Enhanced contrast and high-resolution patterning of PMMA on insulating substrates under ambient gases

Deepak Kumar[1], Cooper Meyers[1], RJ L Smith[1] and J. Todd Hastings[1]

[1]*Electrical and Computer Engineering, Univ. of Kentucky, Lexington, KY 40506*

deepak.kumar@uky.edu and todd.hastings@uky.edu

Patterning on insulating substrates results in pattern distortion due to substrate charging. Variable-pressure electron-beam lithography (VP-EBL), which employs an ambient gas at sub–atmospheric pressures, is a versatile tool to reduce charging during EBL. Previous studies have shown that when patterning PMMA on insulating substrates, VP-EBL can eliminate pattern distortion and enhance resolution[1]. Additionally, the use water during VP-EBL alters the sensitivity and contrast of PMMA on conductive substrate[2] and modifies chemical processes during electron-beam irradiation of Teflon AF[3]. In this work, VP-EBL was conducted to study the effect of ambient gases on contrast and resolution of PMMA on insulating substrates. To our knowledge, these are the first studies of molecules other than water for EBL in gaseous environments.

E-beam exposures were conducted under various gases to study their effect of on contrast of PMMA on insulating substrates, Fig. 1 (a) shows the PMMA contrast curves on fused silica exposed under 1 mbar of helium, water and argon yielding contrast values of 12.5, 10.7 and 11.5, respectively. The clearing dose increases with the gases' molecular weight and proton number, consistent with the increase in scattering cross-section. Fig. 1 (b) shows our previous results where PMMA on silicon was exposed under different water vapor pressures yielding a contrast of 6.8 at 1 mbar.[2] Interestingly, once charging is mitigated by an ambient gas, the contrast of the process on fused silica is significantly higher than on silicon.

The improved contrast and sensitivity of PMMA exposed under helium motivated us to study the resolution under various gases. Fig. 2 compares high resolution "nested-L" structures under high vacuum and helium for PMMA on soda lime glass. Preliminary resolution testing indicated that despite the lower clearing dose, helium still exhibited the best resolution with 25-nm half-pitch dense lines and spaces clearly resolved on soda lime glass. To our knowledge, this is the highest resolution demonstrated to date for EBL in a gaseous environment.

Thus, VP-EBL of PMMA under helium yields higher sensitivity and contrast on insulating substrates without sacrificing resolution.

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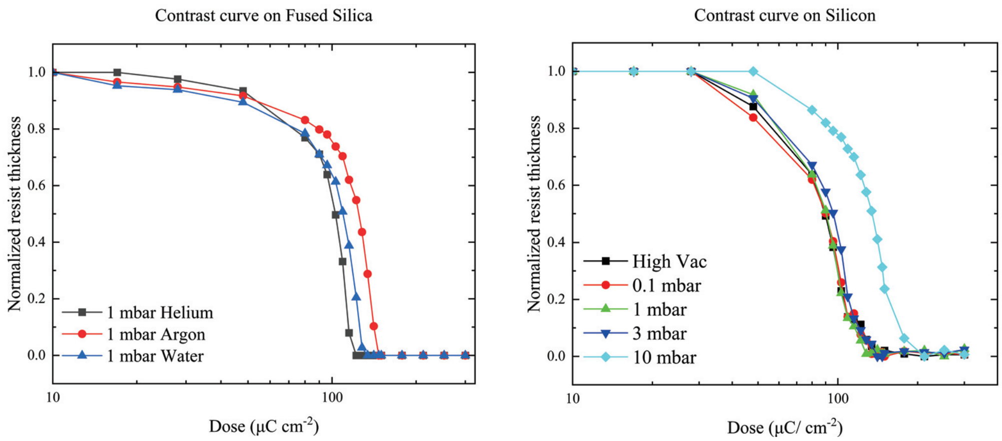
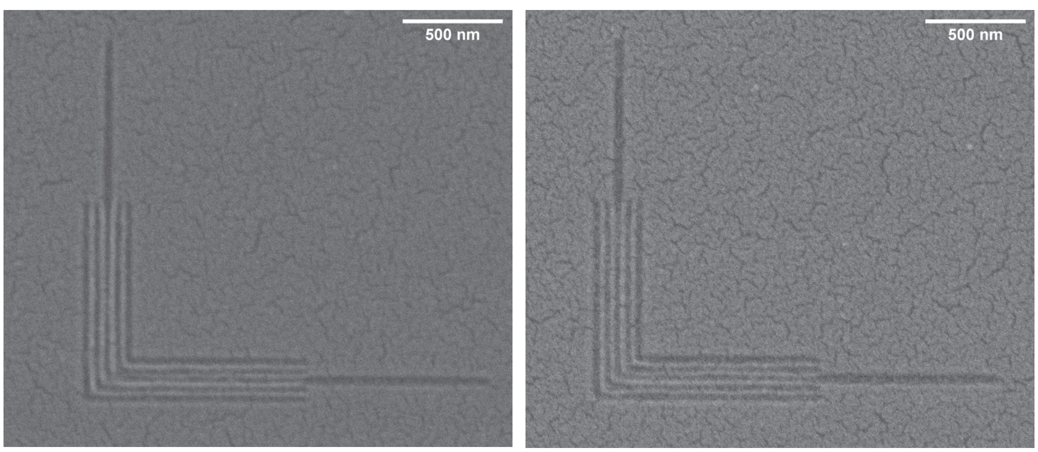


(a) (b)

Figure 1: Normalized residual resist thickness vs exposure dose for PMMA (a) on fused silica under 1 mbar of helium, water, and argon; (b) on silicon under high vacuum and water vapor pressures ranging from 0.1–10 mbar.[2]



(a) (b)

Figure 2: High resolution "nested-L" structures, 25 nm half-pitch; PMMA on soda lime glass exposed at 300 pC/cm and 30 keV beam energy under (a) high Vacuum; (b) 1 mbar helium.