Polymeric Sidewall Transfer Lithography

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Fabricating high-resolution nanostructures has become more and more critical due to the increasing need to shrink devices, especially in integrated circuits. To achieve this goal, advanced techniques such as deep ultraviolet lithography (DUV)[1], extreme ultraviolet lithography (EUV)[2], and electron-beam lithography[3] are employed. Although these advanced techniques are able to create and replicate ultra-small structures, their high cost-of-ownership and time-consuming process make these techniques not commonly accessible. The objective of this work is to develop a low-cost and fast method to generate nanostructures without expensive and sophisticated equipment. The proposed method is based on a polymeric sidewall generated by spin-coating a polymer solution on a pre-patterned vertical structure. The polymeric sidewall thickness is usually in nanoscale and can be transferred into the substrate. Compared to the conventional sidewall transfer lithography[4, 5], this method deposits the sidewall layer easier and faster, and does not require a high temperature environment. Moreover, the dimensions of the polymeric sidewall are expected to be controllable by changing processing parameters, such as the spin-coating speed and the solution concentration.

In the experiment, 1wt% PMMA and 2wt% Teflon-AF solutions were prepared in advance. PMMA was dissolved in toluene and Teflon-AF was dissolved in FC-40. Figure 1 illustrates the experimental process. First, the Teflon-AF was spin-coated on the SiO_2 substrate (Fig. 1(a)) and imprinted by a pre-patterned mold with 350 nm grating (Fig. 1(b) and (c)). Teflon-AF originally has a highly hydrophobic surface. After removing the residual layer by oxygen RIE (Fig. 1(d)), its surface turns into hydrophilic. The hydrophilic surface benefits the process of spin-coating PMMA solution on its top (Fig. 1(e)). The PMMA solution was spin-coated at 1000 rpm, forming a 60-nm thick layer on the SiO_2 substrate. The PMMA layer was removed by oxygen RIE in order to expose the SiO_2 substrate (Fig. 1(f)). After dissolving Teflon-AF in FC-75 solvent, the nanoscale PMMA patterns were formed (Fig. 1(g)). Figure 2 shows the top-view of the PMMA sidewall after dissolving the Teflon-AF base structure. To transfer the PMMA pattern into the substrate, 10nm chromium was deposited on the whole substrate (Fig. 1(h)). After removing the PMMA, the chromium layer was used as a mask to etch the SiO_2 substrate (Fig. 1(i)). After dry etching SiO_2 (Fig. 1(j)) and removing the chromium layer (Fig. 1(k)), the nanoscale sidewalls were successfully transferred into the substrate. Figure 3(a) shows the cross-section of the final patterning result (Fig. 1(k)). Trenches of around 40 to 50 nm in width and 60 nm in depth have been successfully achieved. Figure 3(b) shows the top-view of the trenches. The processing details and optimization to improve pattern uniformity will be reported. The polymer sidewall transfer lithography technique presents a facile route towards the creation of sub-50 nm structure without the need for advanced lithography equipment.

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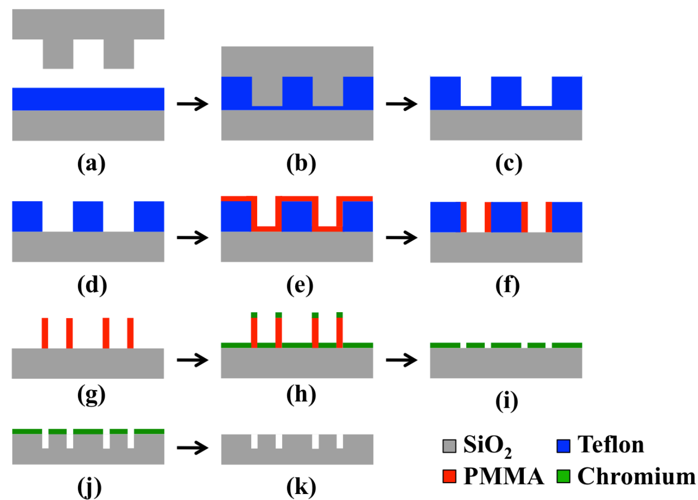

Fig. 1. Schematics of nanostructure creation by polymer sidewall transfer lithography. (a)-(d) Nanoimprint patterning of Teflon-AF and residual layer removal; (e) Spin-coating PMMA; (f) O_2 RIE to remove top PMMA; (g) Teflon-AF removal; (h) Cr deposition; (i) Cr lift-off; (j) Oxide dry etching; (k) Cr removal.

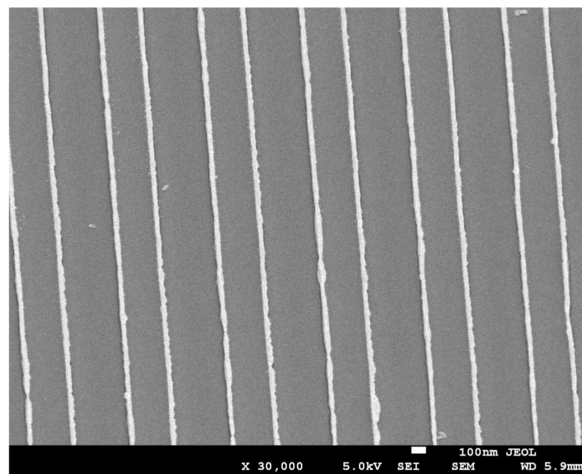

Fig. 2. The SEM image of PMMA sidewalls after removing the Teflon-AF template in FC-75 solvent.

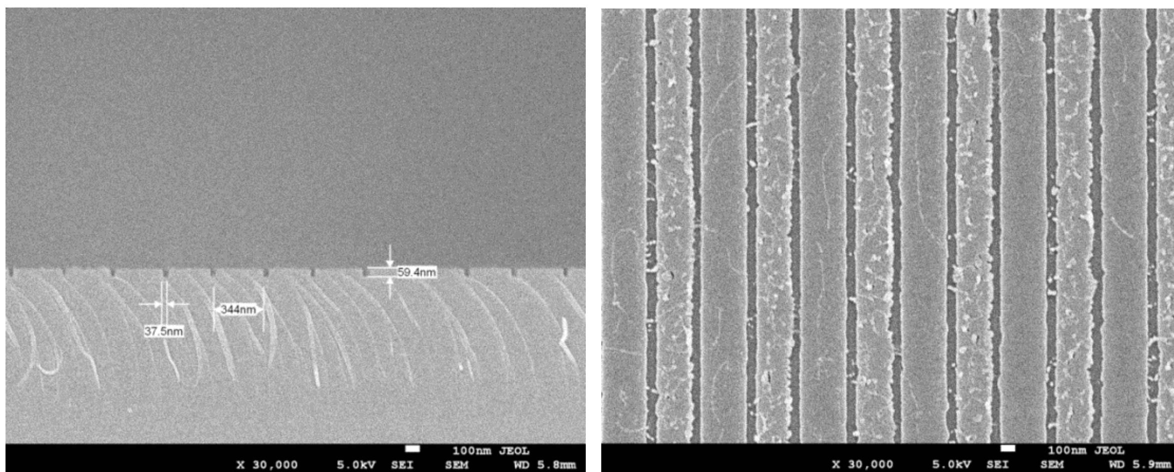

Fig. 3. (a) Left, the cross-section of the substrate after transferring sidewalls into the substrate. (b) Right, the top-view of the pattern after transferring sidewalls into the substrate.