Understanding of Hydrogen Silsesquioxane resist for sub-5-nm half-pitch electron-beam lithography

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Electron-beam lithography (EBL) provides one of the highest achievable patterning resolutions. As demonstrated by electron-beam induced deposition (EBID) methods, patterns as small as 1.6-nm-half-pitch can be achieved.[1] However, EBID methods are typically orders of magnitude slower, due to the high exposure doses required, and less reproducible than resist-based processes. Therefore, EBID is less practical in patterning high-resolution structures over large areas.

On the other hand, the resist-based process using EBL exposure of hydrogen silsesquioxane (HSQ) resist is a promising approach for patterning high-resolution structures due to its higher speed (compared to EBID) and high etch-resistance of HSQ. In the past, we have demonstrated the patterning of 7-nm-half-pitch structures using this process followed by a high-contrast salty-development step.[2] However, the development mechanism of HSQ was currently not well understood.

Here, we report on progress in understanding the contrast enhancement mechanism in HSQ and demonstrate 4.5-nm half-pitch structures using this resist-based process. Figure 1 shows a SEM of 4.5-nm half-pitch nested-"L" structures patterned using Raith's latest EBL tool, the Raith 150^{TWO} at 10 kV acceleration voltage in 10-nm-thick HSQ resist. Patterning at 10 kV instead of higher acceleration voltages sped-up our exposures without significant loss in resolution. To the best of our knowledge, this is the highest resolution achieved using resist-based EBL to date.

It is known that the development of HSQ is self limiting, i.e. development stops beyond a certain development time. This self-limiting nature of the development process often results in footing between closely spaced structures and limits resolution. However, as shown in Fig. 2, the addition of NaCl salt to the NaOH developer appears to allow continued resist development, which resulted in further contrast enhancement with increasing development time. This effect was not seen in development in NaOH alone without salt.

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[1] W.F. van Dorp, B. van Someren, C.W. Hagen et al., Nano Letters **5** (7), 1303 (2005).

[2] J.K.W. Yang and K.K. Berggren, Journal of Vacuum Science & Technology **25** (6), 2025 (2007).

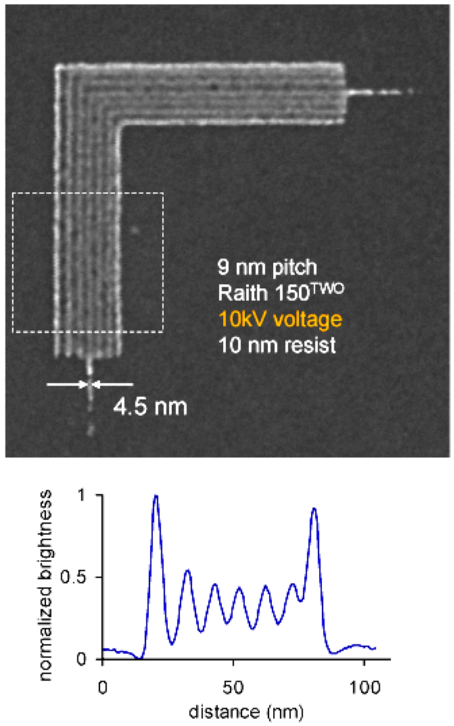

Figure 1. (Top) SEM of 4.5-nm-half-pitch nested-“L” structures patterned using a Raith 150^{TWO} EBL at 10 kV acceleration voltage in 10-nm-thick HSQ. (Bottom) The plots of normalized brightness vs distance at the bottom of both images were obtained by averaging the brightness values of the SEM image along the length of the HSQ lines within the dashed rectangles shown.

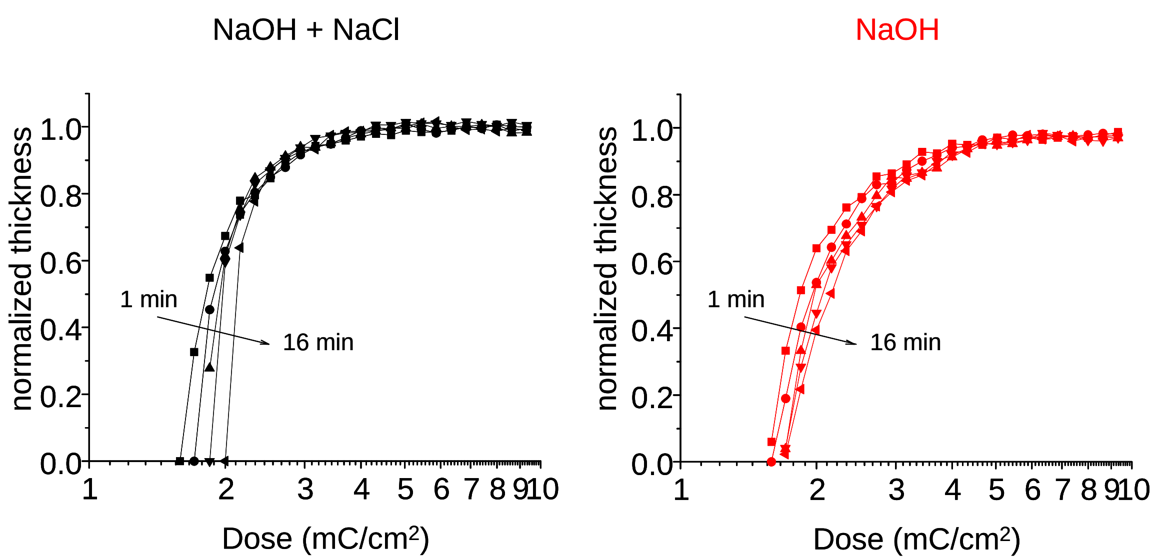

Figure 2. (Left) Contrast curves for HSQ developed in 1% wt NaOH, 4% wt NaCl solution showing improvement in contrast with increasing development time of 1, 2, 4, 8 and 16 mins. (Right) Contrast curves for HSQ developed in 1% wt NaOH without salt. Contrast curves did not change significantly beyond 2 mins of development time.