Electron beam lithography with evaporated resist

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One challenge in nano-fabrication is to pattern on non-flat surfaces, which is desired in many fields such as MEMS, electronic devices, and optical devices. This is because the usual film coating method spin-coating can form a film only on flat surfaces. Pedersen et al. have reported the coating of e-beam resist using plasma polymerized hexane[1]. Previously, we have demonstrated ultra-dense patterning using 2 kg/mol polystyrene (PS) as a negative electron beam resist[2]. Here, we introduced thermal evaporation to deposit a high-purity and uniform polystyrene film on substrate for patterning by e-beam lithography.

Compared with spin-coating method, evaporation has many advantages. Firstly, it can form uniform resist layer on nearly any types of surface. While in spin-coating, organic sub-layer could be dissolved or swelled by solvent. Secondly, to prepare the solution for spin-coating, many aspects should be considered for ideal result, including concentration, viscosity, surface tension, dissolvability and harmfulness. Evaporation is a dry process and can be controlled easily. Moreover, hard baking is not necessary in evaporation. To form PS film by thermal evaporation[3], the tradeoff between evaporation temperature and degradation should be made. For PS with higher molecular weight, higher vaporization temperature is needed, which will lead to fast degradation of the molecule (or oxidation to CO_2 and H_2O gas if vacuum is poor). Here we used 1.2 kg/mol PS for thermal evaporation. An AFM tip was used to demonstrate its capability of patterning on non-flat surface. The evaporated film thickness is ~60 nm.

E-beam lithography was conducted using Raith 150^{TWO} system with 5 kV acceleration voltage and 0.2 nA beam current. Since it is known that for simple cross-linking resist like polystyrene the sensitivity ($\mu C/cm^2$) is inversely proportional to molecular weight (kg/mol), we examine the degradation of evaporated film by comparing its sensitivity with the spin-coated film. Figure 1 shows the contrast curves of the same PS coated by spin-coating and evaporation. As seen, the sensitivity is lower for evaporated polystyrene, which indicates the evaporated film has lower molecular weight due to partial decomposition during evaporation. Figure 2a shows line array pattern with 30 nm half pitch. An array of letters "WIN" (Waterloo Institute for Nanotechnology) with line-width of 28 nm was successfully patterned on an AFM tip using 50 nm evaporated polystyrene, as seen in Figure 2b.

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[1] R. H. Pedersen, M. Hamzah, S. Thoms, P. Roach, M. R. Alexander, N. Gadegaard, Microelectron. Eng. 87, 1, (2010).
[2] S. Ma, C. Con, M. Yavuz and B. Cui, Nanoscale Res. Lett. 6, 446, (2011).
[3] T. Bhuvana and G. U. Kulkarni, Bull. Mater. Sci., 31201, (2008).

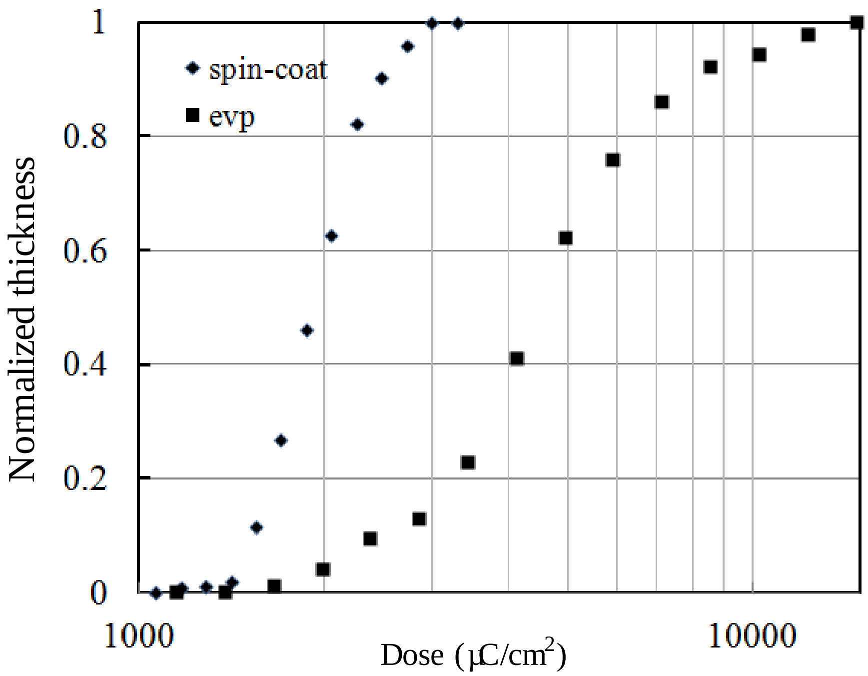

Figure 1. Contrast curves for 1.2 kg/mol polystyrene by spin-coating and evaporation. Both exposed at 5keV and developed by xylene for 30 seconds. The sensitivity (dose for 50% remaining thickness) and contrast are 1920 μC/cm^2 and 4.3 for spin-coat PS, and 4500 μC/cm^2 and 2.6 for evaporated PS.

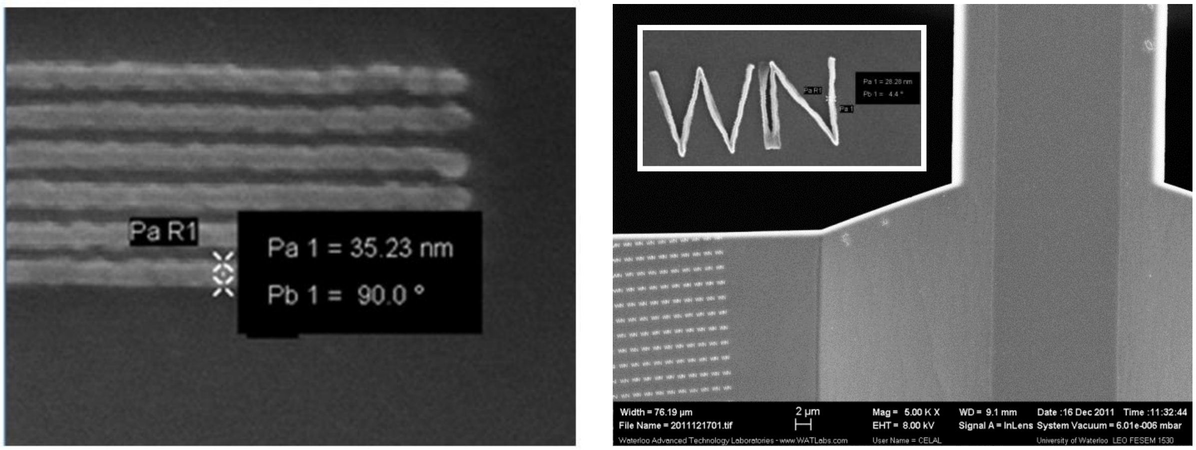

Figure 2. Electron beam lithography at 5 keV using evaporated PS. (a) Line array pattern with 60 nm period. (b) Array of letters WIN exposed on an AFM tip, with the insert as zoom-in showing a line-width of 28 nm.