Comparison Between ZEP and PMMA Resists for Nanoscale Electron Beam Lithography Experimentally and by Numeric Modeling

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A modern alternative to the positive-tone PMMA resist is the ZEP brand co-polymer resist, which offers a higher sensitivity and etch durability for electron beam lithography (EBL) [1]. However, the molecular mechanisms are not entirely understood, and the relative performance of two resists for various process conditions of nanofabrication is not readily predictable. We report a detailed comparative analysis of various aspects of performance of PMMA 950k and ZEP-520 for fabrication of dense nanoscale grating structures, both experimentally and numerically. In our experiments, we varied the grating pitch, the voltage, dose, and development temperature. Gratings with 25-40 nm half pitch in 60 nm thick layers of PMMA and ZEP were exposed with 1–30 keV electrons and developed in MIBK:IPA 1:3 for 20sec or in ZED-N50 for 30sec, followed by a quench using IPA and MIBK, respectively. Developer temperatures of 22°C and –15°C were used. The applicable dose windows were obtained by exposing arrays of gratings with an incremental dose per line to obtain under-exposure, clearance, collapse, and over-exposure conditions [2]. Table 1 and Fig. 1 present a part of the results, and an example for 70 nm pitch grating with 20 nm wide trenches is shown in Fig. 2. As compared to PMMA, the line edge roughness (LER) of ZEP is stronger. However, the sensitivity is 4-5 times higher for ZEP than for PMMA. The sensitivity and LER improvement in ZEP is more pronounced for cold development. To explain the difference in PMMA and ZEP sensitivities, we have conducted a detailed modeling of the average number of main chain scissions per monomer in periodic gratings with a 70 nm pitch in both resists (Figs. 3 and 4). For this purpose, we extended our 3D simulator for electron-induced chain scission and development of PMMA [3] to handle EBL exposures in ZEP resist. Our model of bond scission by electron impact in ZEP is similar to that for PMMA [3], with the difference that the electron impact on the benzene ring may result in a non-local dissociation of the nearest C-C bonds in the main chain of ZEP. The probability of such non-local dissociation upon inelastic interaction of electrons with benzene rings, which is not known precisely for ZEP, was estimated to be 0.67 in this study. From Fig. 3 it can be seen that the predicted scission yield per monomer in ZEP is 10 times higher than in PMMA at similar exposure doses, which is even higher than the observed 4-5 times increase in sensitivity. The difference can be explained by an approximately 2.4 times difference in nominal monomer volumes of ZEP and PMMA. Based on this reasonable agreement of the computed and measured sensitivities, we are currently parameterizing a model for ZEP development in order to execute an extensive numerical analysis of the performance of ZEP as a high sensitivity resist for EBL of nanostructures.

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Table 1. Minimum and maximum applicable exposure doses for fabricating quality 35 nm half pitch gratings in PMMA and ZEP resists, exposed with 3 keV and 10 keV voltages, and developed at room temperature and – 15ºC.

	PMMA resist (all doses in pC/cm)				**ZEP resist (all doses in pC/cm)**			
Vol-tage (keV)	22°C Development		–15°C Development		22°C Development		–15°C Development	
	D$_{min}$	**D$_{max}$**	**D$_{min}$**	**D$_{max}$**	**D$_{min}$**	**D$_{max}$**	**D$_{min}$**	**D$_{max}$**
3	110	115	400	560	27	29	79	100
10	270	403	835	2020	70	90	249	498

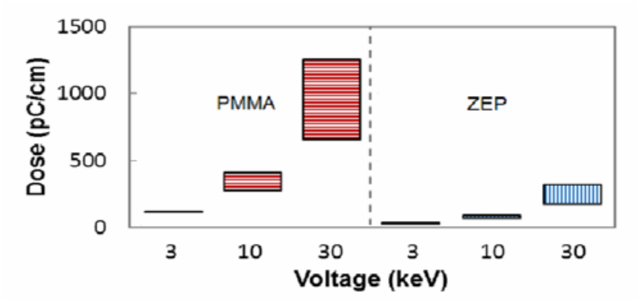

Fig.1 Comparison of sensitivity and applicable dose ranges for PMMA (left) and ZEP (right) with increasing voltage, for room temperature development, of a 70 nm pitch grating.

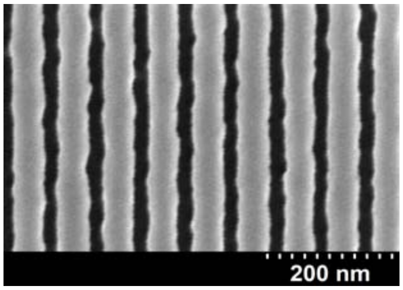

Fig. 2. 20nm wide trenches in a 70nm pitch grating patterned in ZEP by 3 keV exposure and developed at -15°C.

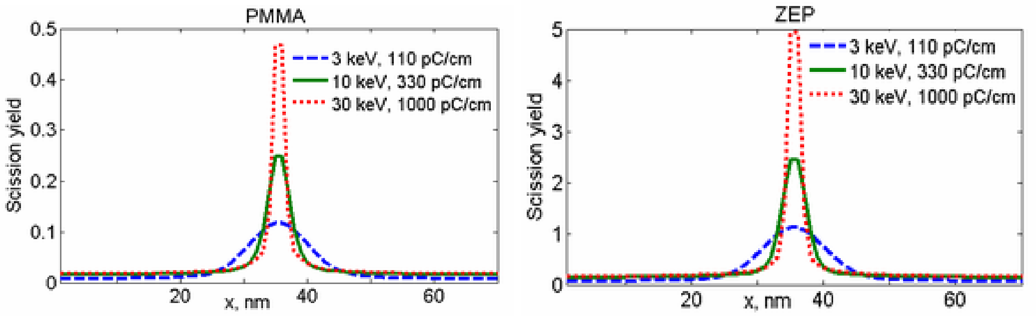

Fig. 3. Computed lateral distributions of the average number of main chain scissions per monomer in PMMA (left) and ZEP (right) for a periodic 70 nm pitch grating, exposed with 3 keV, 10 keV, and 30 keV voltages, for exposure doses from the applicable windows identified experimentally in PMMA (see Fig. 1, left panel). The plots are taken at half-depth of 55 nm thick resist layers.

Fig.4. Computed distributions of the average number of main chain scissions per monomer in ZEP, for exposure doses from the applicable windows identified experimentally in ZEP (Fig. 1, right panel). The other conditions are as in Fig. 3.