) and a switching field distribution of ~15% in the patterned sample was measured using magneto-optical kerr effect.

11:00am **NM-WeM10 Fabrication of Large-area Magnetic Ring Arrays using Ion Beam Proximity Lithography**, ***A. Ruiz***, *V. Parekh, J. Rantschler, P. Ruchhoeft, D. Litvinov*, University of Houston

Arrays of 500nm/300nm outer/inner diameter permalloy rings on a 700nm pitch were fabricated to study transitions between the micromagnetic configurations within these structures. The existence of these states, which are both very stable and confine the magnetic flux within the material, is the basis for next-generation, high-density magnetic memory devices. To form these rings, oxidized silicon substrates were first coated with a 5nm thick Ta layer, a 10nm permalloy ($Ni_{80}Fe_{20}$) layer deposited in a magnetic field to induce anisotropy in-plane, and a 5nm thick Ta capping layer. Circular openings were defined in a 200nm thick resist layer, deposited on the magnetic stack, using ion beam proximity lithography (IBP) and a conformal coating of SiO_2 was applied to the surface by reactive sputter deposition. A directional reactive ion etch removed the oxide coating at the base of the opening and on top of the resist but preserved the oxide wall coating. After removing the resist in an oxygen ashing step, a ring-shaped hard mask remained that was transferred into the underlying permalloy using argon ion milling. Our fabrication approach has two distinct advantages over direct-write processes (i.e., electron beam): the patterns can be formed with much higher throughput using the parallel IBP approach (the entire mask pattern was replicated with a single exposure lasting less than 20 sec.) and the pattern of dots is significantly easier to control than the more complex ring structure. Hysteresis loops were measured using a vibrating sample magnetometer and show evidence of the switching sequence observed in micromagnetic simulations of these structures using the OOMMF code. However, the size and shape variation in the patterning process mask used for printing the dots must first be reduced to better understand the switching behavior. The results do suggest that the field required for onion-to-vortex transition and field required for vortex-to-onion transition to be 85Oe and 330Oe, respectively. We are currently reducing the size variation in the rings by fabricating improved IBP masks with more uniform openings to achieve smaller size distributions, which is expected to substantially reduce the switching field distribution. Currently we have fabricated large area masks that contain patterns with a standard deviation in size of less than 3nm.

11:20am **NM-WeM11 Nano-fabrication of Patterned Media**, ***T.-W. Wu***, *M. Best, D. Kercher, E. Dobisz, Z.Z. Bandic, X.C. Guo, M. Mate, T. Karis, H. Yang, T. Albrecht*, Hitachi Global Storage Technologies **INVITED**

The outlook of magnetic storage technology predicts that, with current 40% growth rate, the recording areal density will hit ~700 Gbits/in2 in 2011. However, the magnetic recording physics also predicts that perpendicular magnetic recording (PMR) media will hit the thermal instability limit as the grain size of the magnetic coating scaled down below ~5nm in diameter. Because patterned media (PM) leverages the geometric decoupling magnetic exchange, a magnetic material even with ultra-small (e.g. d<5nm) but strong magnetically coupled grains can still be utilized to constitute the required recording bit (d=10~15nm) and avoid the thermal instability. Furthermore, because of its geometrically defined bit border, PM can achieve both higher track and linear densities than does the continuous media and hence boost the areal density. As a disruptive magnetic recording technology, PM is viewed as one of the most promising routes to extending magnetic data recording to densities of 1 Tbit/in2 and beyond. The fabrication of PM disk starts with the imprint master mold creation followed by pattern replication by nano-imprinting, pattern transfer by reactive ion etch and finished with blank deposition of a magnetic coating. The key challenges in the PM substrate fabrication are how to create those nano-scaled features (e.g. pillars with 20nm in diameter) with acceptable fidelity? How to create them with an incredibly high density (e.g. a square lattice with less than 40nm in period) in a very large area (e.g. ~2 square inches) and also within a reasonable time frame? How to inspect them with a reasonable statistics basis? In addition, those features need to be arranged in a circular array and have a very stringent long range order as well. Although the physical feasibility at each critical stage has been demonstrated to a degree in the recent years, to ensure a manufacturing feasibility for the production of patterned disk substrates, the process robustness and reliability, parts longevity, high throughput tooling and low cost operation, etc. are still far from completion and remain as immense challenges. In order to achieve the goal of PM hard disk drive (HDD) production in 2011 time frame, many scientific innovations and technology advances, such as the r-θ ebeam machine, guided self-assembly patterning, double-side high throughput imprinting and RIE, etc. are critically needed.

12:00pm **NM-WeM13 Direct Integration of Carbon Nanostructure Family into Bimetal Micro-tubular Scroll**, *J. Choi*, ***Y. Song***, Wayne State University

Carbon nanostructures including carbon graphene patches, onions, fibers and nanotubes were directly grown on 120 nm thick freestanding Ti (100 nm)/Ni (20 nm) bimetal structures. During the direct growth of carbon nanostructures, the bimetal layers are scrolled. The interplay between stress driven by the scrolled bimetal and anisotropic carbon nanostructure growth increases the number of turns and induces the transition of carbon nanostructure growth behavior from the lateral to the vertical growth at the growth temperature of 375 oC.

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