Nanostructure manufacturing via holographic photolithography

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We report on development of optical holographic methods for high-throughput manufacturing of nanostructured materials with one-, two-, and three-dimensional morphology. These materials have many potential applications including optical coatings and membrane separations, among others.

Holographic photolithography is one top-down patterning technique with promise for making such nanostructures more quickly. Figure 1 shows our prototype lithography tool. A 405 nm diode laser incorporates a volume grating that narrows its output spectrum to yield an adequate ~1 m coherence length. Beamsplitters separate the laser beam into five optical beams, which are directed by mirrors to converge at a photoresist-coated substrate. Allowing three beams of appropriate polarization to interfere yields a two-dimensional interference pattern (Figure 2). Using two beams instead results in one-dimensional fringes, while four such beams interfere to create a three-dimensional pattern. Exposure to these interference patterns causes a photochemical reaction which changes the resist's solubility, creating a latent image. Morphology of the latent image can be predicted using custom software (Figure 3). Post-exposure processing, including postbaking and development, reveals the polymer nanostructure. The structure can be used itself or as a template for e.g. electroplating or chemical vapor deposition.

Our current holographic lithography tool can pattern ~25 mm substrates, and we are designing a larger system to handle ~200 mm wafers. The static holographic lithography demonstrated thus far is promising, but the patterned material's volume is low. No extant lithographic method has the speed to manufacture three-dimensional engineered nanostructures continuously at industrial scale (though nanoimprint methods are adequate for one- and two-dimensional structures). A method is needed to control the phase of one or more of the interfering beams to sync the interference pattern to a moving substrate. As a next step, we propose coordinated holographic industrial-scale electromagnetic lithography (CHISEL) to enable continuous nanoscale manufacturing with volume rate six orders of magnitude larger than that of layer-by-layer projection photolithography.

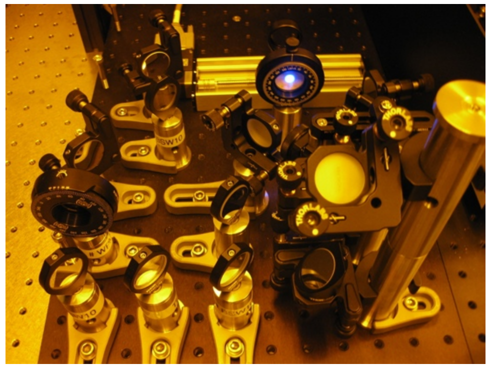

Figure 1: Photograph of prototype holographic photolithography tool.

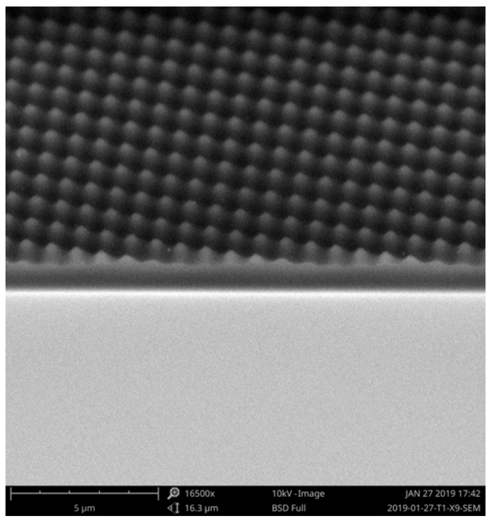

Figure 2: Example 2D microstructure made via 3-beam exposure.

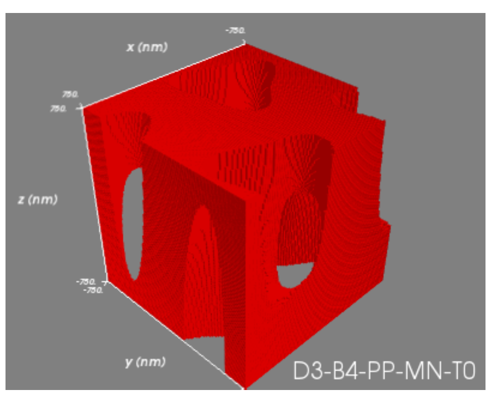

Figure 3: Example calculation of morphology resulting from 4-beam interference.