Two-Photon Laser Lithography of photonic microstructures in photoresist SU-8

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Abstract

High quality three-dimensional micro-and nano-structures were fabricated in photoresist SU-8 by two-photon laser lithography. Extended periodic microstructures with so-called woodpile architecture are demonstrated to have good quality and exhibit fundamental and higher-order photonic stop-gaps in the infrared wavelength range of 2.0-8.0 μm. These SU-8 structures can be used as photonic crystal templates suitable for infiltration by high refractive index materials. To illustrate the resolution limit of SU-8 material, we also demonstrate fabrication of SU-8 nanorods with ultrahigh resolution of about 30 nm.

Periodic three-dimensional (3D) micro- and nano-structures are important in photonics due to their potential use as photonic crystals. Photonic crystals have unique capabilities of controlling the emission and propagation of light via photonic band gap (PBG) effects[1]. Since the direct, large scale 3D fabrication of photonic crystals from semiconductors has proven to be tedious, cheaper and simpler fabrication strategies involving microfabrication of so-called photonic crystal templates which can be subsequently infiltrated by other materials having higher refractive index. Here we report fabrication of 3D photonic crystal templates by two-photon lithography in a commercial photoresist SU-8.

The optical setup used for two-photon lithography is described in detail in our earlier works[2,3]. In brief, it consisted of a Ti:Sapphire Hurricane X source (Spectra-Physics), $\Delta\tau_{pulse}$=130 fs, λ_{pulse}=800 nm, repetition rate of 1 kHz, whose radiation was focused into SU-8 samples by an oil-immersion objective lens with magnification 60× and numerical aperture NA=1.4. The 3D drawing was accomplished by translating the sample along a pre-defined trajectory within (100×100×100) μm range with accuracy of several nanometers using a piezoelectric transducer-controlled translation stage. The samples were films of SU-8 (Microchem), spin-coated to a 50 μm thickness on glass substrates. Single-photon absorption in SU-8 is negligible around λ_{pulse}. Therefore, two-photon absorption is responsible for the local photomodification in the irradiated spatial regions where polymer cross-linking takes place. These regions thus become stable against the subsequent chemical development, which removes unexposed SU-8, leaving only solid exposed parts with refractive index of n ≈ 1.6 suspended in air with n=1. The samples were inspected using a scanning electron microscope (SEM), and their optical properties were studied by transmission and reflection measurements at infrared wavelengths using a Fourier-Transform infrared (FTIR) spectrometer.

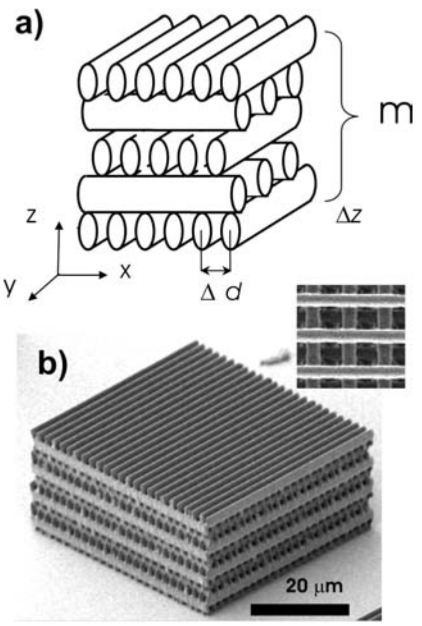

Figure 1. Woodpile architecture and its parameters (a), SEM image of the woodpile structure in SU-8 (b).

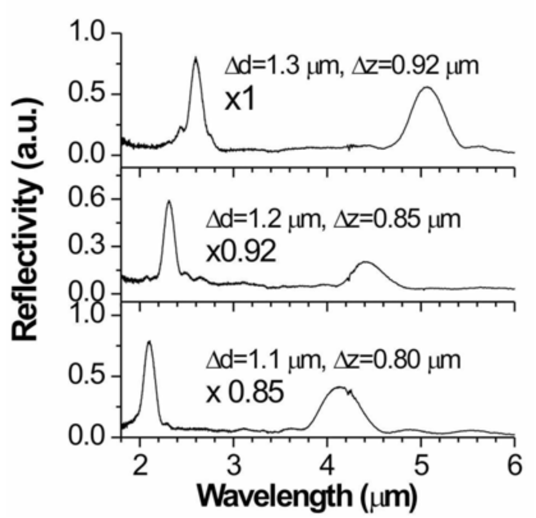

Figure 2. Infrared reflectivities of woodpile structures with different lattice parameters.

The woodpile architecture[4] chosen for the fabrication and definition of its parameters are shown in Fig. 1 (a). SEM images of the woodpile sample fabricated by two-photon lithography in SU-8 are shown in Fig. 2 (b) and the inset. The size of the recorded linear features depends on the laser pulse energy which was kept 0.55 nJ during the recording. The sample is a perfect parallelepiped with dimensions of (48×48×21) μm. The individual rods have smooth surfaces and elliptical cross-sections with minor and major diameters of 0.5 μm and 1.3 μm, respectively.

Figure 2 shows infrared reflection spectra of three samples measured along the layer stacking direction. The structures have lattice parameters scaled down compared to the first sample (the topmost spectrum) as indicated in the plots. In all spectra two major high reflectance regions can be seen centered at shorter (near 2.0 μm) and longer (near 4.0 μm) wavelengths. The reflectivity peaks can be explained by the presence of multiple stop-gaps, or forbidden spectral ranges existing along certain directions only. Second-order stop gaps seen around 2.0 μm wavelength are an evidence of good structural quality achieved, since higher photonic bands are more susceptible to disorder. The peaks' spectral positions depend on the lattice scaling factor in qualitative agreement with Maxwell's scaling, which constitutes clear evidence of their photonic band nature.

For stop gaps to occur at shorter wavelengths, higher resolution of the lithography is needed.

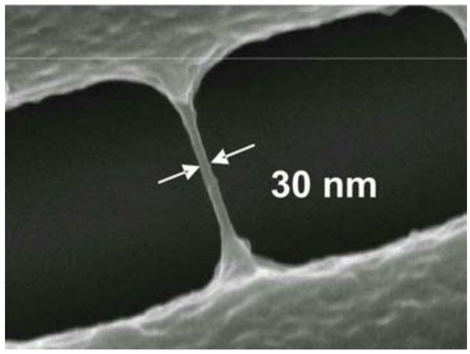

Figure 3. Optically recorded nanorod suspended between two massive SU-8 walls.

We have explored the limiting resolution of SU-8 by fabricating single rods between two thick SU-8 walls (see Fig. 3). The smallest features obtained have lateral sizes of about 30 nm, which corresponds to λ/25 resolution. Though only single features (as opposed to extended periodic structures) can be fabricated at the moment with this high resolution, this result illustrates the capabilities of two-photon lithography applied to SU-8.

In conclusion, we have fabricated SU-8 photonic crystal templates which exhibit low levels of structural deformations, and show substantial signatures of photonic bands. SU-8 templates are mechanically and chemically robust to withstand the infiltration that might require elevated temperatures and chemically harsh environments. Although our structures have lower resolution in comparison to others' works[5], as far as infiltration and coupling of the optical radiation into the structures is concerned, their free-standing nature is an important advantage.

References

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