Electron-beam Exposure Dependent and Adjustable Sidewall Slopes of PMMA and ZEP520A in Comparison

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In electron-beam lithography (EBL), electron scattering denoted as proximity effect (PE) leads to a broadened energy distribution in the resist. To compensate for this, desired critical dimensions of the structures are usually obtained by carrying out a 2D PE correction. However, the inhomogeneous intensity distribution along the depth of the resist layer is frequently not considered nor any surface inhibition effects. For nanoscale structures, it is further crucial that developer induced lateral resist erosion becomes comparable to the vertical development. All these effects have a large impact on the sidewalls of the structures which usually emerge as non-vertical[1, 2]. A control of defined sidewall slopes could be utilized, e.g., in a lift-off process and ultimately for 3D grayscale patterning.

In this work, we present the contrary behavior of sidewall slopes of the positive tone resists PMMA and ZEP520A and investigate the adjustability. An array of lines and spaces (gaps) was exposed with varying feature doses (FD) and background doses (BD) applied inside the line and outside the gap, respectively. While the sidewall and the substrate surface of PMMA samples confine an obtuse angle (θ>90 °), an undercut (and thus an acute angle (θ <90 °)) can be observed for ZEP520A as shown in Fig. 1. For both resists, the slope property becomes more pronounced with increasing BD – but in a contrary way – and can thus be adjusted. Simulations with a z-dependent point spread function representing the PE show that the backscattering has a strong impact on the properties of the sidewalls. For an initial resist layer of 500 nm and a Si substrate, the absorbed dose in the resist on substrate level is larger than the one at the resist surface (Fig. 2). This leads to a larger development rate at the bottom. A surface inhibition has a similar effect. We will show that the contrary behavior of the two resists results from the different shapes of the contrast curves plotted in Fig. 3 and that the dark erosion of the resist plays an important role. We further present that our previously introduced approach to determine more precise resist development parameters for negative tone resists[3], which relates to the above mentioned exposure patterns, can in part be extended to positive tone resists. These resist models will ultimately enable a precise simulation of the resist profile especially for 3D electron-beam patterning.

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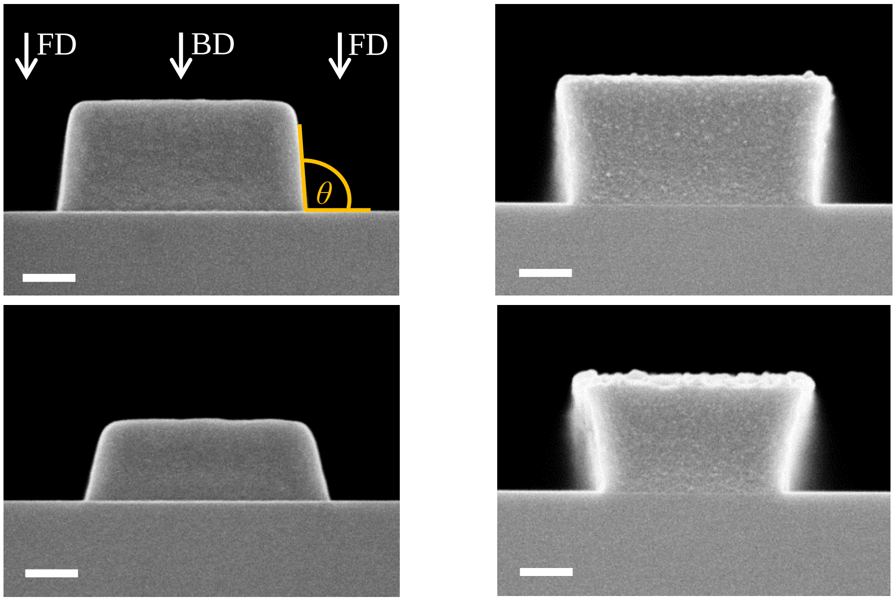
[1] X. Zhao et al., *J. Vac. Sci. Technol. B* 32 (2014) 06F508

[2] M. Sarkar et al., *Microelectron. Eng.* 130 (2014) 1-7

[3] C. Kaspar et al., submitted to *Microelectron. Eng.*



(a) (b)

Figure 1: SEM images of lines exposed with EBL in (a) PMMA and (b) ZEP520A. From top to bottom the background dose BD increases while the feature dose FD is constant. Scale bars: 200 nm.

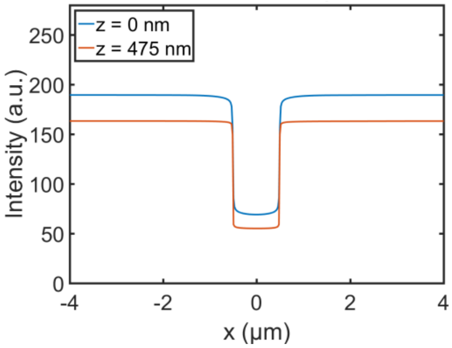


Figure 2: Simulated intensity distribution at the surface (z=475nm) and the bottom (z=0 nm) of the resist layer for a line as depicted in Fig. 1. The simulation was carried out with a 3D point spread function.

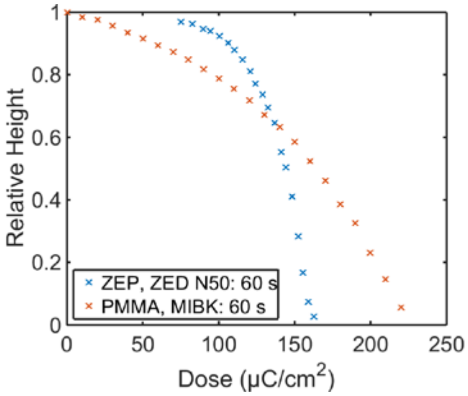


Figure 3: Contrast curves of PMMA and ZEP520A.