High Resolution Electron Beam Lithography Using Polystyrene Negative Resist

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In electron beam lithography (EBL), negative resist is preferred for some applications such as fabrication using liftoff of hole arrays in a metal film. However, there is no negative resist that have gained similar popularity to PMMA or ZEP positive resist. Bilenberg *et al.* has selected four negative EBL resists and compared their performance: calixarene, ma-N 2401, SU-8 and mr-L 6000 [1]. As chemically amplified resists, SU-8 and mr-L 6000 offer superior sensitivity, but with low contrast and resolution (more strictly speaking, half pitch for dense periodic line array patterns) that is limited by the diffusion of the photoacid generator during postbaking. Ma-N 2401 has sensitivity comparable to that of ZEP resist, but with far inferior resolution. Among the four resists, calixarene offers the highest resolution, and 1.6 Tdots/in^2 (corresponding to a dot array of 20 nm period) using very thin resist film has been demonstrated [2]. However, it has low sensitivity, and the acid generated in the exposed area may diffuse into the unexposed area, causing blurring of the latent image. In recent years, the inorganic resist hydrogen silsesqioaxene (HSQ) probably attracted more attention than any other negative resist, with a record resolution of 4.5 nm half pitch [3]. One drawback for HSQ resist is its instability, thus spin coating, baking, exposure and development must be done quickly [4].

In addition, all the above resists are commercially formulated with typically high cost and short shelf life. Therefore, it is desirable to have a negative resist like PMMA, which is a simple polymer with low cost, practically unlimited shelf life, and able to be dissolved at will to give desired film thickness. Polystyrene is such a resist, and previously dense periodic pattern with 40 nm period lines have been demonstrated [5]. In this work, we investigate the ultimate resolution (half pitch for dense periodic structure) that can be achieved with polystyrene.

We dissolved 2 kg/mol molecular weight polystyrene in chlorobenzene to obtain a film thickness of 30 nm. After exposure, the resist was developed using xylene (o-, m-, p- mixed), chlorobenzene or cyclohexane at room temperature or 50^{o}C. However, it was found that the different developers/development temperatures did not have noticeable effect on the final structure. As shown in Fig. 1, we achieved the patterning of 20 nm period lines and 15 nm period 2D dot array, which is believed to be the highest pattern density ever obtained using organic EBL resists. Besides ultrahigh resolution, polystyrene is more (by ~3×) resistant to dry etching than PMMA. However, as shown in Fig. 2 for the contrast curve, the major drawback for polystyrene resist is low sensitivity (D_{50}=1150 μC/cm^2 at 5 keV), which would limit its application to small scale nano-patterning in R&D.

[1] Bilenberg B et al. 2006 *J. Vac. Sci. Technol. B* **24**(4) 1776.
[2] Mohamad Z B, Shirai M, Sone H, Hosaka S, Kodera M 2008 *Nanotechnol.* **19** 025301.
[3] Yang J K W, Cord B, Duan H, Berggren K K, Klingfus J, Nam S W, Kim K B, and Rooks M J 2009 *J. Vac. Sci. Technol. B* **27**(6) 2622.
[4] Clark N, Vanderslice A, Grove III R and Krchnavek R R 2006 *J. Vac. Sci. Technol. B* **24**(6) 3073.
[5] Austin M D, Zhang W, Ge H, Wasserman, Lyon S A and Chou S Y 2005 Nanotechnol. **16** 1058.

