Fabrication of Three-Dimensional Periodic Nanostructures in Negative Photoresist Using a Colloidal Phase Mask

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Periodic three-dimensional (3D) nanostructures have many interesting applications in photonic crystals, fluidic filters, and mechanical truss materials [1-4]. One effective method to fabricate 3D structure is phase shift lithography, where an optical phase element diffracts light and generates a 3D intensity distribution in close proximity as govern by the Talbot effect [4,5]. Such method has been employed by various groups, where a conformal polydimethylsiloxane (PDMS) mask is used to pattern periodic 3D nanostructures [3-5]. Another method to implement phase-shift lithography is with the use of assembled 2D nanopshere array, which replaces the physical mask as the optical diffractive element [6]. In this scheme, the nanoparticles can be directly assembled on the photoresist to reduce fabrication complexity. However, in previous implementation of this method the light propagation and resist absorption greatly restricts the intensity pattern, and the height of the patterned structure has been limited.

In this work, we will extend the proposed self-assembled colloidal phase-shift lithography process to the fabrication of thick 3D periodic structure. We will examine in close proximity to the nanosphere array the light propagation and attenuation in thick resist materials. Figure 1 shows a general fabrication process for phase-shift lithography by 2D nanosphere array. A negative photoresist SU-8 was selected for these experiments due to low light absorption at the exposure wavelength to fabricate taller nanostructures. Colloidal phase masks with various ranges of sphere size will be tested to generate different periodic intensity profiles. The fabrication parameters such as exposure dose and post-exposure bake temperature will be optimized experimentally to confirm the well-organized and durable 3D periodic structures inside the photoresist.

Preliminary results are shown in Figure 2(a)-(b), where a monolayer of 2D nanosphere array assembled on photoresist determines the 3D intensity patterns inside the thick photoresist layer. After the exposure, the nanosphere array were removed using ultrasonication system, and the post-exposure bake step was performed with an optimized temperature and time followed by the developing step. Periodic 3D nanostructures were successfully patterned inside the negative photoresist with thickness of 2.5-2.7 μm, as depicted in Figure 2(c)-(d). Using finite-difference time-domain (FDTD) methods, we will continue to increase the thickness of negative photoresist layer with optimizing the exposure parameters for fabricating taller 3D nanostructures.

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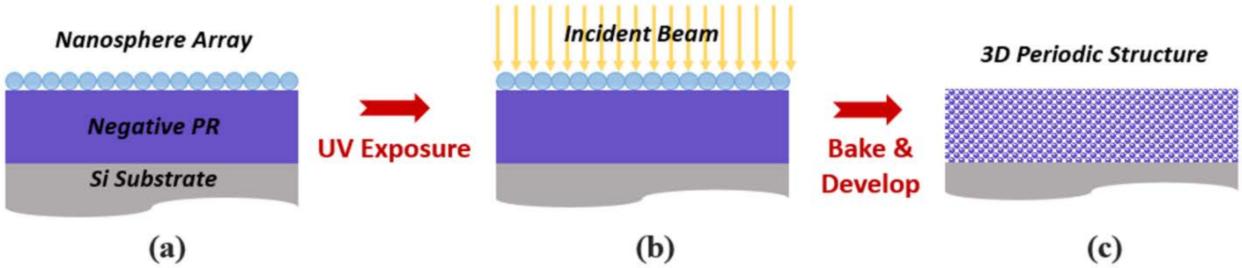

Figure 1. Fabrication process for thick 3D periodic nanostructure. (a) Assemble a monolayer of nanophere array directly on a negative photoresist, (b) UV exposure on the target area, (c) resulting in 3D periodic photoresist structure after the post-exposure bake and develop.

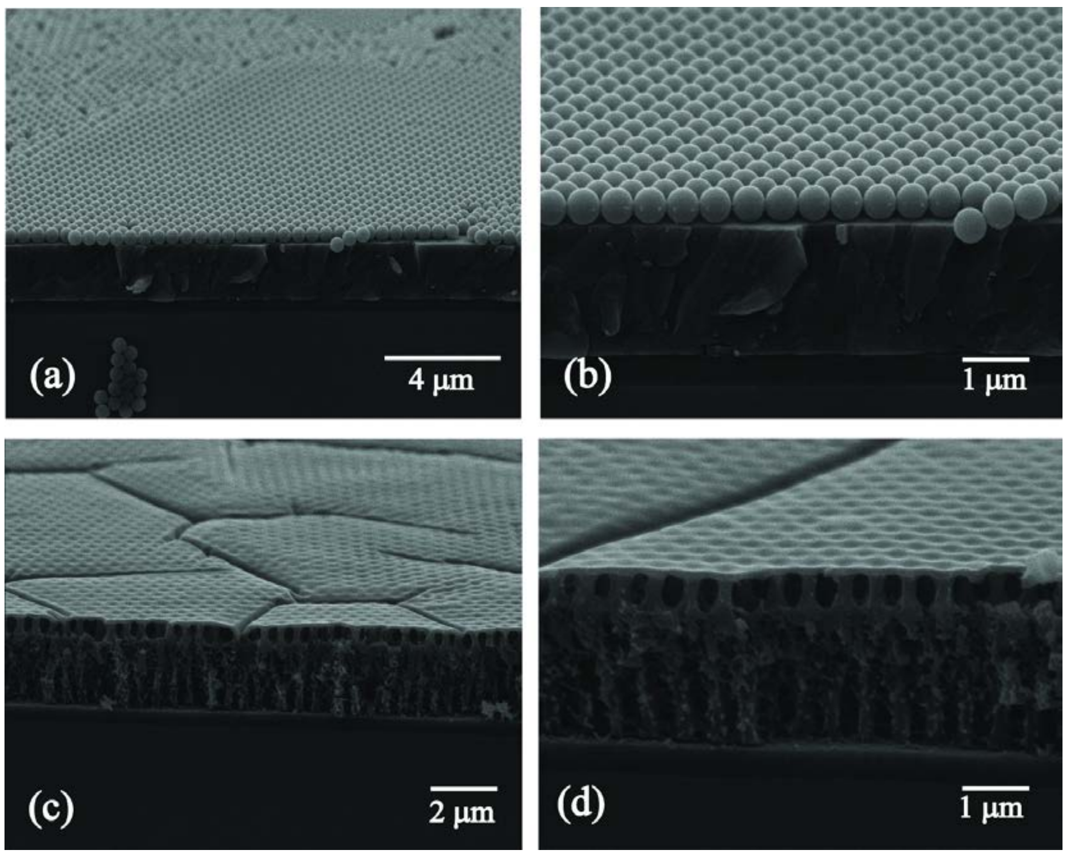

Figure 2. SEM image of (a)-(b) a monolayer of 500 nm diameter nanosphere array on 2.5 μm-thick negative photoresist SU-8 before UV exposure, (c)-(d) 3D periodic photoresist structures after UV exposure, removal of nanospheres, post-exposure bake and developing steps.

References:

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