Plasmonic Roller Lithography

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There is growing interest in novel lithography technologies capable of generating patterns continuously over large areas, such as photo roller lithography (PRL)[1–3] and roll-to-roll nanoimprinting lithography (R2RNIL)[4,5]. Compared to R2RNIL, PRL does not involve imprinting and demolding process, thus exhibits good reproducibility by employing a flexible photomask on a rotating quartz cylinder with an ultraviolet (UV) light source placed inside. Despite recent advancements in PRL[3], the resolution is still limited to micron-scale. Further development towards improving the resolution is a must. In this work, we demonstrate a plasmonic photo roller system, which pushes the resolution of PRL to nano-scale by using specially designed masks based on plasmonic waveguide lithography[6]. In the previous planar plasmonic lithography system with mask made on silica as the substrate[6], uniform patterns with high aspect ratio were obtained. By making a flexible photomask in a plasmonic roller system, sub-wavelength can be printed continuously over a moving substrate coated with photoresist (PR).

A schematic of the plasmonic roller system with flexible plasmonic mask is shown in Figure 1. A polarized UV laser beam is directed into the quartz cylinder and onto the PR layer coated on the moving substrate. The plasmonic photomask has an Al grating with a period of 245 nm, and a duty cycle of 0.5. The grating is separated by a spacer layer from a thin Al layer that functions as spatial light filter to ensure pattern uniformity[6]. The electric field distribution of the plasmonic waveguide lithography system is shown in Figure 1A1 and principle of the waveguide coupling is illustrated in Figure 1B. As a proof-of-principle experiment, a small area mask is fabricated by using electron beam lithography with a pattern area of 2 mm × 1 mm. Upon illumination of transverse magnetic (TM) polarized 405 nm light, the flexible mask on the rolling quartz and the PR coated moving substrate on a motorized stage are in conformal contact. Continuous nano-scale patterns are successfully produced as shown in Figure 2. The scanning microscope image (SEM) image of the pattern on PR is shown in Figure 2A, and the patterned resist under an optical microscope is shown in Figure 2B. The patterns are composed of parallel periodic lines with the linewidth around 55 nm (1/7 of the exposure light wavelength) on PR with thickness of 100 nm (aspect-ratio around 2:1). With further optimization of the plasmonic roll lithography system, fabrication of large-area plasmonic masks could enable such systems to find practical applications in the large-scale production fabrication of electronics and photonics components.

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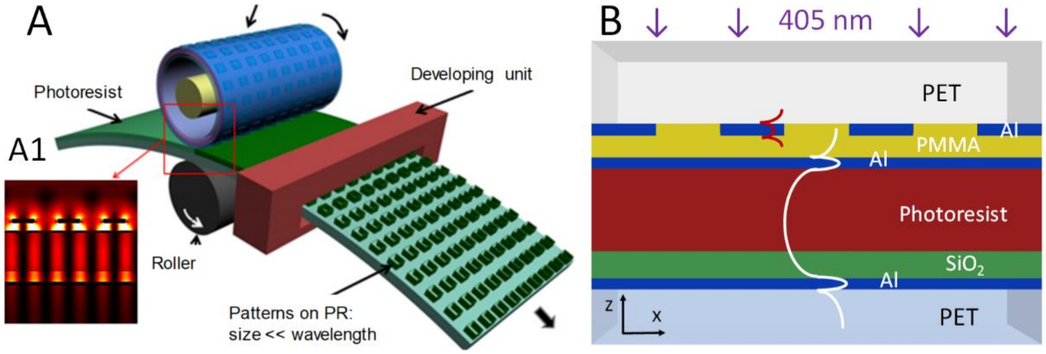

Figure 1 Schematic of plasmonic photo roller system.
(A) The schematic of the plasmonic photo roller system (A1) Light distribution in the plasmonic system based on Al waveguide. (B) Light coupling in the plasmonic waveguide lithography system. The PR film and photomask on polyethylene terephthalate (PET) substrates are illuminated by TM polarized 405 nm laser light.

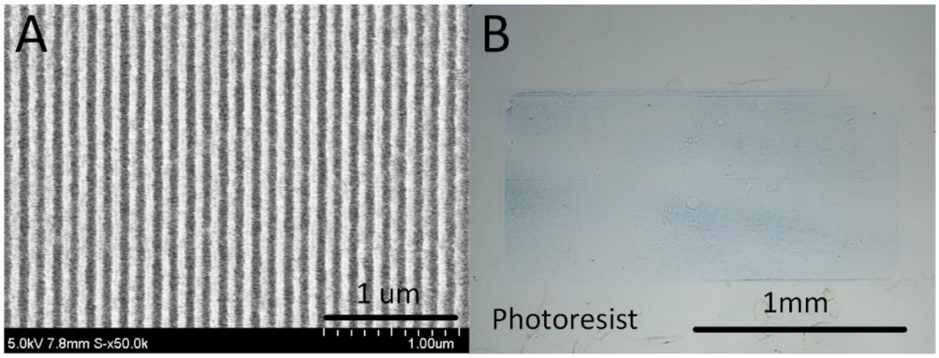

Figure 2 Experimental results made by plasmonic photo roller system.
(A) SEM images of the nanoscale pattern in PR with thickness of 100 nm. The pitch of the pattern is 122 nm. (B) Resist patterns under an optical microscope. The size of the patterned area is 2 mm × 1 mm.