Nanomanufacturing Science and Technology Focus Topic
Room: 207 - Session NM+MN+MS+TF-TuM

Lithography Strategies for Nanomanufacturing
Moderator: T.S. Mayer, Penn State University

8:00am **NM+MN+MS+TF-TuM1 A SANE Approach to Programmable Soft Lithography**, ***T.W. Odom***, Northwestern University **INVITED**

The prototyping of nanoscale features has rarely been separated from the scaling of them. In order to create arbitrary patterns, serial techniques such as e-beam lithography or focused ion beam milling must start from scratch every time; also, the patterns cannot be generated over large areas. In contrast, parallel fabrication methods such as molding, imprint lithography and soft lithography can scale patterns, but they are limited to transferring the same pattern on the mold. The development of new tools that can combine the strengths of serial approaches (prototyping patterns, high resolution) with those of parallel ones (high throughput, large patterned areas) is critical for next-generation applications based on nanostructures.

This talk will describe an all-moldable nanofabrication platform that can generate—from a single master—large-area nanoscale patterns with programmable densities, fill factors, and lattice symmetries. Solvent-assisted nanoscale embossing (SANE) can increase the spacing of patterns up to 100% as well as decrease them down to 50% in a single step by stretching or heating a thermoplastic substrate. In addition, SANE can reduce critical feature sizes as small as 45% compared to those on a master by controlled swelling of patterned molds with different solvents. SANE can also produce different and reconfigurable lattice symmetries, which enables new opportunities to manipulate the electronic, photonic, and magnetic properties of nanomaterials.

8:40am **NM+MN+MS+TF-TuM3 Micromolding Surface-Initiated Polymerization: A Versatile Route for Microscale Replication onto a Solid Support**, *C.A. Escobar, J.C. Tuberquia, N. Nizamidin,* ***G.K. Jennings***, Vanderbilt University

This presentation will introduce the use of confined surface-initiated ring-opening metathesis polymerization (SI-ROMP) of perfluoroalkyl or alkyl norbornene monomers from solid substrates to synthesize surface-bound polymer structures with tunable physical and chemical properties that accurately replicate those exhibited by Nature's engineered, microscopically rough, and highly functional surfaces. This approach not only allows mimicking of highly evolved and functional surface architectures but also provides versatility in that it introduces a wide variety of chemical compositions available in materials chemistry, including partially fluorinated polymers with ultralow critical surface tensions. Optical microscopy and scanning electron microscopy confirm growth of the polymer structures and the precise replication of the microscale and nanoscale features exhibited by the target natural surface with the added freedom to expand beyond Nature's chemical building blocks. Contact angle measurements show that the surface architectures exhibit both hydrophobic and oleophobic behavior, and in some cases, superhydrophobic properties. This approach is not limited to natural surfaces and could be applied in a straightforward manner to a variety of synthetic surfaces that have microscale features.

9:00am **NM+MN+MS+TF-TuM4 Si Mold Etching with Hard Mask for Bit-Patterned Media**, ***M. Kurihara***, Hitachi, Ltd., Tokyo, *M. Satake, Y. Tsuchiya, T. Nishida,* Central Research Laboratory, Hitachi, Ltd., Japan, *Y. Tada, H. Yoshida,* Hitachi Research Laboratory, Hitachi, Ltd., Japan, *N. Negishi*, Central Research Laboratory, Hitachi, Ltd., Japan

Bit-patterned media (BPM) is one of the promising candidates for hard disk media with areal density greater than 1.0Tb/in^2. Nanoimprint lithography (NIL) for BPM has also been investigated as a patterning technique to reduce the production cost. One of the critical issues in NIL mold fabrication is the etching selectivity between silicon and the organic mask pattern due to the following two reasons. One is a significant decrease of pattern thickness to meet the photo-lithography requirements. This decrease remained when applying the self-assembly polymer process to fine patterning. The other is the micro-loading effect that causes the etching rate drop with pattern size shrinking.

In this work, we have developed a hard mask process to compensate for the low etching selectivity. First, the micro-loading effect in the $HBr/Cl_2/O_2$ gas chemistry was evaluated with a SiO_2 hard mask of 20-nm thickness. This SiO_2 hard mask was patterned from 30 to 50 nm by EB lithography and etched with CHF_3 gas chemistry. The coefficients of micro-loading in silicon etching were evaluated based on the relationship between hole depth and etching time with a hole diameter of 30, 40, and 50 nm respectively. With increase of the sidewall taper angle, the micro-loading effect could be improved by about 60%. We also confirmed that there was a hole with a depth of 87 nm with a diameter of 30 nm. Extrapolating this micro-loading effect, it is expected that a hole with a depth greater than 80 nm with a diameter of 10 nm will be achieved. This result will satisfy the pattern aspect ratio of 2, which is required in NIL. We will also demonstrate the Si mold etching with a hard mask by applying the self-assembly polymer in which the areal density is greater than 1.0Tb/in^2.

