13. Fabrication of 3-D Photonic Crystal (PhC) Structures

Sponsors:
National Science Foundation
Contract DMR-0213282

Project Staff:
Minghao Qi, Christel Zanke, Professor John D. Joannopoulos, Professor Henry I. Smith

The remarkable agreement between the optical characterization and simulation of the fabricated 3D PhC with designed point defects, which was reported last year, could open up a new frontier in ultra-high-density optical integration. Whether this achievement remains a laboratory show-case or a realistic platform for future optical VLSI, however, relies critically on a process, especially lithography, that is suitable for the volume manufacturing of 3D PhCs. Two of the most important requirements, low cost and high throughput, cannot be met if electron-beam lithography is required.

Here we describe two approaches that could potentially eliminate the need for the electron-beam lithography. In our PhC design, the central problem is to form a hexagonal-close-packed (hcp) lattice of circular holes in a large area. Simple two-beam interference lithography (IL) can produce an hcp array of holes from two separate exposures, one rotated 60° relative to the other. However, the individual holes are elliptically shaped, which is undesirable for PhC applications.

The first and the easiest approach is based on dual wet etch (Fig. 1). It is well known that wet etch results in undercut, especially for reactions whose rates are limited by surface reaction, rather than mass transport. Wet etched holes in thick films tend to be circular and bear little information of the resist pattern on top of them. In Fig. 1a, two IL exposures defined an hcp lattice of elliptical holes in photoresist. After two sequential wet etches of an antireflection coating (ARC) layer and a Cr layer, the pattern becomes circular (Fig. 1b)

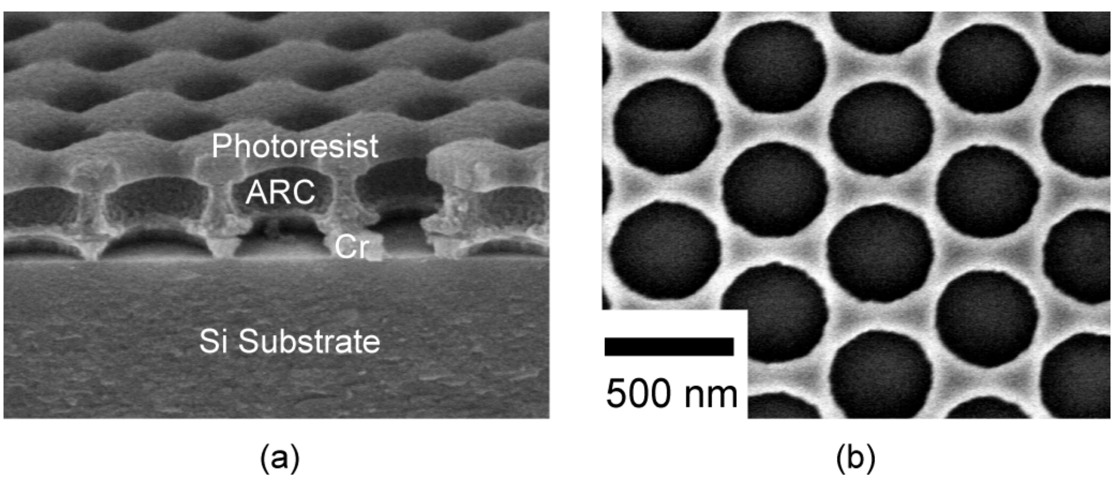

Figure 1. Mechanism and results of the dual-wet-etch process. (a) The photoresist has elliptical holes patterned with IL double exposures 60° apart. An anti-reflective coating layer (ARC) is etched with the same developer as the photoresist. Clear undercuts can be observed. The holes in Cr layer is also defined with a wet etchant (CR-7). (b) The result of the dual wet etch process. The PhC pattern in Cr has almost circular holes.

Unfortunately, this simple scheme does not apply to general PhCs with arbitrary periods. The thickness of the ARC and the period of the PhC pattern have to be carefully matched in order to achieve circular holes. However, the ARC thickness is also determined by the IL setup. Moreover, there is currently no conceivable way of achieving multilayer overlay with this approach.

In order to achieve layer-to-layer alignment, we have developed the system shown in Fig. 2a. The major difference from proximity optical lithography is that the radiation source is a coherent plane wave with linear or circular polarization. For this reason, this set up is called coherent diffraction lithography (CDL).

CDL is based on the self-imaging effect, sometimes referred to as the Talbot Effect. In brief, a mask, which contains a periodic pattern, is illuminated with a monochromatic plane wave. Beams diffracted from the mask pattern overlap and interfere downstream. At certain discrete distances from the mask the pattern of interference reproduces the periodic structure on the mask. These distances, D_n, the Talbot distances, are given by

$$D_n=(np^2)/\lambda$$

where n is an integer, p is the spatial period, and λ is the wavelength of the incident light. A successful CDL patterning is shown in Fig. 2 (b) and (c). Note the better quality of resist pattern than the original mask!

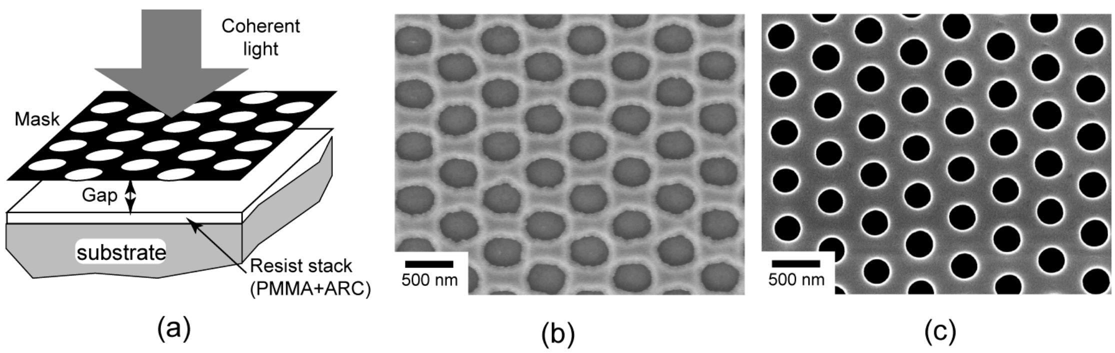

Figure 2: Schematic and experimental verification of the concept of coherent diffraction lithography (CDL). (a) A mask with a periodic pattern in a thin metal film is placed in close proximity to the substrate. The incident light is a coherent plane wave with linear or circular polarization. The gap between the mask and substrate should match the Talbot distances, D_n, and is critical in achieving desired pattern transfer. (b) The mask image, notice the rough, elliptical holes in Cr. (c) The smooth, circular holes in PMMA after CDL.

CDL, combined with an overlay alignment technique, ISPI, which is reported in a separate section in this report, should make possible the volume manufacturing of 2D and 3D PhCs.