Electron beam lithography using dry thermal development

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In electron beam lithography, the exposed resist is typically developed using a solvent or aqueous developer. One potential issue with liquid developer is resist peel off due to poor adhesion to the substrate, or resist pattern deformation and collapse due to capillary force during developer drying. Dry development is therefore desirable for some processes. Here we show that dry development can be realized using a simple electron beam resist polystyrene (PS), which has demonstrated ultra-dense patterning using low molecular weight of 2 kg/mol [1], or ultra-high sensitivity lithography using high molecular weight of 900 kg/mol [2]. The dry development is possible because exposed thus cross-linked PS evaporates due to thermal decomposition at a slower rate than unexposed PS.

In the experiment, PS with molecular weight of 2 kg/mol (Mw/Mn=1.10) was dissolved in chlorobenzene and spin-coated on a silicon wafer. After exposure at 20 kV, the film was baked on a hot-plate at high temperatures that led to decomposition of PS [3]. Figure 1 is the contrast curve for PS that was developed by baking at 350°C for 30 min. The contrast curve was measured using AFM, and shows a resist contrast (defined as $\gamma=[\log(D_{100}/D_0)]^{-1}$) of 3.2, which is moderately high. However, the resist sensitivity is very low, at around 20000 $\mu C/cm^2$. Nevertheless, sensitivity is not an intrinsic property of a resist, and could be improved by, e.g., using lower baking temperature and/or shorter annealing time, though this may also affect the resist contrast. The optimization of baking temperature and time is underway. Alternatively, higher sensitivity can also be obtained by exposure at lower electron beam energy or using higher molecular weight PS.

Under the same exposure and development condition, the line array patterns with periods of 200 nm, 100 nm and 60 nm are shown in Figure 2. The line width is approximately 50 nm, and the array with period down to 100 nm can be reasonably well defined, whereas the next one with 60 nm period cannot.

[1] S. Ma, C. Con, M. Yavuz and B. Cui, Nanoscale Res. Lett. 6, 446 (2011).
[2] C. Con, R. Dey, M. Ferguson, J. Zhang, R. Mansour, M. Yavuz and B. Cui, submitted to Microelectronic Engineering.
[3] S. L. Malhotra, J. Hesse and L. P. Blanchard, Polymer, 16, 81 (1975).

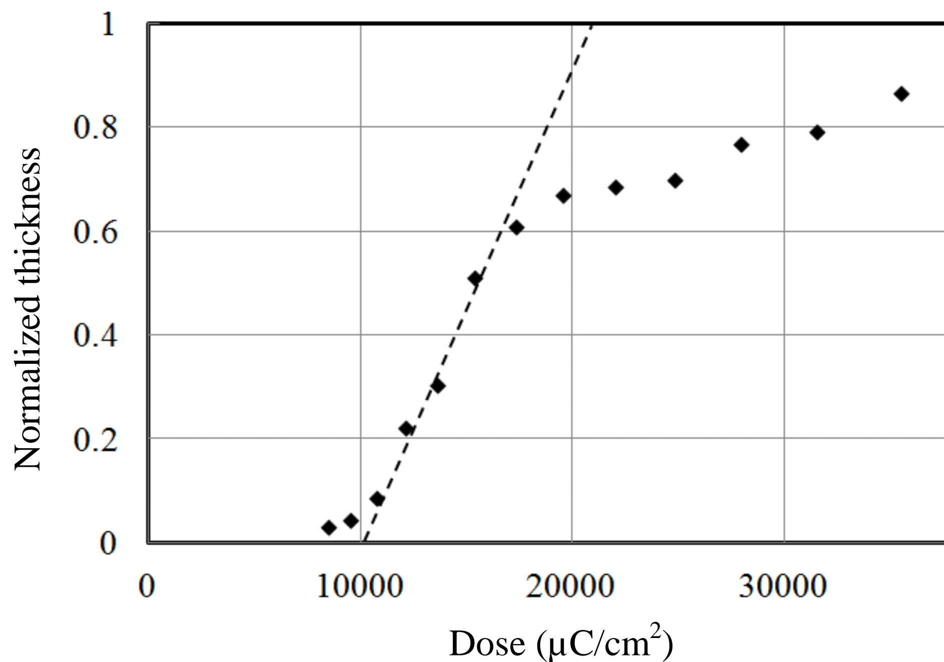

Figure 1. Contrast curve for 2 kg/mol polystyrene exposed at 20 kV and thermally developed at 350°C for 30 min.

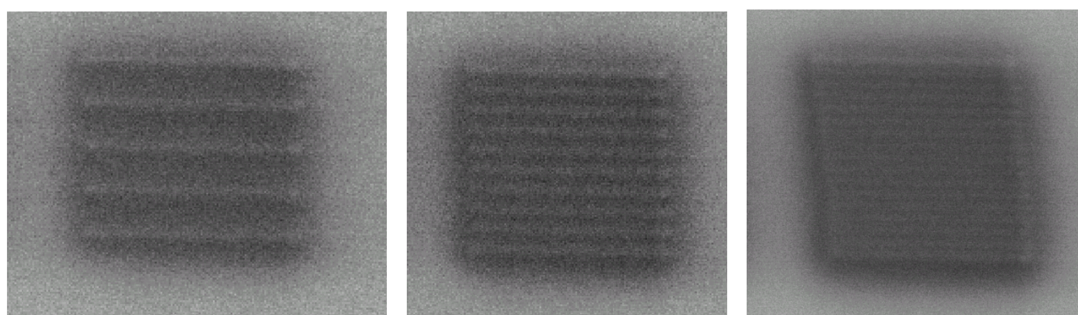

Figure 2. SEM images of polystyrene line arrays exposed at 20 kV and thermally developed at 350°C for 30 min. (left) 200 nm period; (middle) 100 nm period; (right) 60 nm period.