Fabrication of large-surface-area arrays of periodic nanostructures using azo-benzene containing polymer masks

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During the last decades, arrays of periodic nanostructures have attracted an increasing interest of researchers and technologists. In particular, the fields of nanophotonics and optical metamaterials have undergone a significant progress. Traditional electron-beam and focused ion beam lithographies allow fabricating nanostructures with an unprecedented precision. However, their throughput is low and the fabrication of even a 1 cm^2-area pattern requires enormous time. On the other hand, modern optical lithography can as well be used for fabricating nanopatterns but on much larger surface areas in a much shorter time. For complicated patterns, high-precision photomasks still have to be fabricated by using the two above mentioned techniques, but for simple geometries, such as periodic nanostrip and nanopillar arrays, the exposure of a photoresist with interfering laser beams and a simple post-processing can yield rather high-quality periodic nanopatterns.

We report on the development of an optical interference lithography technique that is based on using azobenzene functionalized polymers (azo-polymers) instead of conventional photoresists. Starting with recording a surface relief grating in a thin polymeric film, spin-coated on a stack of intermediate layers on a silicon substrate, we finally perform reactive ion etching (RIE) of the substrate and obtain the desired structures. Large-area patterns (1cm^2 or so) with feature sizes on the order of 100 nm can be fabricated by using this fast and straightforward technique.

An advantage of this technique is the relative simplicity of obtaining surface relief gratings in azo-polymer films. The grating formation in the azo-polymers we use is governed not only by the irradiance, but also (and especially) by the polarization distribution within the illuminating interference pattern. Owing to this, grating inscriptions can be done under ordinary room illumination [1, 2]. Furthermore, no chemical development of the irradiated azo-polymer film is needed. We can use one or several subsequent illuminations of the azo-polymer film with different interference patterns to produce one- or two-dimensional patterns of the modulated film thickness. With more than two subsequent illuminations, rather complicated patterns can be obtained.

A thin layer of Al_2O_3 beneath the azo-polymer film is needed to obtain a hard mask from the inscribed surface relief grating in the polymer for etching silicon. An example of a hard mask obtained in this way is shown in Fig. 1. Figure 2 shows a mask prepared for fabricating a periodic nanopillar array; this mask is obtained by using two subsequent illuminations of the polymer film with two orthogonal interference fringe patterns. Further reactive ion etching yields either rounded (Fig. 3) or flat (Fig. 4) bottom profiles, depending on the processing parameters. Periodic nanopillar arrays with different sizes and bottom geometries are shown in Figs. 5 and 6. The silicon nanostrutures like these can be further processed, e.g., by covering them with metal for applications in plasmonics or nanoimprinting. They also can find applications in diffractive optics and surface enhanced Raman scattering spectroscopy, as well as in fabricating metamaterials and hydro- and oleophobic surfaces.

Figures

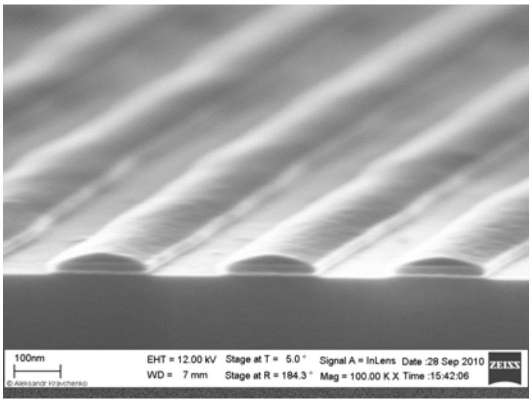

Figure 1. SEM image of a hard mask with remaining azo-polymer on the top of it after single exposure.

