Developer-Free Direct Patterning on PMMA by Low Voltage Electron Beam Lithography

D. A. Zheng[1], M. A. Mohammad[1], S. K. Dew[1], M. Stepanova[1,2]

[1]*Department of Electrical and Computer Engineering, University of Alberta, T6G 2V4*
[2]*National Institute for Nanotechnology NRC, Edmonton, Alberta, Canada T6G 2M9*

The conventional electron beam lithography development stage employing liquid developers introduces challenges such as selection of optimal developer formula, development time, temperature, etc. In addition, dense structure resolution is limited by processes such as swelling and capillary force pattern collapse. A very promising method has been explored recently [1,2] that avoids the liquid development stage. If successful, this technique will greatly simplify dense nano-patterning by eliminating the development stage and its associated problems. In this work, we have studied in detail the developer-free processing of popular PMMA resist. With the aid of AFM, we have observed that the thickness of PMMA exposed by electrons (Raith 150) can be reduced significantly (Fig. 1(a)) without using developer. Collected data show that the amount of thickness reduction is dependent on dose, energy and film thickness. To help better understand the data, we defined a charge-dependent etch rate (mm^3/C) to describe how effective the beam is in reducing the thickness. Experimental results show that the thickness reduction is proportional to dose and film thickness while inversely proportional to energy. (Fig. 2) Moreover, by heating the sample, we could increase the etch rate and obtain deeper trenches. (Fig. 1(b) & 3) Under some conditions, sample heating enabled trench clearance. It seems that heating is more effective in lower dose regimes. This bias may be due to the island formation through carbonization of PMMA at high temperatures. (Fig. 1(b)) [3] Meanwhile, by comparison, it seems that heating shifted the critical dose which distinguishes the behaviors of PMMA as positive or negative resist to a lower value. (Fig.1) However, due to high temperature (140 °C at PMMA surface) and long baking (30 minutes), the patterns were severely distorted. In order to find an optimum value that increases the etch rate without distortion, [4] we are currently experimenting with different temperatures and heating schedules. Experiments to obtain a more detailed voltage trend and thickness reduction with heating are being conducted. In parallel, we are also trying to fabricate dense high resolution structures such as periodic gratings in PMMA. So far, we are able to fabricate dense 70 nm half-pitch structures. (Fig. 4) Finally, we are also attempting a developer-less removal of resist fragments by introducing our exposed substrates to an environment of reactive gases. [5]

[1] H. Koop *et al.*, J. Vac. Sci. Technol. B **28**, 802 (2010).
[2] M. Kotera and Y. Akiba, Jpn. J. Appl. Phys. **49**, 06GE08 (2010).
[3] H. Duan et al., J. Vac. Sci. Technol. B **28**, C6C58 (2010).
[4] N. Arjmandi, L. Lagae, and G. Borghs, J. Vac. Sci. Technol. B **27**, 1915 (2009).
[5] L. Varghese, L. Zhao, and M. Qi, *Abstract # P18-8, EIPBN 2010*.

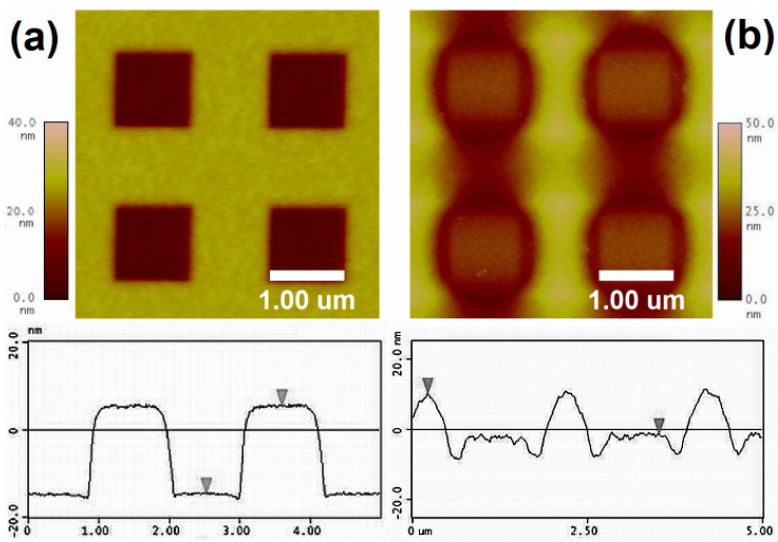

Fig. 1. AFM images of 31 nm thick PMMA exposed at 3 keV, 1000 μC/cm^2. No development. *(a)* Without heating. Height difference on average is 11.25 nm. *(b)* Heated at 140 °C for 30 minutes. Height difference on average is 15.35 nm while the carbonized island is about 5-6 nm in height.

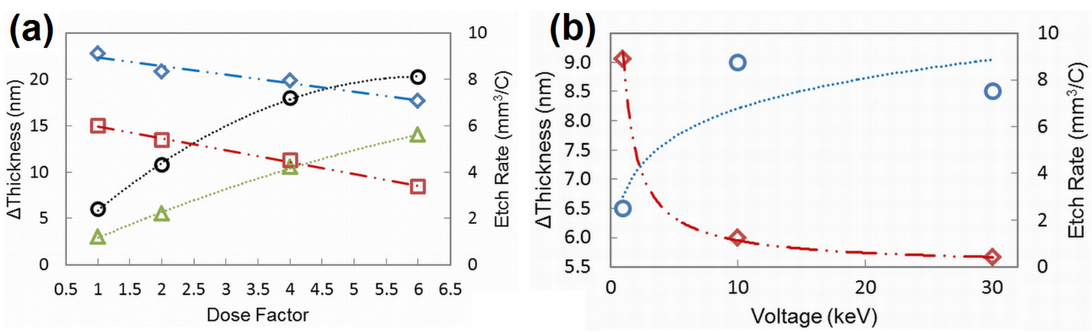

Fig. 2. (a) The change in thickness and etch rate of 63 nm thick un-heated PMMA due to 1 keV (triangles and diamonds) and 3 keV (circles and squares). Dose equivalents to 1 for 1 keV and 3 keV are 33 μC/cm^2 and 100 μC/cm^2, respectively. *(b)* The change in thickness (circles) and etch rate (diamonds) of initially 63 nm thick PMMA as a function of exposure voltage.

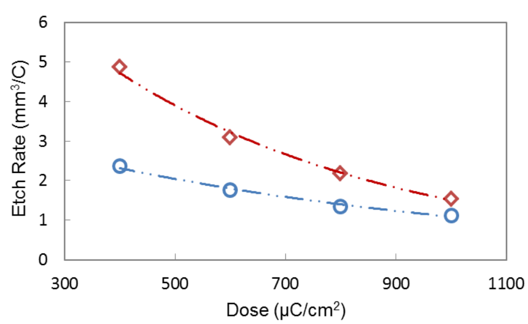

Fig. 3. Comparison of etch rate vs. dose for heated (diamonds) vs. un-heated (circles) samples, at 3 keV exposure.

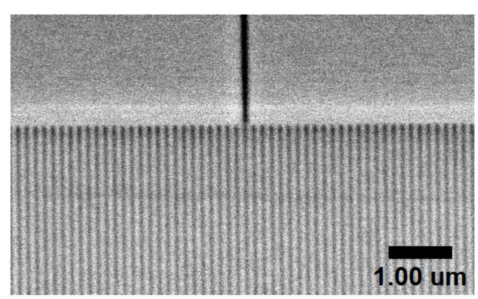

Fig. 4. SEM image of 70 nm half-pitch gratings, exposed at 3 keV, with no development.