Fabricating 3D Nanostructures Through Colloidal Extreme Ultraviolet Lithography

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Single-exposure 3D nanopatterning methods is inherently parallel in nature and is attractive over layer-by-layer processing owing to their high throughput. Previously, researchers have employed Talbot lithography as a cost-effective method to generate 3D nanopatterns by utilizing a near-field phase mask [1-2]. Various strategies have been devised to create inexpensive phase masks for use in conjunction with Talbot Lithography, including utilizing a monolayer of close-packed colloidal nanoparticle assembly. While these methods effectively facilitate the fabrication of 3D nanostructures with high throughput, their spatial resolution is diffraction-limited due to the wavelength of the light source used in the exposure process and has been constrained to the 300 nm period. To overcome this limitation, using extreme ultraviolet (EUV) lithography is a promising approach to circumvent wavelength constraints while leveraging Talbot Lithography as the underlying physical principle in the process.

In this work, we investigate patterning of periodic 3D nanostructures using EUV exposure of a colloidal nanoparticle array. This process is depicted in Figure 1, where EUV light passes through the periodic nanoparticle array, demonstrating Talbot effect due to multiple focal spots, wherein the intensity of light varies as a function of cross-sectional depth in the photoresist layer. A tabletop higher harmonic generation (HHG) source powered by a 45-femtosecond infrared (IR) laser with a 790 nm center wavelength and 10 mm beam diameter is utilized to produce EUV light with a wavelength of 30 nm [3]. This experimental setup will enable exposure lithography with sub-200 nm particle diameters to fabricate 3D nanolattices comprising periodic geometric patterns. The IR laser is focused onto a 100 μm diameter glass capillary, accompanied by a continuous flow of argon gas, which generates a strong electric field in the medium facilitating the HHG process to output EUV light. The EUV beam is focused onto the sample stage chamber after beam filtering for the exposure experiments.

In our experimental demonstration, a silicon substrate spin-coated with a 100 nm thick layer of ZEP-520A e-beam photoresist is utilized. It is then coated with a self-assembled layer of polystyrene nanoparticles with 100 to 200 nm in diameter using Langmuir-Blodgett assembly techniques for use as a diffractive near-field phase mask. Exposure under normal incidence illumination results in the formation of honeycomb patterns consisting of nano-hole arrays, as shown in Figure 2. The results indicate that the top layer structure has broken off the sample, which revealed the underlying structure with different geometry. This work can potentially be beneficial for novel photonic crystal applications in the future [4]. We will present detailed finite difference time domain (FDTD) simulation to validate the experimental findings in more details.

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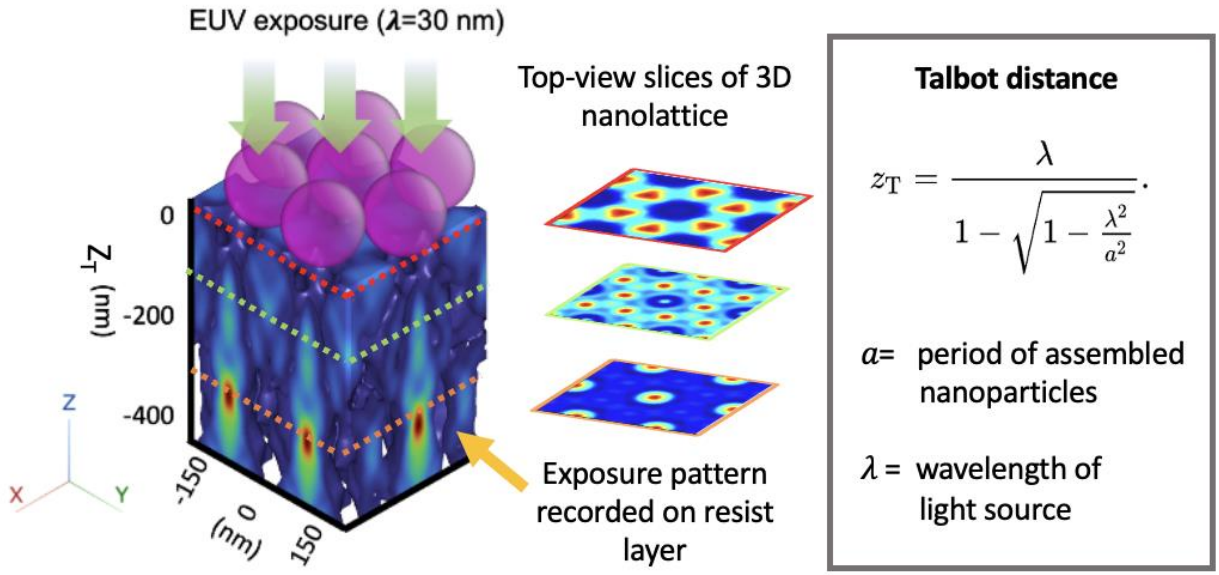

Figure 1. *FDTD simulation schematic of 3D nanolattice exposure intensity recorded on a photoresist layer through 150 nm polystyrene nanoparticles.*

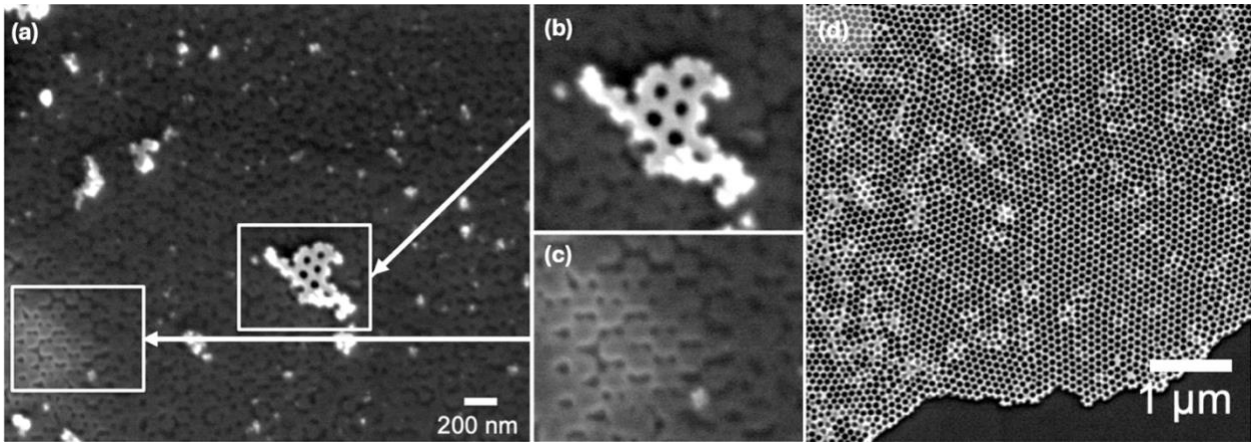

Figure 2. *(a) Topographical-view SEM of EUV exposure using 150 nm polystyrene nanoparticles as a near-field phase mask, (b) zoomed-in top view of intact top layer of the Talbot exposure pattern, (c) zoomed-in top view of underlying layer of the Talbot exposure pattern, (d) SEM of delaminated top-layer of the exposure pattern.*

References

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