Contrast curve engineering by using multi-layer polystyrene electron beam resist

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In electron beam lithography (EBL), the resist properties are characterized by its sensitivity and contrast, which can be derived from its contrast curve. To a certain degree, resist sensitivity and contrast can be tailored by experimental parameters. For example, for positive resist such as PMMA, the sensitivity can be increased by using lower electron beam energy, stronger or more concentrated developer (e.g. MIBK:IPA=1:1, instead of 1:3), and higher development temperature or longer development time. The dependence of contrast on those parameters is not obvious, but for typical resist increased sensitivity is always accompanied by decreased contrast. Nonetheless, the tailoring of the contrast curve using single resist layer is limited. Here we propose that, by using polystyrene with different molecular weights (Mw), a multi-layer resist stack can be designed in order to engineer the contrast curve of the stack with great freedom.

Polystyrene is chosen because its sensitivity is proportional to its Mw [1-3], which is commercially available from ~1 kg/mol up to 2000 kg/mol. Moreover, it is not necessary to have polystyrene with many different Mw, as one can "simulate" an arbitrary Mw (actually should be Mn, number averaged molecular weight, which is more important than weight averaged molecular weight Mw) by mixing two polystyrenes having very different Mw [4]. As shown schematically in Figure 1, if the resist layers have very high contrast that is the case for low Mw range polystyrene and the sensitivity of the layers differ greatly from each other, a contrast curve with roughly a stair-case shape may be achieved, which is ideal for the fabrication of multi-level zone-plate/Fresnel lens [5].

A straightforward way to generate the resist stack is by spin-coating polystyrene layer by layer. However, so far we are not successful because it was found that the previous layers were dissolved by the solvent during the coating of a new layer. It is known that double-layer PMMA can be spin-coated, and thus we believe the same is possible for polystyrene if a suitable solvent or mixture of solvents can be identified. As a proof of concept, here we obtained double layer of polystyrene by thermally bonding one layer to the other, with the first layer spin-coated on a bare silicon wafer, and the second layer on an anti-adhesion treated wafer. The contrast curve of two layer stack, 22 kg/mol on top of 50 kg/mol, is shown in Figure 2. Here the effective 22 kg/mol is simulated by a mixture of 50 kg/mol and 4.5 kg/mol polystyrene. Due to the small difference between the two Mw, the contrast curve has a continuous and smooth slope, yet the contrast is decreased to 2.0 that is lower than single layer resist with similar Mw (γ~3.0). More layers with broader Mw range is under study and will be presented.

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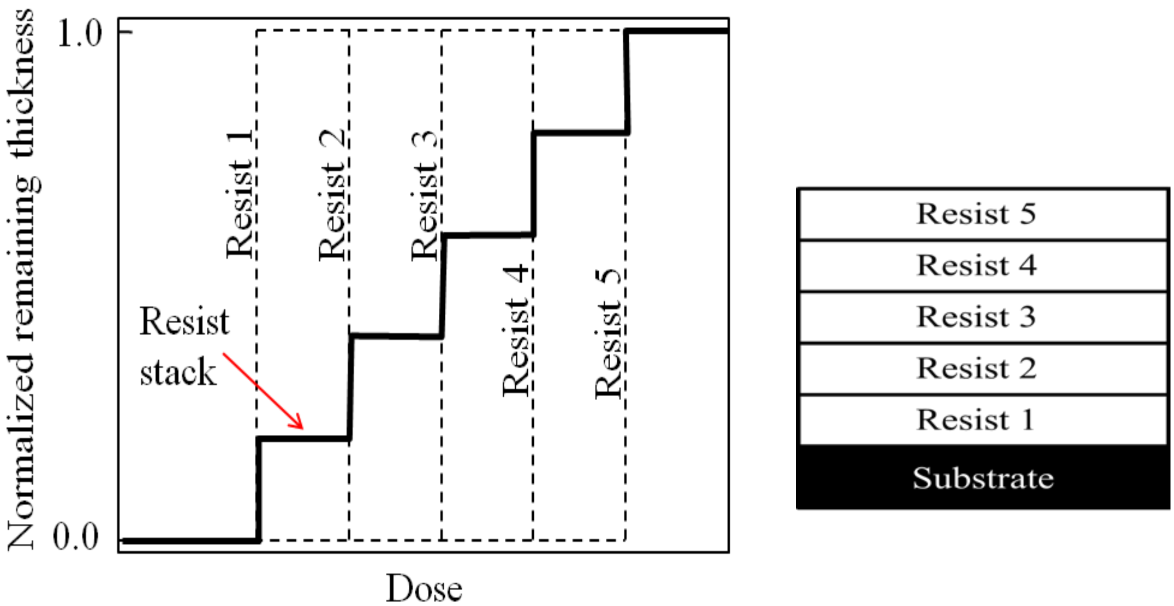

Figure 1 Schematic of contrast curves of five high contrast resists having decreasing sensitivity, as well as the contrast curve for the stack of the five resists with the most sensitive on the bottom and the least sensitive on top.

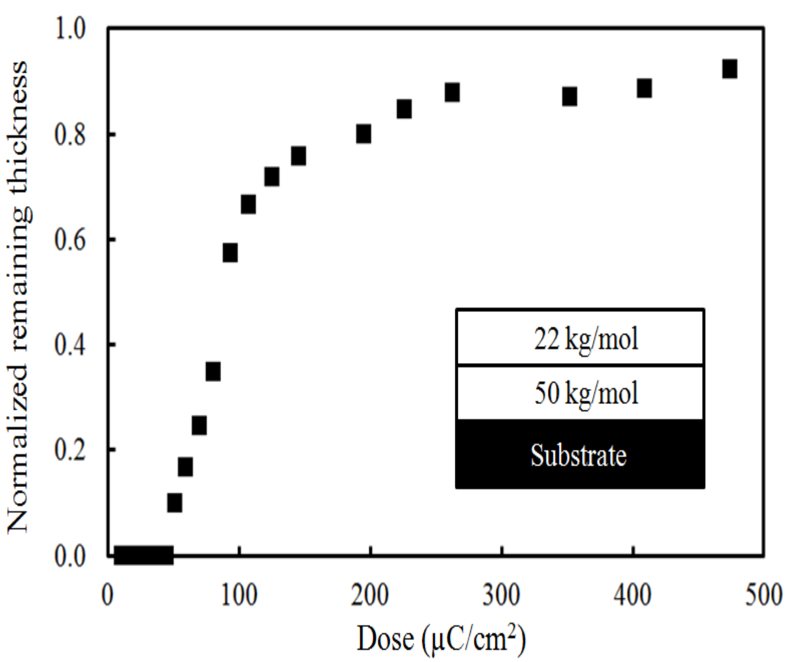

Figure 2 Contrast curve for a two-layer polystyrene resist stack, with each layer ~180 nm thick. Here 22 kg/mol is a calculated effective Mn for a mixture of 4.5 kg/mol and 50 kg/mol polystyrene. Exposed at 20 keV, and resist height measured by AFM.