The effects of molecular weight on resist evaluation parameters in poly(methylmethacrylate) developed at sub-zero temperatures

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The high resolution and high contrast capabilities of poly(methylmethacrylate) (PMMA) still make it the most widely utilized resist for nanolithography. Recent activities involving the development of PMMA at sub-zero degree temperatures have demonstrated significant improvements in contrast, line edge roughness, and consistent realization of nanometer-scale features [1-3]. However, the low temperature development of PMMA of different molecular weights has not been investigated. To this end, we present a study on the effects of molecular weight on the resist evaluation parameters in PMMA developed at various temperatures. PMMA of different number-average molecular weights ranging from 50 K to 2.2 M were electron-beam exposed and developed at temperatures ranging from 20 to – 10 °C. Electron-beam writing was performed in a JEOL JBX-6000FS nanowriter at 50 kV. Development was carried out in 1:3 MIBK/IPA and 1:7 MIBK/IPA. Normalized contrast curves measured for different molecular weight PMMA at various development temperatures in 1:3 MIBK/IPA demonstrated a trend of converging to a single curve as the development temperature decreased. Extrapolations from the contrast curves showed that contrast improved as the development temperature decreased while the sensitivity decreased. A noticeable feature is that the tails of the contrast curves became flat at low development temperatures. At the lower temperature, contrast behavior suggests that the broken polymer fragments occupy a conformal volume that is essentially the same for different molecular weights and that this conformal volume is created at the same value of electron dose and dissolves in the developer at the same rate thus leading to similar electron beam sensitivity values. Such a conformal volume [Euler's minimal surfaces] is created based on energy and surface area minimization concepts and based on constraints imposed by the rigidity of the fragments at development temperatures lower than the glass transition temperature. Also this volume is smaller than the entanglement threshold volume as explained by Cord et al. [3]. These results along with those from using gratings as resolution test will be presented. For 35 nm-thick 950 K PMMA, 35 nm pitch gratings were realized at 20 °C while less than 32 nm pitch gratings were realized at 0 and – 10 °C in 1:7 MIBK/IPA. The effects of molecular weight on the minimum realizable grating periodicities will be presented and discussed.

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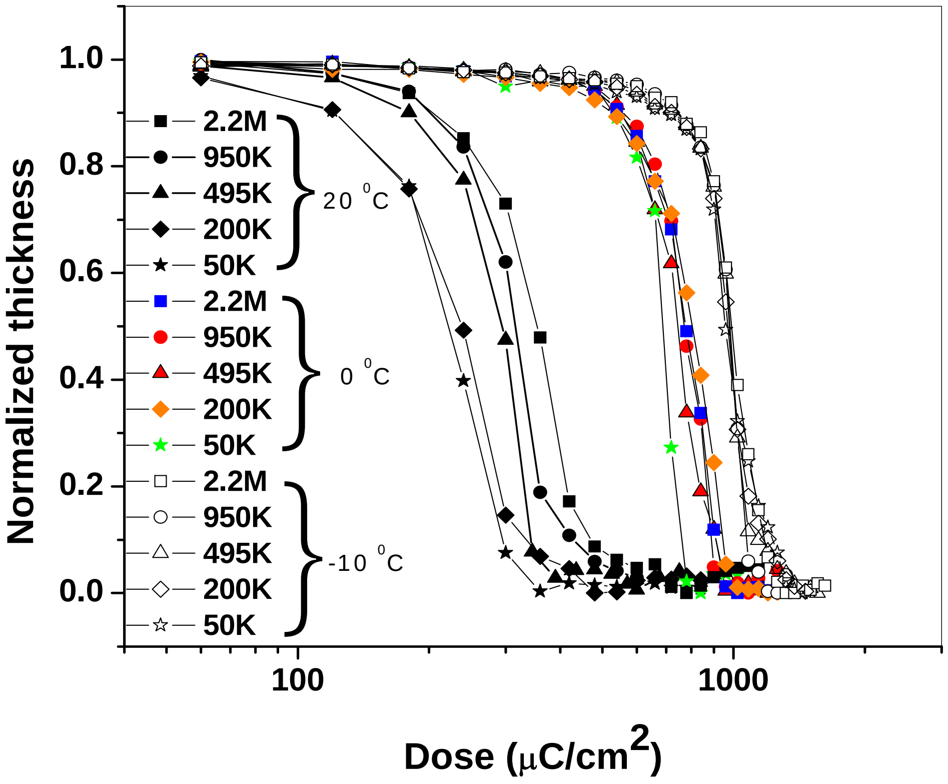
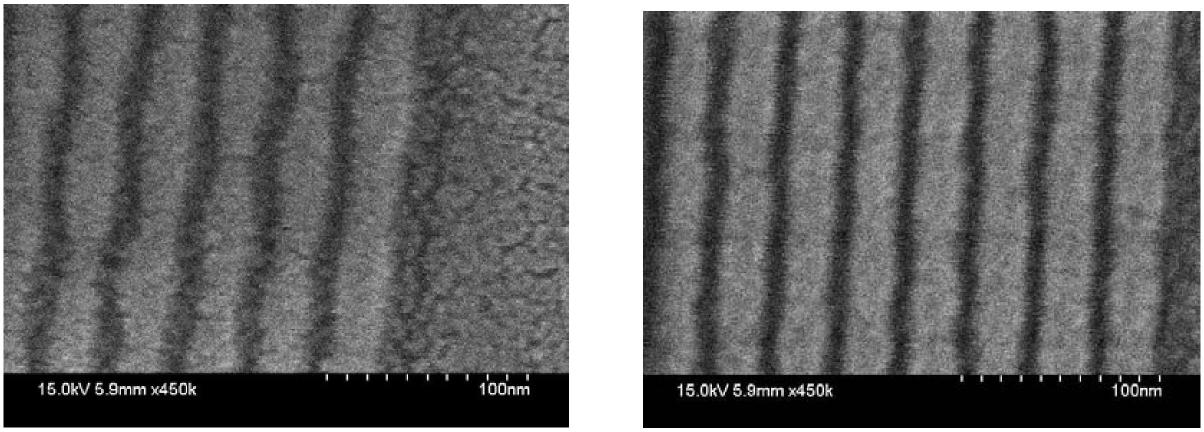


FIG. 1. Contrast curves for PMMA of different molecular weights in 1:3 MIBK/IPA at various temperatures. PMMA resist thicknesses were determined using atomic force microscopy.



(a)

(b)

FIG. 2. Gratings in 950K PMMA developed in 1:7 MIBK/IPA at (a) 20 ^{0}C, and (b) 0 ^{0}C .