Water Vapor Assisted Electron Beam Etching of PMMA in a SEM

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Manufacturing micro/nanoscale devices is a challenge that has many solutions, all with their own caveats depending on the desired finished product. Electron beam lithography (EBL) is one of these preferred solutions, however, EBL is expensive and can be inconsistent when pushing the limits of resolution without proper control over the environment. Our alternative method of EBL omits the development step in the original protocol by etching the PMMA (polymethyl methacrylate) directly, without the use of wet etchants. Which can lead to wall collapse of high aspect ratio patterns.

Our method achieves carbon etching by introducing water vapor to the SEM chamber inducing a low-pressure environment (10-100 Pa) while exposing the surface of the PMMA with relatively long dwell times (>1ms). In this study, we investigated the limits of this novel carbon-etching method by adjusting the chamber pressure, electron beam parameters and the distance that the electron beam passes through the water vapor ambient. While we initially hypothesized that the etching was due to hydroxyl radical distribution directly above the surface, we are entertaining the idea that the etching mechanism is occurring due to secondary electrons.

Our patterns used to define an etching rate can be seen in Figure 1a. These images depict 1x10 µm boxes that have been etched by the aforementioned method. It is easily seen that lower beam energies (5 keV) generate a 'cleaner' etch in comparison to the 30 keV pattern. This is due to a 'skirting effect' of water radiolysis in an electron microscope. For higher acceleration voltages, the products from water radiolysis have a larger distribution area, thereby, depositing these products over a larger area. This phenomenon is observed as 'halos' around the original etched pattern. It can also be noted that at 30 keV, our resulting etches did not penetrate to the substrate. This supports both the 'hydroxyl radical etch' theory as well as the 'secondary electron etch' theory. More work needs to be done to determine the actual etching mechanism but we effectively determined an etch rate of .003 μm^3/sec and .005 μm^3/sec for 5 keV and 10 keV beam energies, respectively. We also were able to get a 30 nm width channel, suggesting that we can rival the limits of traditional EBL with our own method.

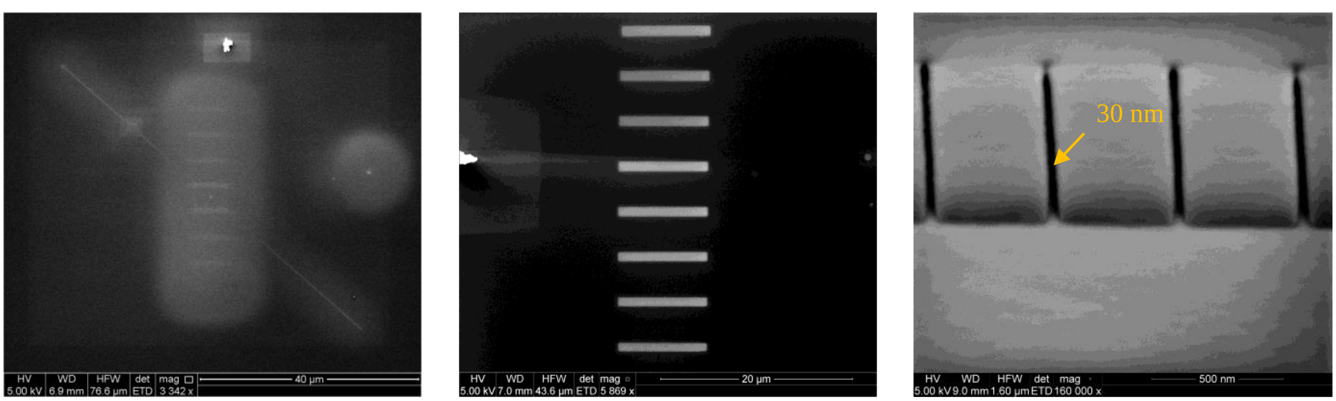

Figure 1: 8 1x10 µm boxes etched using increasing electron dose (from the bottom to the top) at a) 30 keV and b) 5 keV. We attained 30 nm resolution when introducing a pressure limiting aperture (PLA) to reduce the distance that the beam traveled through water vapor.