Teflon AF Patterning using Variable Pressure Electron-Beam Lithography

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Teflon AF is a class of amorphous fluoropolymers that has unique properties such as low dielectric constant, high thermal and chemical resistance, high optical clarity, and low refractive index. As a result, Teflon AF has garnered significant interest for semiconductor, biomedical, and photonic applications, and different methods for patterning it have been demonstrated. For instance, Czolkos et al. used UV photolithography and liftoff to pattern Teflon AF.[1] Our group previously patterned Teflon AF directly by e-beam exposure with no development step,[2] and Jesorka and Shaali used it as a negative e-beam resist with a fluorinated solvent developer.[3] We also note that a variety of other fluoropolymers have been evaluated as resists for 157-nm, EUV, and e-beam lithography.

In this work, we employed variable-pressure electron-beam lithography (VP-EBL), typically used to mitigate charging, for positive tone patterning of Teflon AF. This process eliminates problems associated with lifting off spin coated films, provides complete material removal (unlike direct patterning), and minimally affects the properties of the undeveloped Teflon (unlike negative tone processes). Rectangles (25 μm × 100 μm) were exposed in spin-coated Teflon AF films (480-nm thick) using beam energies of 10, 20, and 30 keV. Exposures were conducted under either high vacuum ($\sim 5\times 10^{-5}$ Torr) or 1 Torr of water vapor in a FEI environmental scanning electron microscope (ESEM) with a Raith ELPHY Plus pattern generator. Samples were developed for 120 seconds in ethanol, and a profilometer was used to measure the pattern depth before and after development.

Plots of pattern depth vs. dose in Fig. 1(a-c) confirm that a significant relief pattern is present before development for both high-vacuum and 1 Torr (H_2O) exposures. However, water vapor does not appear to accelerate pattern formation through e-beam induced etching. For high-vacuum exposures, development revealed both positive and negative tone behavior at lower and higher doses respectively; however, the pattern failed to clear under all conditions. For exposure in water vapor, positive tone behavior was observed with full clearance. This dramatic difference may be associated with radiation induced reactions involving water, as the radiation degradation of Teflon depends strongly on the ambient environment. Higher resolution structures could also be pattered as shown in Fig. 1(d). We conclude that exposure of Teflon AF in a water vapor ambient enables positive tone patterning using a developer that is widely compatible with other materials.

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[1] I. Czolkos, B. Hakonen, O. Orwar, and A. Jesorka, Langmuir **28**, 6 (2012).
[2] V. Karre, P.D. Keathley, J. Guo, and J. T. Hastings, IEEE Trans Nanotechnol **8**, 2 (2009).
[3] A. Jesorka and M. Shaali, *U.S. Patent Application 14/017,323*.

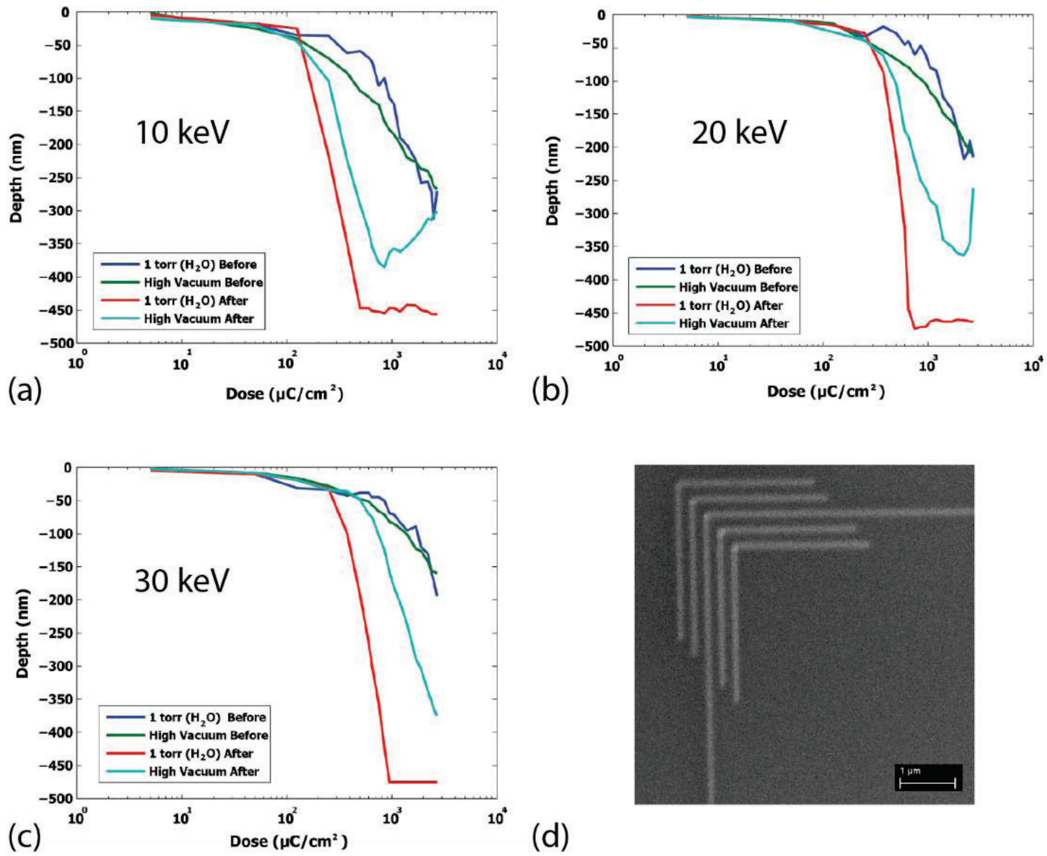

Figure 1: (a-c) Pattern depth vs. dose for e-beam exposure of Teflon AF using (a) 10 keV, (b) 20 keV, and (c) 30 keV beam energies under high-vacuum and 1 Torr water vapor conditions. Depths were measured both before and after development in ethanol as noted in the legends. High vacuum exposures exhibited both positive and negative tone behavior but failed to clear (note minima in depth near 900 and 2000 $\mu C/cm^2$ at 10 and 20 keV respectively). However, exposure under water vapor yielded positive tone behavior, and clearing doses ranged from 500 to 1000 $\mu C/cm^2$. Estimated contrasts were 1.5, 2.9, and 2.0 for 10, 20, and 30 keV respectively. (d) Nested-L pattern with 100-nm half pitch exposed at 30 keV in 1 Torr H_2O.