Planar interference lithography by exploiting high-k modes

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Plasmonic lithography[1] has shown the potential to break the diffraction limit in optical lithography [2], by exploiting the small wavelength of the surface plasmon polaritons (SPPs). Though the feature size of the patterns can be subwavelength, it still suffers from the low contrast and the shallow depth, which seriously limit its practicality. In our work, by using a new plasmon-assisted nanolithography approach, we aim to achieve high aspect ratio subwavelength patterns with pitch equal to one-half the period of the specially designed photomasks.

A lithography diagram and a simulated design are given in figure 1 (a) and (b), respectively. The grating mask on a glass substrate has a 245 nm period with 0.5 metal filling ratio. The PMMA spacer is 40 nm with 10 nm Al underneath. 250 nm thick photoresist (PR) and 40 nm PMMA are on a PET substrate in sequence. The working principle is as follows: when the grating mask is shined by 405 nm wavelength TM polarized light, harmonic modes are excited with the extra momentums provided by the grating. The first order wave couples to the SPPs at the Al/PMMA interface and form a strong high-k resonance. The thin Al film is added to the mask in order to absorb the direct incident light, but transmits the resonance, which is also the plasmonic mode supported by the thin Al. Therefore uniform subwavelength patterns can be imaged on the photoresist. Figure 1 (c) displays the optical transfer function (OTF) at 405 nm through the Al layer. To achieve high aspect ratio features, the photoresist is sandwiched between two lower index PMMA layers to form an optical waveguide. The interference of two anti-propagating waves scattered by the grating forms a standing wave with a sufficient intensity contrast and a large pattern depth throughout the photoresist layer. Figure 1 (d) illustrates the electric field with a high field intensity contrast along a horizontal line in the photoresist with the contrast around 0.97.

Experimentally, we utilized metallic grating masks and thin smooth metal films. The mask is made in conformal contact with the photoresist coated on a flexible substrate. When exposed by a UV laser source with its beam diameter about 1cm, deep subwavelength 1D periodic structures were obtained with approximately 61 nm half pitch (i.e. less than 1/6 of the light wavelength). Figure 2 (a) (b) and (c) are the corresponding SEM images of the photoresist patterns under various polarized light illuminations. Efforts are currently underway to further improve the aspect ratio of the patterns.

[1] X. Luo and T. Ishihara, Appl. Phys. Lett. 84, 4780 (2004).
[2] P. Zhu, H. Shi, and L. J. Guo, Opt. Express 20, 12521 (2012).

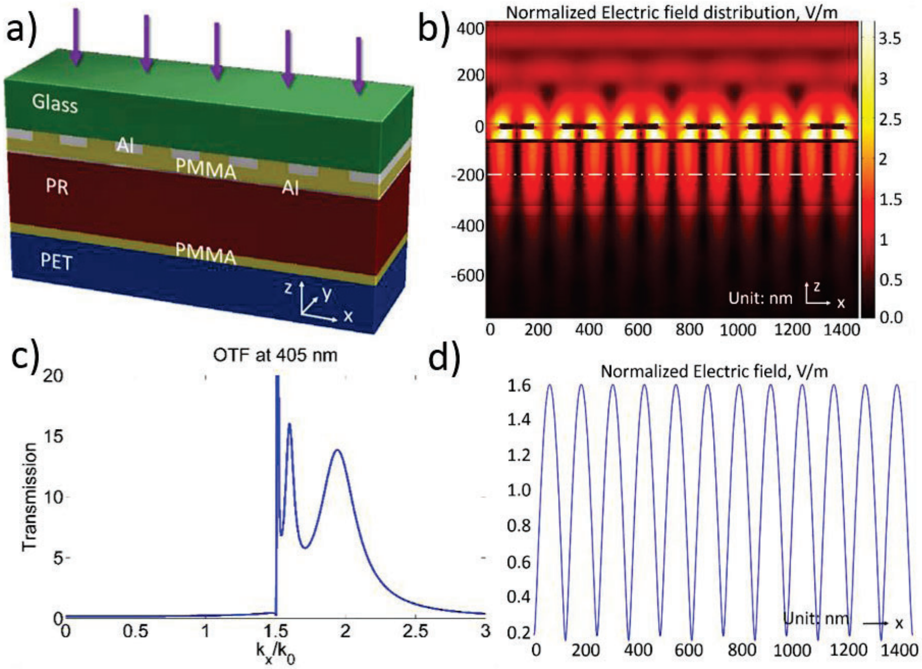

Figure 1 (a) Schematics of the proposed multilayer structure for plasmon-assisted nanolithography. (b) Simulated normalized electric field distribution, the white dash line indicates a horizontal plane in the photoresist. The incident electric field is 1 V/m and x, y, z axes are in nanometers. (c) The OTF of the 10 nm Al layer in the design at the wavelength of 405 nm. The peaks with high transmission correspond to the plasmonic modes supported by the thin Al. (d) Normalized electric field along the dash line with the field intensity contrast around 0.97.

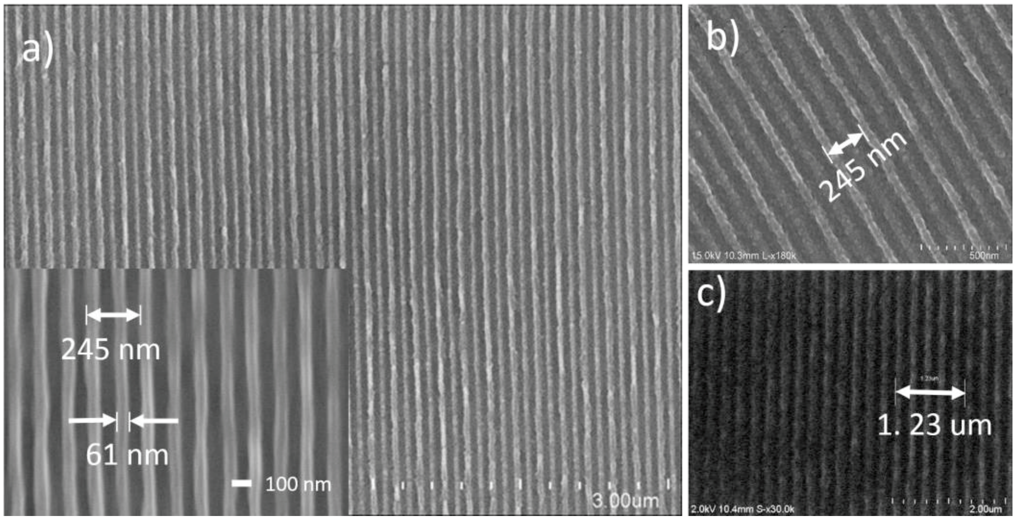

Figure 2 (a) SEM images of the photoresist after exposure and development, with TM polarized light illumination, 122.5 nm period patterns. The bottom left is the zoom-in image. (b) A SEM image of the photoresist with 30° polarized light illumination, double 122.5 nm period patterns. (c) A SEM image of the photoresist with TE polarized light illumination, 245 nm period patterns.