Guest Editorial

Nanopatterning: Commercial and Technological Promise

This special section of the *Journal of Microlithography, Microfabrication, and Microsystems* (JM^3) is focused on nanopatterning. Nanopatterning is an extension of the lithographic techniques used in microlithography and micromachining to address the needs of top-down nanosystem technologies as well as the semiconductor and micromachining industries. The emerging set of nanopatterning techniques and technologies have the potential to rapidly advance top-down nano-based science and commerce, and also hold promise to provide a pathway for directed self-assembly.[1] Nanopatterning is a technique that is bridging the gap between the promise and reality of nanotechnology. This special section addresses advancements and needs in nanopatterning for both nano- and micromanufacturing.

The articles that comprise this special section suggest that nanoimprint lithography, which might be the enabling technology bundle,[2] is one of the key elements that make nanotechnologies an enabling technology.[3] Nanopatterning and moreover nanotechnology are enabling disruptive technologies that are fostering startups at an incredible pace.[4,5] To date there have been two global nanotechnology road-mapping efforts spawning three efforts,[1,6,7] all of which point to the need for atomically precise top-down nanotechnology lithographic solutions. The following 13 articles emphasize the emergent and fermentation nature of nanotechnologies and nanoimprint lithography today.

Chen et al. investigate pattern placement error experimentally. They focus on pattern distortion caused by different thermal expansions between templates and substrates in nanoimprint lithography. Their work suggests that nanoimprint lithography at low temperature or room temperature should be free from pattern distortion or placement errors.

Lin and Chen discuss ultrasonic nanoimprint lithography (U-NIL), a method to overcome the drawbacks of energy consumption and long processing times that occur in conventional nanoimprint lithography methods. They provide a discussion on the U-NIL fabrication process.

Hocheng and Nien provide us with a nanoimprinting process focused on productivity. They discuss nanoimprint technology as a method for volume production for nanoscale devices. In particular, they focus on the filling process of mold cavities, which plays a key role in determining the productivity of the nanoimprinting process and the quality of the final imprint product. They provide a simulation of PMMA polymer and its effects on cavity aspect ratio, pattern density, and contact friction existing between the mold and polymer on the applied pressure and mold filling. The authors investigate simulated differences in cavity aspect ratios and mixed pattern density and provide a sensitivity analysis of the effect of the contact friction coefficient.

Worgull et al. describe a German-Canadian cooperation project that studied hot embossing for nanoimprinting both theoretically by a process simulation and experimentally. A process was modeled using selected microstructured tools they adapted for nanoimprinting, and the simulation results were compared with practical experiments. In the simulation they characterized a typical representative of a thermoplastic material, which was analyzed in detail by IMT. Based on this analysis, a viscoelastic material model was developed.

Nagase et al. investigate a maskless nanofabrication fabrication method using sputter etching with a Ga focused ion beam (FIB) to obtain nanogap electrodes with high reproducibility. This method is based on *in situ* monitoring of etching steps by measuring a current through patterned electrode films. Their method provides a simple and highly reproducible fabrication that should be useful for systematically investigating the electrical properties of single molecules.

Pérennès et al. utilize deep x-ray lithography for nanoimprint molding. They introduce simple double-casting replication methods for high aspect ratio microstructures fabricated by deep x-ray lithography using intermediate molds of soft materials. They investigate two types of soft material, PDMS and PDMA. They demonstrate the possibility of replicating HARMST fabricated by DXRL through the casting of soft material as an intermediate mold.

Suraprapapich et al. describe the regrowth of self-assembled InAs quantum dots by molecular beam epitaxy. They found that quantum dots regrown on nanohole templates have improved dot uniformity and narrow PL spectra, while those regrown on the stripe template form into chains whose lengths are determined by the underlying stripes.

Battula, Theppakuttai, and Chen present a technique to create nanopatterns on hard-to-machine bulk silicon carbide (SiC) with a laser beam. The do so by depositing a monolayer of silica (SiO_2) spheres of 1.76 μm and 640 nm in diameter on an SiC substrate and then irradiating them with Nd:YAG lasers of 355 and 532 nm. The study demonstrates the possibility of nanopatterning transparent materials using nanosecond lasers and thereby overcoming the diffraction limit of light.

Schift provides a description of his sacrificial layer technique to provide perforated polymer membranes using nanoimprint lithography. The membranes with micrometer-sized pores were partially released from the substrate by locally dissolving the underlying layer. He further asserts that the fabrication process for supported polymer membranes has the advantages of being versatile and fast, and by underetching through the holes of the patterned top layer, the area of detachment can be defined without any additional lithographic step.

Gierak et al. investigate ion beam technology for nanopatterning. They show that FIB technology is capable of overcoming some basic limitations of current nanofabrication techniques and allows innovative patterning schemes for nanoscience. The FIB-based methods they describe and exploit here are well-suited for several diverse nanotechnology applications.

C. van Rijn discusses laser interference lithography as a nanopatterning tool and describes the experiments he performed to develop microsieves with submicron pore sizes using multiple laser interference lithography. The exposure method is fast, inexpensive, and applicable for large areas and critical dimensions to 100 nm.

Curran and Dewalsh provide a new nanolithographic process for all-optical nanoscale memory. In their approach, the high-frequency components of the near field are used to "write" information in nanostructured composite ultrathin films with feature sizes of 200 nm. They provide evidence to support a factor of 10 improvement for all-optical memory.

Eijkel et al. explore the intellectual property base of nanopatterning and how it pertains to the enabling technology bases of microsystems, microfabrication, and nanotechnology.

In conclusion, this special section provides 13 articles focused on novel nanopatterning technologies. The authors speak to the rapid progression in our field, novel applications, and the maturity of nanopatterning. At least two articles speak of novel products such as nanogap electrodes and all-optical storage technologies, and one speaks to the state of nanotechnology patents and more specifically to the state of nanolithographic patterning. Nanopatterning might lead to a "unit cell approach" that is so far lacking in microsystems and nanosystems but is an underlying reality of semiconductor microfabrication.[8] This special section also reflects the global nature of our field with papers from Asia (specifically Japan, Thailand, Taiwan, and China); Europe (specifically France, Germany, Italy, the Netherlands, Switzerland, and the United Kingdom); and North America (Canada and the U.S.). Finally, many of the collaborations are from institutes that span the globe.

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