Large Area Plasmonic Roller Lithography for High-Aspect Ratio and Sub-Diffraction Limit Patterning

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There has been a great demand on nanoscale fabrication technologies in a large area with a high productivity for many photonic applications e.g. wire grid polarizers, and nanogratings for AR displays. Photolithography is the most widely used technology, but its resolution is limited by the light diffraction. Plasmonic waveguide lithography can overcome the diffraction limit utilizing surface plasmon polaritons and with aspect ratio and large area uniformity.[1] Further development utilizing epsilon near zero hyperbolic metamaterials (ENZ HMMs) can produce much finer patterns than that on the mask owing to the selectivity to a certain plasmonic mode and the low loss[2]. In addition, a photoroller system was demonstrated to push the former plasmonic waveguide lithography for higher productivity[3]. However, the feature size on the photomask were small and had to be done by electron beam lithography, making it very challenging to fabricate a large area flexible mask . In this work, we extend the ENZ HMM approach to roller lithography, with a large area mask fabricated by photolithography. Using 442nm exposure light, we were able to demonstrate nanograting patterns with a pitch of 128 nm utilizing the 5th order diffraction by ENZ HMM, and the high aspect ratio of the photoresist patterns has also been achieved by the additional metamaterial layer on the substrate.

The plasmonic photomask was designed by COMSOL Multiphysics. The simulated result and the schematics of the photomask and the substrate are shown in Fig. 1. 27 nm thick Al gratings with a period of 1280 nm and a duty cycle of 0.45 were fabricated on a transparent PET film by metal transfer assisted nanolithography[4]. 8 alternating layers of Al/Al_2O_3 with 9/55 nm serving as HMM were evaporated over a thin SU-8 spacer layer. A TSMR-V90 photoresist with a thickness of 100 nm was used on a specially prepared flexible substrate. The optical setup for the system is shown in Fig. 2. The photomask is put on a quartz cylinder and illuminated by a TM polarized 442 nm laser. Fig. 3 shows the SEM images of the exposed photoresist patterns. 128 nm pitch nanogratings were obtained. The feature size ~60nm is much beyond the diffraction limit of 442 nm wavelength light.

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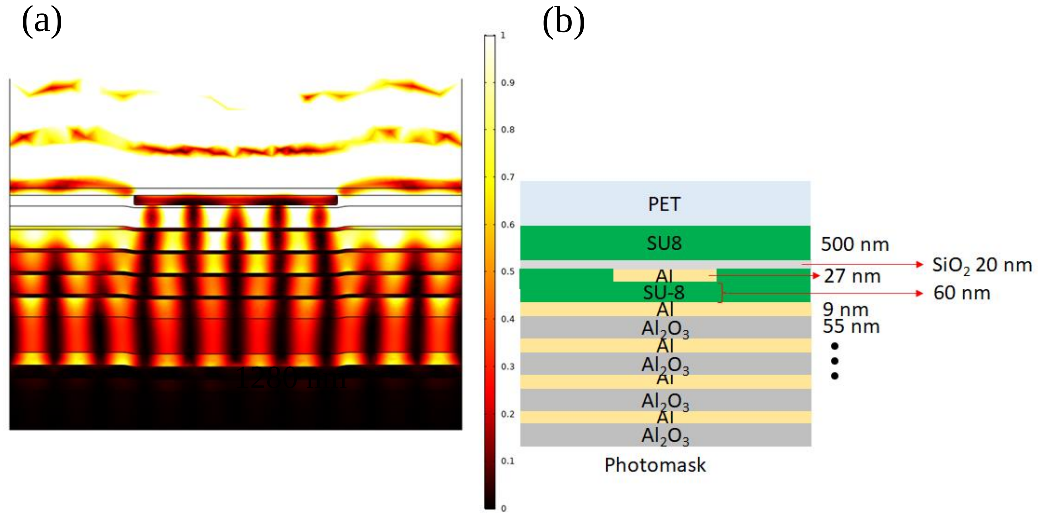

Fig. 1 (a) The simulated result of the normalized electric field intensity in the plasmonic photomask. The high uniformity along the vertical axis and the high contrast along the horizontal axis can be obtained. (b) A schematic of the photomask.

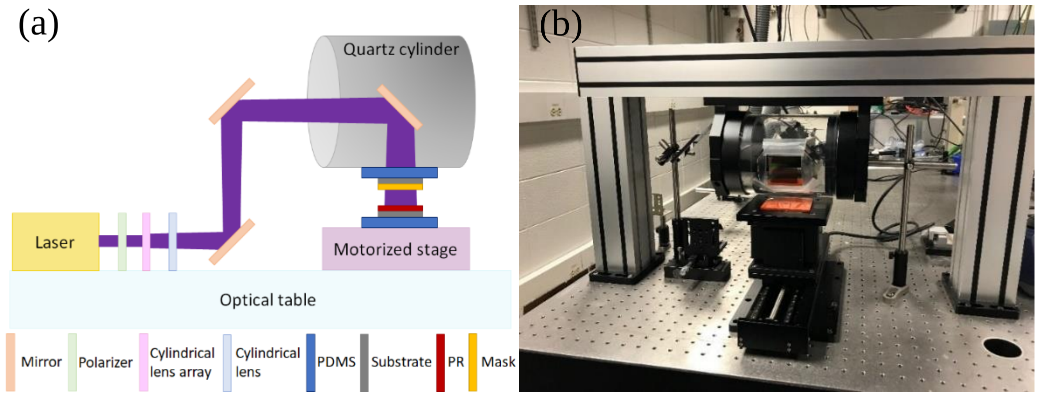

Fig. 2 (a) A schematic and (b) a picture of the optical setup for the plasmonic roller lithography. 442 nm diode laser is formed into a line beam and incident into the photomask wrapped on the quartz cylinder. The substrate is placed on the rubber sheet on the motorized stage.

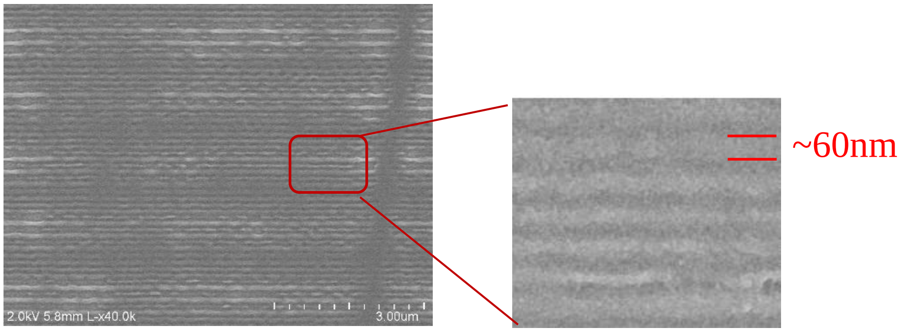

Fig. 3 (a) The resolved gratings by PIL by ENZ HMM and (b) the close image of them showing the 128 nm period.