Subwavelength optical lithography of complex nanopatterns by diffraction

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Conventional optical lithography is limited to minimum feature sizes, of about a half micron. To achieve higher resolution, one need to rely on either shorter wavelengths (e.g. DUV), or complicated lens systems (e.g. oil immersion lithography).[1] In this work, we utilize the high orders of light diffraction patterns, and demonstrated that one could make a variety of subwavelength nanostructures with a simple lithography process.

The process we followed was similar to the hard contact alignment, except that we inserted a spacer (a rim of photoresist surrounding the mask patterns) between the mask and wafer to create a well-defined and adjustable separation. With this approach we are able to make use of high orders of diffraction to obtain intriguing nanopatterns of deep sub-wavelength dimensions on the wafer.

One example is the classical Poisson (Arago) spot - i.e., a bright spot appearing behind the shadow of an opaque disc. As shown in Figure 1a, for various disc diameters R , we observed (after exposure and development) their respective Poisson spots on the wafer. As the disc' size was changed, for a fixed separation, the Poisson spot size changed accordingly; i.e., ~ 1/R. By picking a disc of appropriate size, one could get a subwavelength ring-type structure (Figure 1b).

If the mask contains shapes other than discs, more complicated structures may be obtained. Figure 2(a) displays the resultant diffraction patterns of an opaque square and triangle, both of which not only have a Poisson spot in the center, but also contains other fine details due to the combined effect of high orders of diffraction, together with the photoresist response. More sophisticated structures developed by this technique may be seen in Figure 2(b). Out of simple patterns on the mask, one can generate extremely complex structures with 3-dimensional topography with a single lithography step.

This technique can also be a quantitative tool for both dimensional and light intensity measurements. Figure 3 illustrates a comparison between experimental and theoretical diffraction patterns, which are highly sensitive to spacer thickness. Similarly, incident light intensity can be derived from resist thickness, and we will show that spatial maps of diffracted intensity can be generated, and will be compared to theory.

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[1] Timothy A. Brunner, J. Vac. Sci. Technol. B 21, 2632 (2003)

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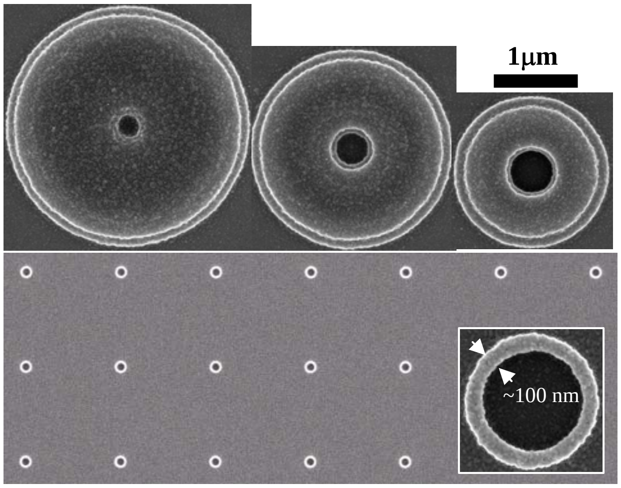

Figure 1. (a) Poisson spots developed from opaque discs (3 μm, 2.5 μm and 2 μm in diameter) on the mask, the Poisson's spots measure 238 nm, 294 nm and 519 nm in diameter respectively. For the exposure, a spacer of ~1.3 μm is inserted between the mask and wafer, resist thickness on the wafer is ~480 nm, using 405 nm UV light. (b) Array of ring-type structures (~ 100 nm side wall) developed from 1 μm discs.

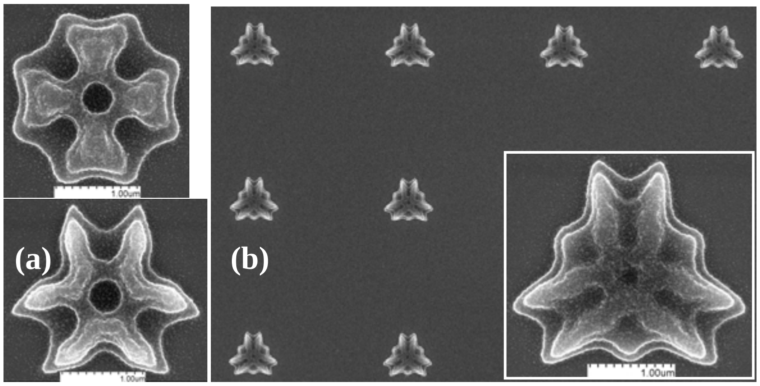

Figure 2. (a) Nanostructures developed from a 2 μm square (top) and a 3 μm triangle (bottom); (b) Array of complex nanostructures developed from 3.5 μm triangles, showing 3-dimensional topography (insert).

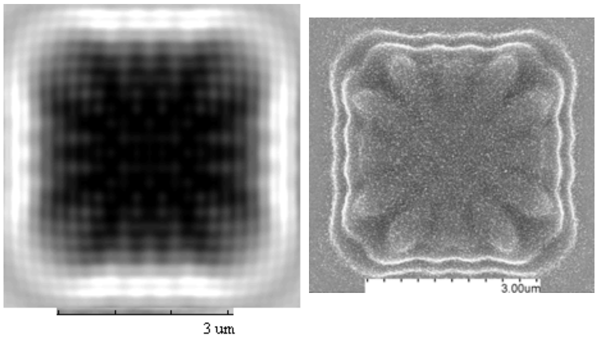

Figure 3. (Left) The calculated light intensity map of the diffraction pattern of a 3.5 μm square; (Right) the developed diffraction pattern of a 3.5 μm square. Both were obtained with the spacer thickness set to 1.8 um.