Effects of developer temperature on electron-beam–exposed hydrogen silsesquioxane resist for ultra-dense silicon nanowire fabrication

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Hydrogen silsesquioxane (HSQ) is a well known low-k dielectric material that has received much attention as a negative-tone resist. Due to its small molecular size, HSQ has been shown to act as a very high-resolution electron beam resist [1]. A preliminary report has demonstrated that higher development temperature can lead to improvement in HSQ contrast [2]. In this paper, we report a comprehensive study on the impact of temperature on HSQ contrast and resolution with special applications to the fabrication of gratings and nanowires in silicon. By increasing temperature from 20 °C to 45 °C for a .54 N tetramethyl ammonium hydroxide (TMAH) developer, the contrast of HSQ resist on a silicon substrate increased from 2.1 to 4.3 as calculated from the contrast curves in Figure 1. Using JEOL JBX-6000FS/E electron beam nanowriter with an acceleration voltage of 50 kV and a nominal spot size of ~ 5 nm at 20 pA beam current, gratings with various periodicities were written on 25 nm-thick HSQ film on silicon. Figure 2 shows plots of HSQ linewidth as a function of dose for various grating periodicities for development temperatures of 20 °C and 45 °C. The results demonstrate that the dosage window was significantly enlarged at the higher temperature. It is shown clearly that better defined lines and gratings were obtained at higher temperatures as shown in Figs. 3 (a) and (b). Web-like connections between the lines were observed in 25 nm-period gratings developed at 20 °C. Indeed, these web-like formations were also observed for gratings with periodicities below 25 nm at all the temperatures investigated. The minimum linewidth obtained in all cases was 6 nm which closely approximated the beam diameter. Comprehensive results on gratings and linewidths will be presented.

Pattern transfer in silicon using HSQ mask was also investigated using both dry and wet etching techniques. Prior to inductively-coupled-plasma reactive ion etching process, the HSQ mask was baked at 450 ^{o}C after development to ensure the complete dissociation of the Si-H bonds. Figure 4 (a) shows a silicon nanowire array with 27 nm-period fabricated on silicon-on-insulator (SOI) substrate using $Cl_2/BCl_3/Ar/O_2$ plasma. Figure 4 (b) shows 27 nm-period silicon nanowire array on SOI substrate obtained by a one-step wet etching process in TMAH. Detailed results of etched lines and gratings with periods down to 25 nm will be presented.

[1] M. J. Word, I. Adesida, and P. R. Berger, *J. Vac. Sci. Technol.* ***B*21**, L12 (2003)
[2] Y. Chen, H. Yang, and Z. Cui, *Microelectronic Engineering* **83**, 1119 (2006).

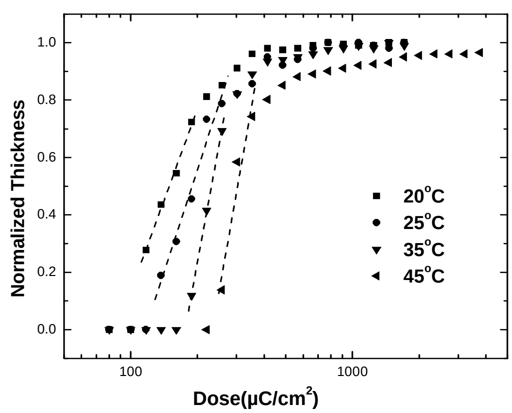


Fig. 1 Contrast curves at various developer temperatures.

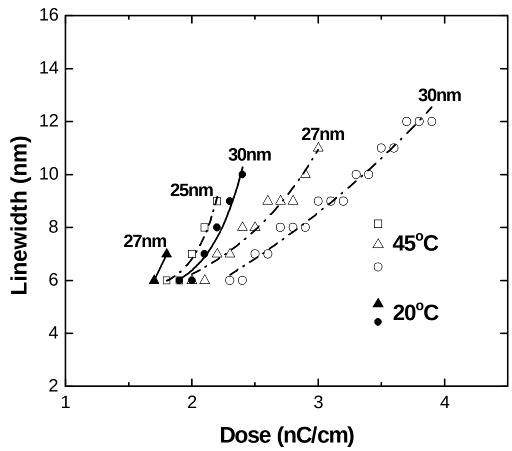
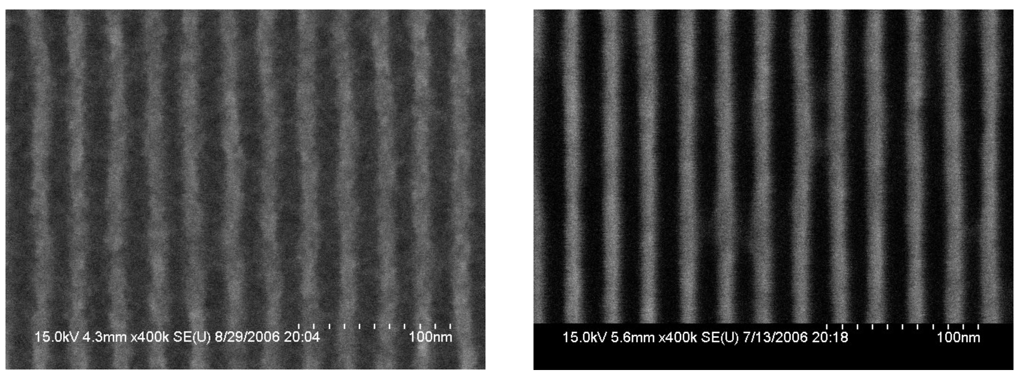


Fig. 2 Linewidth as a function of dose for various grating periodicities.



(a) **(b)**

Fig. 3 SEM images of 25 nm gratings (a) developed at 20 °C and (b) at 45 °C.

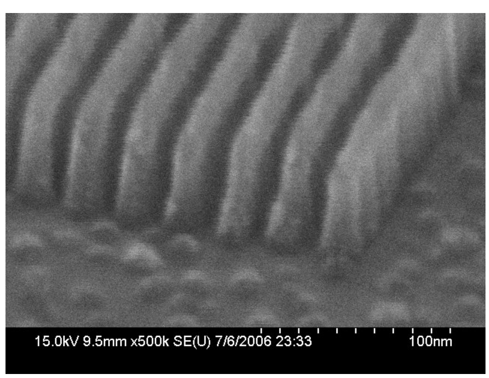


Fig. 4 (a) 27-nm-period gratings in Si obtained using ICP-RIE etching.

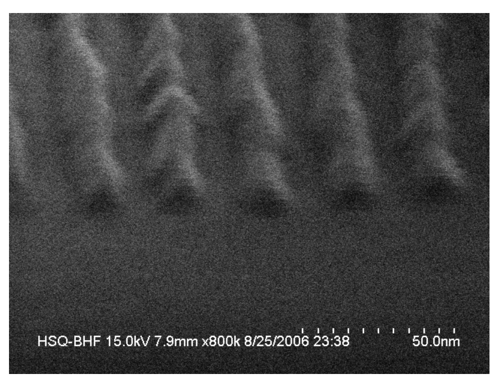


Fig. 4 (b) 27-nm-period gratings in Si obtained using wet etching.