9:20am **NM+MN+MS+TF-TuM5 Directed Assembly of Block Copolymers to Advance the Performance of Conventional Lithography**, ***P.F. Nealey***, University of Wisconsin **INVITED**

Our research program aims to integrate self-assembling block copolymers into current manufacturing practice. The fundamental concepts of the approach are that 1) the most advanced production-oriented exposure tools (e.g. 193 nm, EUV, or electron beam lithography) and resist materials are used to create patterns of differing chemical functionality on the substrate, and 2) films of block copolymers can be directed to assemble in the presence of the chemical pattern into predictable and desirable morphologies, thereby augmenting and enhancing the lithographic process. In comparing the pattern in resist to the pattern of domains induced to assemble in the block copolymer film, directed assembly has been demonstrated to achieve high degrees of pattern perfection, placement of features at the precision of the lithographic tool used to make the chemical pattern, improved dimensional control of features, improved line edge and line width roughness, and resolution enhancement by factors of two to four. In addition, the approach has been demonstrated to robustly achieve non-regular device-oriented geometries used in the fabrication of integrated circuits also with resolution enhancement by multiplication of feature density by interpolation on low duty cycle chemical patterns. After describing current capabilities, remaining technological questions and pathways towards implementation in specific applications will be discussed.

10:40am **NM+MN+MS+TF-TuM9 Measured Backscattered Electron Profile for Optimized Proximity Effect Correction**, ***D.A. Czaplewski***, *L.E. Ocola*, Argonne National Laboratory

Electron beam (e-beam) lithography has been used to create nanoscale patterns in myriad of resists with features as small as single nanometers. When creating resist features on the single nanometer length scale, the process window to create the desire resist structure becomes increasingly small. Overdosing or under dosing of critical features causes changes in critical dimensions. In addition to the dose required for a single feature, the contribution of additional dose due to proximity of nearby features must be considered. To solve this problem, finite element analysis software packages are available for adjusting dose assignments for different features based on size, shape, and placement with respect to other features. The FEM software can only work as good as the input parameters. These parameters come from the backscattered electron profile. Here, we present the measured electron backscattered profile using a negative e-beam resist. In order to measure the backscattered profile, we use a pattern of intersecting lines surrounded by a large annulus. The lines are measured while the annulus provides a circularly symmetric backscattered electron dose. The lines and annuli are written with varying doses. By measuring the thickness of the resist, the contribution from both the lines and the annulus can be determined for different doses and different shapes by using the resist contrast curve. By using the contrast curve to assign doses to specific resist thicknesses, the specific resist and developer effects are removed from the data. The resultant backscattered electron profile can be used as input into the FEM model to create more accurate resist dose assignments for proximity effect corrected patterns for all resists.

11:00am **NM+MN+MS+TF-TuM10 CMOS Density Scaling in Non-Planar Multi-Gate Devices: A Patterning Perspective**, ***M.A. Guillorn***, *J. Chang, S. Bangsaruntip, C.-H. Lin, W.E. Haensch*, IBM T.J. Watson Research Center **INVITED**

The use of planar Si CMOS device technology may continue beyond the 22 nm node. However, the requirements for the gate dielectric and junction depth needed to maintain control of short channel effects might prove to be unobtainable in devices scaled to meet the integration density requirements of the 14 nm node and beyond. Consequently, an additional method for improving the electrostatics of the device is required. This realization has driven a steady increase in research on non-planar multi-gate CMOS devices over the past 5 years. Raising the Si channel out of the plane of the

substrate creates the opportunity to form the gate electrode around multiple sides of the channel. This geometry results in a superior situation from an electrostatics standpoint compared to a planar device where the gate electrode is present only on the top surface of the channel.

In this talk, we will discuss the challenges of fabricating three non-planar multi-gate devices from Si on insulator (SOI) substrates: (1) the FinFET, where the gate controls two sides of a thin Si mesa or fin (2) the Trigate where the gate controls three sides of a Si fin and (3) a gate-all-around nanowire transistor where the gate electrode surrounds all sides of a suspended Si channel. We will present experimental results from advanced prototypes of these devices fabricated at dimensions and densities relevant to 14 and 10 nm node technology. An emphasis will be give to the unique role lithography and patterning play in determining the electrical behavior of these devices. These results offer insight into what may lie ahead for Si CMOS scaling and how it will impact the demands placed on patterning and metrology.