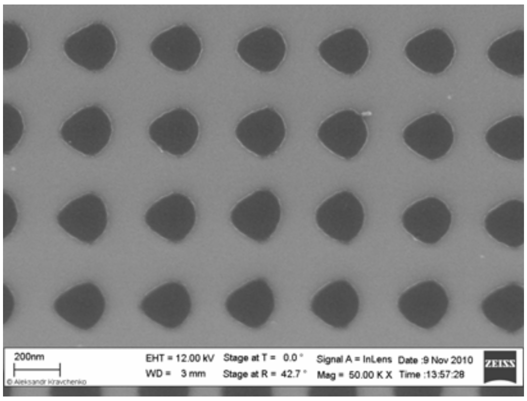

Figure 2. SEM image of a hard mask obtained by using two subsequent exposures of the azo-polymer.

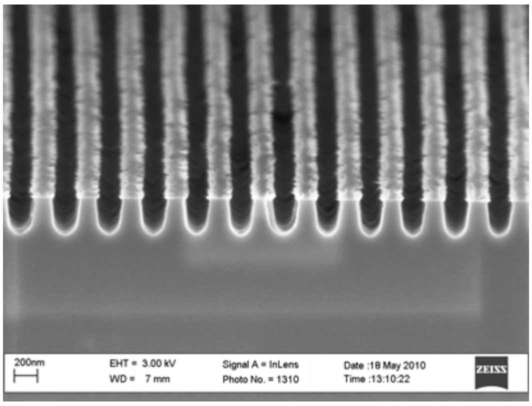

Figure 3. SEM image of a silicon substrate etched with a hard mask by inductively coupled plasma RIE (ICP-RIE).

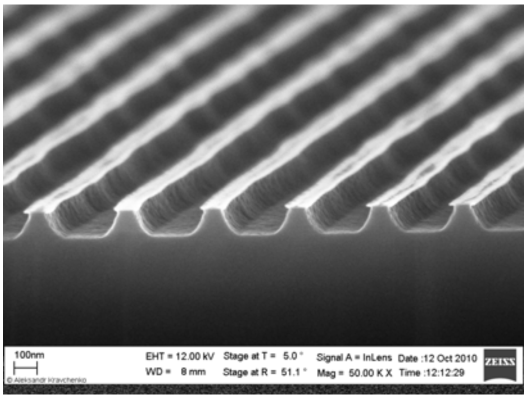

Figure 4. SEM image of a silicon substrate etched with a hard mask by conventional RIE.

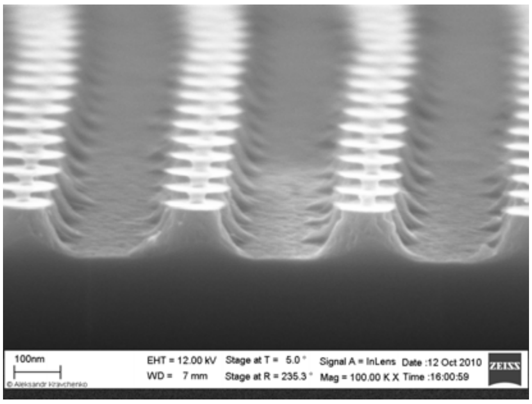

Figure 5. SEM image of a silicon nanopillar array etched with a hard mask by RIE.

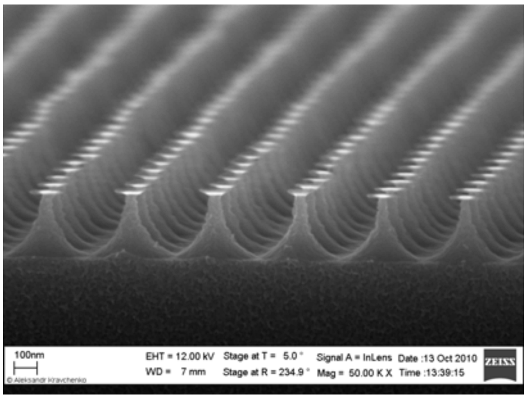

Figure 6. Silicon nanopillar array etched at different processing parameters compared to that in Fig. 5.

References

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