Fabrication of Optical Phase Masks for Holographic Lithography of Three Dimensional Photonic Crystals

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Photonic crystals are artificial dielectric materials which use a modulation of the refractive index along one or more spatial dimensions to taylor the optical properties on a wavelength scale. The ultimate control over light propagation can only be achieved by the use of three dimensional Photonic Crystals (3D-PhC). Several fabrication methods for 3D-PhCs have been proposed during the last couple of years. One of them is 3D holography, which uses the interference pattern of several intersecting laser beams to expose a 3D structure in a resist layer. After development, the remaining resist can be infiltrated with a high index material, resulting in a 3D PhC structure. A drawback of 3D holography is the need to control the angle, phase, polarization and intensity of the four or five intersecting beams. The recent proposal[1] to use an optical phase mask (OPM) to generate the beams would dramatically reduce the complexity of the holographic setup. An OPM diffracts a single incident beam into five beams with well defined angles, polarizations and intensities. Figure 1 shows a schematic of an OPM, which consists of two SiO_2/Si gratings with perpendicular orientation, separated by a Si spacing layer. The whole structure is placed on a SiO_2 substrate.

This paper presents the development of a fabrication process for such phase masks. The process starts with the deposition of a SiO_2 layer on the substrate. Even though the substrate is also made of SiO_2, deposition of the upper and lower SiO_2 layer by the same sputter process ensures that the refractive indices are identical. The first grating is exposed by E-beam lithography in a PMMA layer on top of the SiO_2. A thin metal layer on top of the resist dissipates the charge. The grating is etched into the SiO_2 by a reactive ion etch step using a CHF_3/Ar mixture. With the PMMA still on top of the structure, the etched trenches are now refilled by sputtering Si (fig. 2a). After lift-off (fig. 2b), the excess Si surface is removed by a chemical mechanical polishing step using Logitech Syton Typ SF1 polishing fluid on a Logitech Chemcloth polishing pad. The surface is repeatedly polished for 1-2 minutes with 30 turns per minute and a pressure of 300g/cm² until the surface is flat. The Si spacing layer is then sputtered on the sample (fig. 2c), followed by the definition of the second grating using the same process as for the first grating.

[1] T. Y. M. Chan, O. Toader and S. John, Phys. Rev. E 73, 046610 (2006)

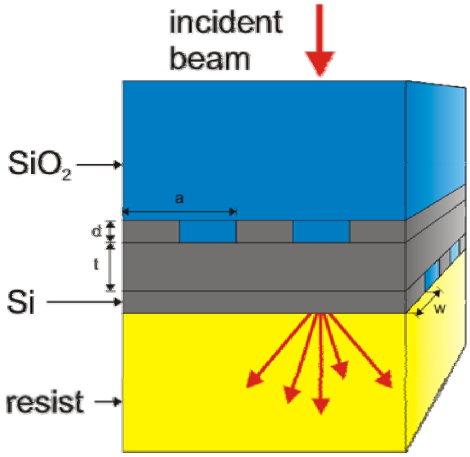

Figure 1: Schematic of the Optical Phase Mask. Typical dimensions are: bar thickness d~50nm, bar width w~250nm, period a~550nm and spacing layer thickness t~600nm.

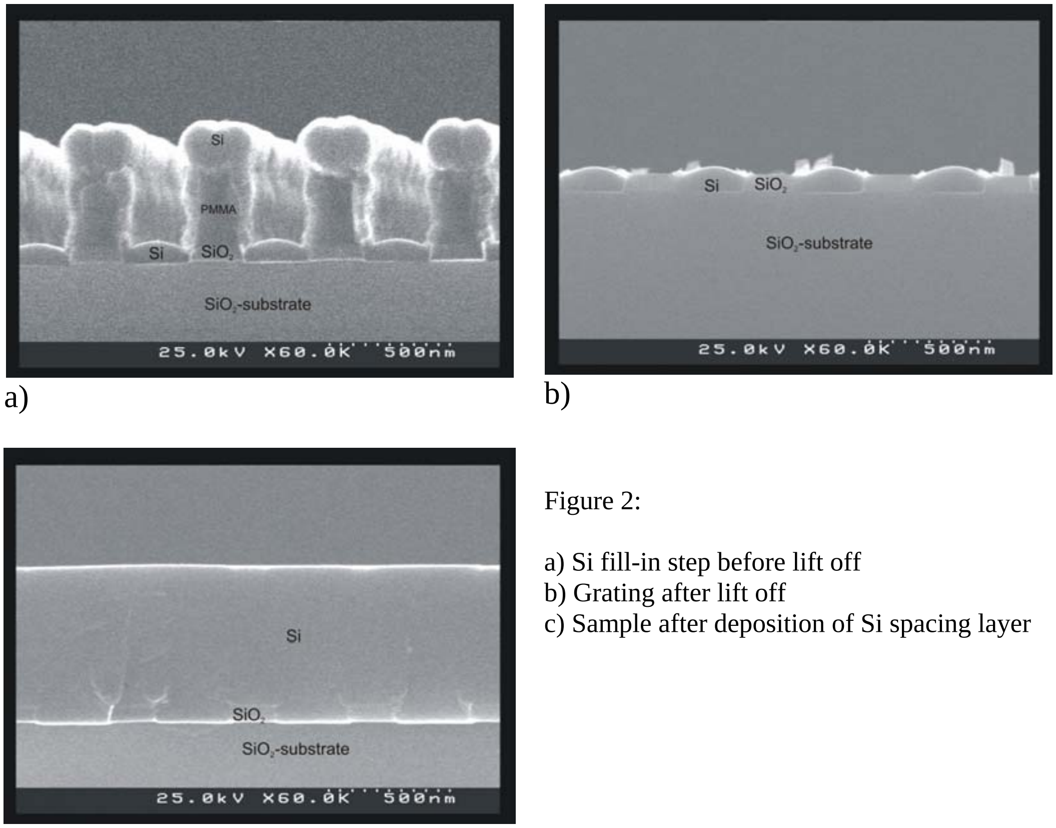

Figure 2:

a) Si fill-in step before lift off
b) Grating after lift off
c) Sample after deposition of Si spacing layer