Near-Field 3D Lithography Using Self-Assembled Nanospheres

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In recent years near-field phase-mask lithography has been demonstrated to be an attractive method to fabricate complex 3-dimensional (3D) nanostructures [1-3]. In this approach thick photoresist is placed in direct contact with a phase mask, which generates a 3D near-field intensity distribution when illuminated. The photoresist then records the intensity pattern, yielding a 3D structure. Since the mask and substrate are in contact, the lithography setup is immune to environmental disturbances and does not require active alignment control. However, the 3D intensity pattern generated depends on the quality of the 2D phase mask, which are typically fabricated using expensive lithographic means [1-3].

In this work we propose a maskless phase lithography process. In this approach, instead of using a physical mask, nanospheres are assembled directly on the substrate to provide the phase modulation required to generate the near-field intensity pattern. Self-assembly of monodispersed colloidal particles has been demonstrated as an effective "bottom-up" method to form a physical template for additive/subtractive processes [4], but in our work they are employed as an optical phase element. The proposed method uses a simple 2D self-assembled geometry to allow the patterning of more complex 2D and 3D structures.

The concept of the proposed method is depicted in Figure 1, where a hexagonal array of nanospheres is illuminated by UV light. The diffracted fields behind the nanospheres interfere to generate 2D intensity pattern, $I(x,y,d)$, that is a function of propagation distance d. Therefore by using a spacer to control the distance between the photoresist layer to the nanospheres, various 2D structure more complex than the original geometry can be patterned. A thick resist layer can also be used directly under the nanospheres to fabricate a 3D structure.

Preliminary fabrication results are shown in Figure 2. First, we demonstrate patterning of various complex 2D periodic geometries by controlling the propagation distance, as shown in Figure 2(a)-(d). Here nanospheres with 450 nm diameter are illuminated by a 325 nm wavelength laser, and d was selected to be 40, 500, 850, and 760 nm, respectively. The inset diagrams are theoretical simulation of the intensity pattern using finite-difference time-domain (FDTD). Second, we utilize thick photoresist to fabricate 3D periodic nanostructure, as shown in Figure 2(e). In this experiment, nanospheres with 350 nm diameters were used to pattern a resist layer 1500 nm thick. The periodicity in the vertical direction is due to Talbot effect, and can be designed by selecting the ratio of nanosphere diameter to illuminating wavelength.

In this work we describe a maskless phase lithography process to fabricate complex 2D and 3D nanostructures. We will present the detail process concept, theoretical modeling, and fabrication results. The proposed process can find applications in photonic/phononic structures, 3D scaffold and uniform-porous filter for biological applications.

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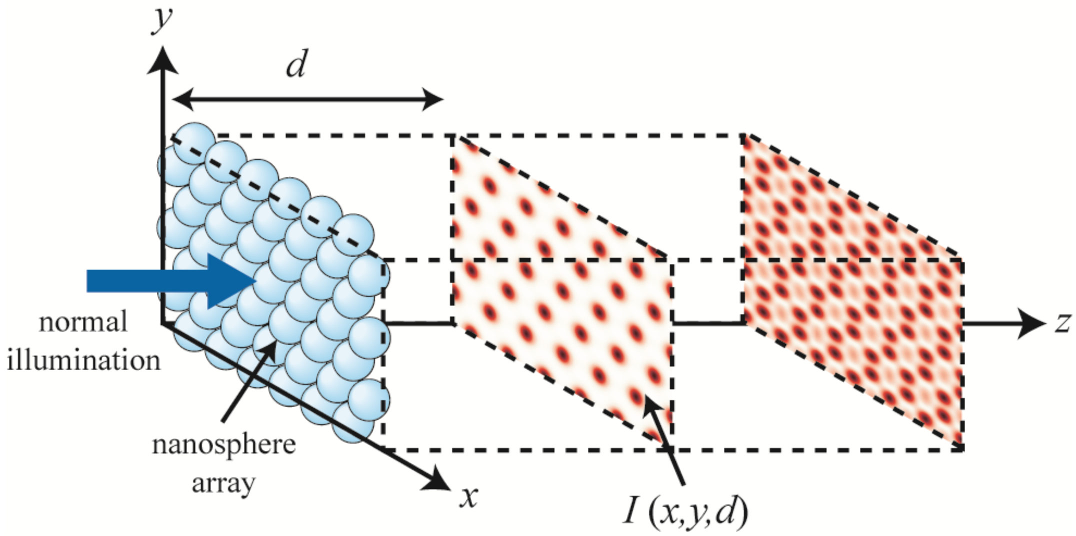

Figure 1 Schematic of the proposed maskless lithography process. A hexagonal array of self-assembled nanospheres is used to generate complex 3D near-field intensity pattern.

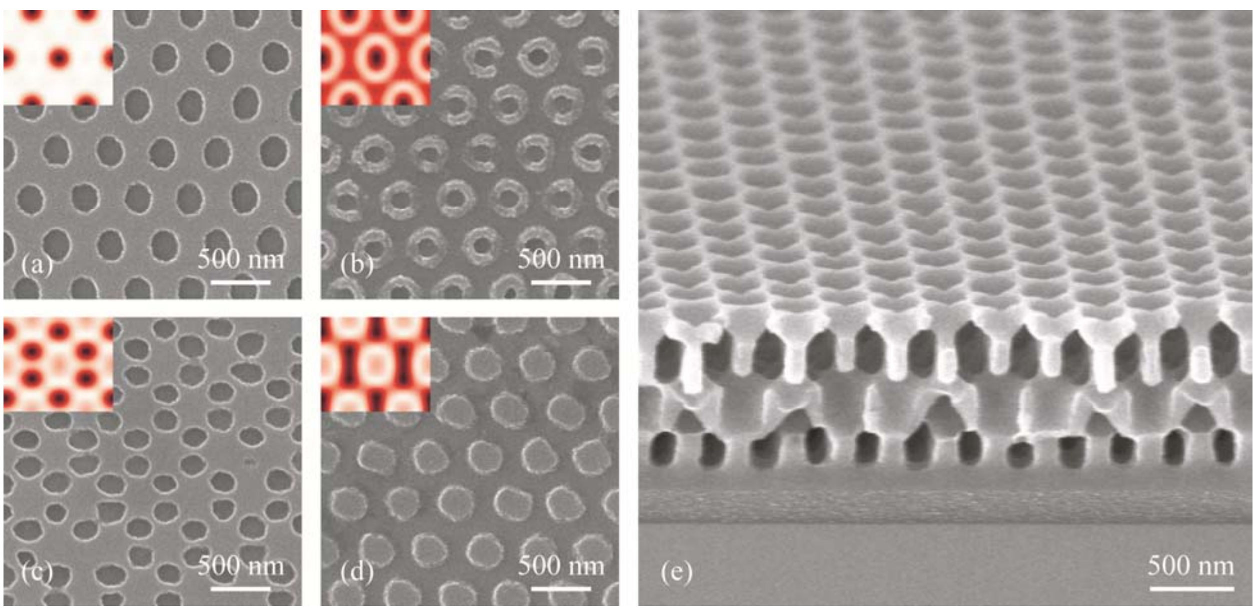

Figure 2 Micrograph of fabricated nanostructure using the proposed method. (a)-(d) Top-view of various 2D structures with 450 nm lattice spacing patterned by controlling the propagation distance *d* from the nanosphere array. (e) cross-section view of 3D nanostructure with 350 nm lattice spacing by using thick photoresist. Three Talbot periods can be observed.

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