High-Contrast Salty Development of Hydrogen Silsesquioxane

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In electron-beam lithography (EBL), the highest resolution one can achieve depends primarily on (1) the electron-beam spot size and (2) the resist contrast. As the electron-beam spot size is constrained to the type of EBL system used, which is not easily modified, the only practical route to improved patterning resolution is by using resists with better contrast. Recent efforts to increase the contrast of hydrogen silsesquioxane (HSQ) have focused on developing with more concentrated bases,[1] and elevating development temperatures.[2] While these strong developers improve contrast, they also can cause material damage and are thus unsuitable in certain situations: for instance, hot or concentrated bases etch Si and hence are not compatible with Si processing.

In this work, we instead increased the contrast of HSQ by adding salt (NaCl) to a base developer. Figure 1a shows contrast curves of HSQ using different amounts of salt in an aqueous solution of 1% wt NaOH. Figure 1b shows the contrast improvement with increasing amounts of added salt for two different base concentrations. For 2% wt NaCl in 2% wt NaOH we demonstrated a contrast of 6.7, which was much higher than the value of 3.5 that we obtained from development in 25% wt TMAH without salt. We notice also that the addition of NaCl increased resist contrast without significantly increasing the onset dose. Hence, by adding salt to the developer, one can achieve higher resolution without longer electron-beam exposure times.

Finally, we studied the effect of development with salt on the fabrication of nanostructures. Figure 2a shows an SEM image of 16-nm-wide HSQ lines in a 100-nm-pitch grating. An even denser grating with 20-nm-wide lines at a 50-nm pitch is shown in Figure 2b. These gratings were formed by single-pixel electron exposure of HSQ spun to a thickness of 110 nm on Si at 30 kV acceleration voltage in a Raith 150 EBL tool, followed by development in an aqueous solution of 1% wt NaOH with 4% wt NaCl for 3 mins. Without the contrast enhancement from adding NaCl it was not possible to fabricate such dense HSQ structures.

In addition to enhancing the contrast of HSQ, these experiments could provide an improved understanding of the development mechanism of HSQ. A possible development mechanism will be discussed.

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[1] W. Henschel, Y. M. Georgiev, and H. Kurz, J. Vac. Sci. Technol. B **21**, 2018 (2003).

[2] Y. F. Chen, H. F. Yang, and Z. Cui, Microelectronic Eng. **83**, 1119 (2006).

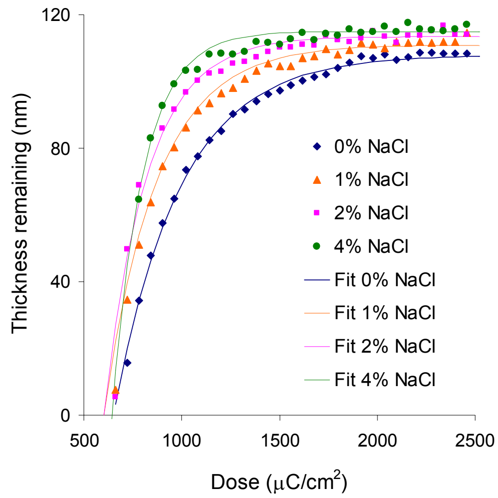

Figure 1a. Plot of remaining HSQ thickness vs. exposure dose for varying amounts of added NaCl salt to aqueous 1% wt NaOH developer. An exponential function was used to fit each data set.

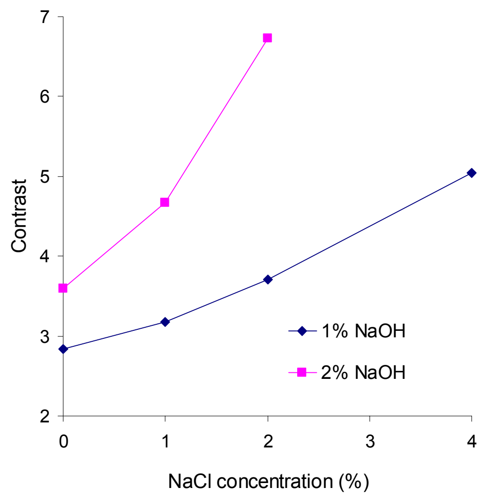

Figure 1b. Plot of resist exposure contrast vs. NaCl concentration for different developer base concentrations.

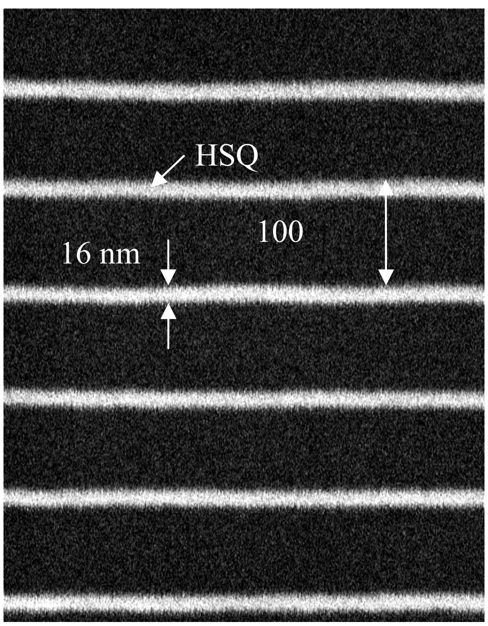

Figure 2a. SEM micrograph of 16-nm-wide HSQ lines in a 100-nm-pitch grating on Si. Lines were exposed at 30 kV and developed with 4% wt NaCl in 1% wt NaOH.

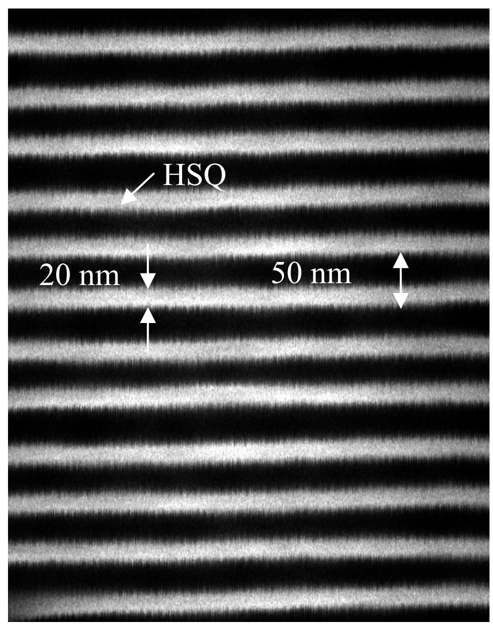

Figure 2b. SEM micrograph of 20-nm-wide HSQ lines in a 50-nm-pitch grating on Si. Lines were exposed at 30 kV and developed with 4% wt NaCl in 1% wt NaOH.