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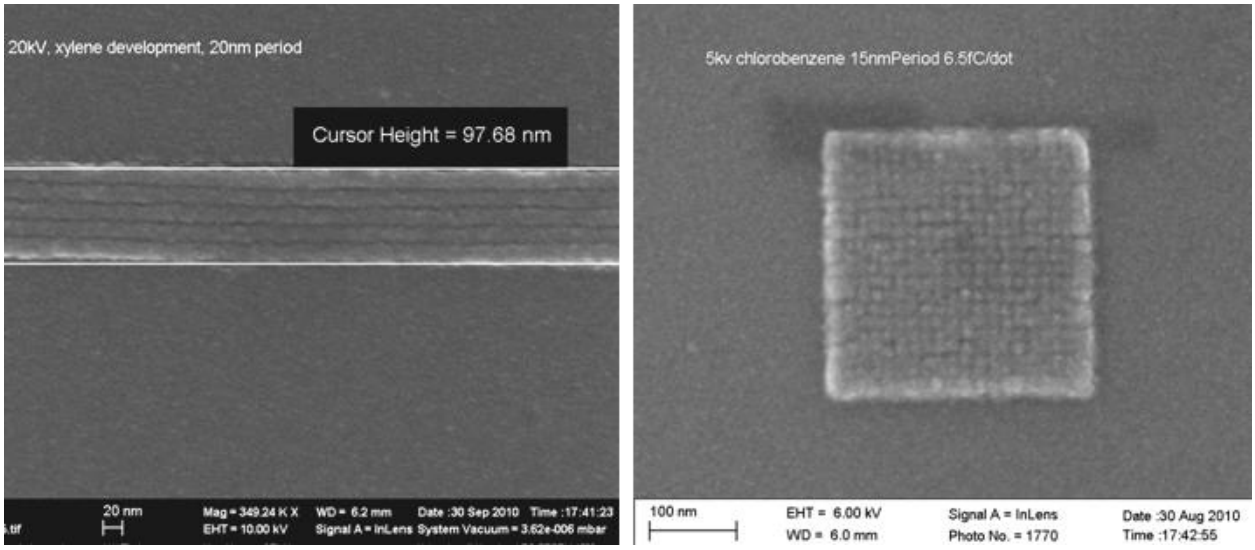

Figure 1 (left) Line array with 20 nm period in polystyrene resist developed by xylene for 1.5 min; (right) Dot array with 15 nm period developed using chlorobenzene for 1.5 min.

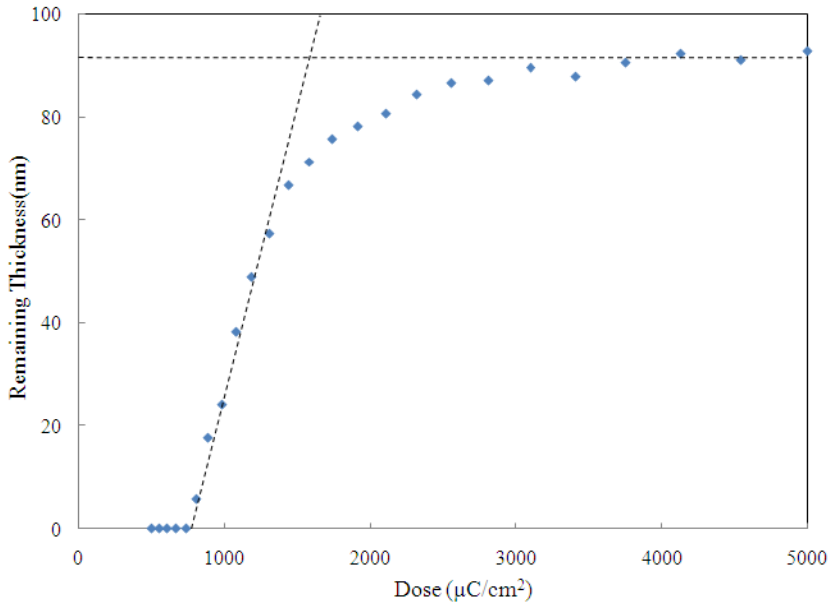

Figure 2 Contrast curve for polystyrene exposed at 5 keV and developed by xylene for 1.5 min. The contrast is calculated to be 3.7. Note that here the film is thicker than the high resolution experiment, in order to obtain more accurate measurement by AFM.