11:40am **NM+MN+MS+TF-TuM12 High Resolution Dry Development**, *D.L. Olynick, **D.G. De Oteyza**, P. Perera, P. Kulshreshtra, P. Ashby, M. Schmidt, S. Dhuey, B.D. Harteneck, R.M. Falch, A. Schwartzberg, P.J. Schuck, S. Cabrini*, Lawrence Berkeley National Laboratory

As features sizes continue to shrink, new approaches are required to overcome roadblocks toward high-resolution lithographic patterning. One significant roadblock towards miniaturization is pattern collapse due to capillary forces during drying.[1] We have invented a dry development method for creation of high resolution and high aspect ratio resist features. We use resists that undergo an optical absorption change after exposure to high-resolution radiation (here we use electron beam lithography). This optical change allows the material to be selectively laser ablated such that the resolution is defined by the high-resolution radiation and not limited by the laser spot size. Using methyl-acetoxy calix[6]arene, a CW 532 nm laser, and spot sizes ~300 nm, we have produced features down to 10 nm in a film 120 nm thick, with pitch resolution down to 30 nm(Fig. 1). Calixarene was introduced as a high resolution electron-beam resist [2] and has demonstrated 12.5 nm half-pitch in extreme ultra-violet lithography.[3] Typically, films are spun thin to prevent high-resolution pattern collapse in thicker films but using the dry development, the patterns are well defined even in the thick films. Note, the resist acts negative with solvent development, as the cross-linked material can not be removed, whereas it is positive under laser dry development at the same electron-beam dose conditions. This is in contrast to the thermal dry development process where calixarenes are developed in negative tone.[4] With thermal development, patterns were demonstrated at 25 nm half-pitch in a 25 nm film (1:1 aspect ratio.

We have systematically studied the optical absorption contrast behavior as a function of electron beam dose, laser wavelength, and laser dose. At 532 nm laser wavelength, we identified that the absorption is a two photon process and found one functional group which is responsible for the optical contrast. We will discuss the options for materials beyond calixarenes.

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References

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Authors Index

Bold page numbers indicate the presenter

— A —

Ashby, P.: NM+MN+MS+TF-TuM12, 2

— B —

Bangsaruntip, S.: NM+MN+MS+TF-TuM10, 1

— C —

Cabrini, S.: NM+MN+MS+TF-TuM12, 2
Chang, J.: NM+MN+MS+TF-TuM10, 1
Czaplewski, D.A.: NM+MN+MS+TF-TuM9, **1**

— D —

De Oteyza, D.G.: NM+MN+MS+TF-TuM12, **2**
Dhuey, S.: NM+MN+MS+TF-TuM12, 2

— E —

Escobar, C.A.: NM+MN+MS+TF-TuM3, 1

— F —

Falch, R.M.: NM+MN+MS+TF-TuM12, 2

— G —

Guillorn, M.A.: NM+MN+MS+TF-TuM10, **1**

— H —

Haensch, W.E.: NM+MN+MS+TF-TuM10, 1
Harteneck, B.D.: NM+MN+MS+TF-TuM12, 2

— J —

Jennings, G.K.: NM+MN+MS+TF-TuM3, **1**

— K —

Kulshreshtra, P.: NM+MN+MS+TF-TuM12, 2
Kurihara, M.: NM+MN+MS+TF-TuM4, **1**

— L —

Lin, C.-H.: NM+MN+MS+TF-TuM10, 1

— N —

Nealey, P.F.: NM+MN+MS+TF-TuM5, **1**
Negishi, N.: NM+MN+MS+TF-TuM4, 1
Nishida, T.: NM+MN+MS+TF-TuM4, 1
Nizamidin, N.: NM+MN+MS+TF-TuM3, 1

— O —

Ocola, L.E.: NM+MN+MS+TF-TuM9, 1
Odom, T.W.: NM+MN+MS+TF-TuM1, **1**
Olynick, D.L.: NM+MN+MS+TF-TuM12, 2

— P —

Perera, P.: NM+MN+MS+TF-TuM12, 2

— S —

Satake, M.: NM+MN+MS+TF-TuM4, 1
Schmidt, M.: NM+MN+MS+TF-TuM12, 2
Schuck, P.J.: NM+MN+MS+TF-TuM12, 2
Schwartzberg, A.: NM+MN+MS+TF-TuM12, 2

— T —

Tada, Y.: NM+MN+MS+TF-TuM4, 1
Tsuchiya, Y.: NM+MN+MS+TF-TuM4, 1
Tuberquia, J.C.: NM+MN+MS+TF-TuM3, 1

— Y —

Yoshida, H.: NM+MN+MS+TF-TuM4, 1