Stability of HSQ nano-lines defined by e-beam lithography

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Hydrogen silses quioxane (HSQ), a negative tone inorganic resist for e-beam lithography (EBL) has been known for its attractive properties like high resolution capability, small molecular size, and for its physical and mechanical strength. Because of these unique features, HSQ has been used widely to fabricate nanowire devices for logic computing and biochemical sensing. Mechanical stability of nanoscale HSQ lines is an important factor to determine pattern transfer fidelity into Si or other materials. It has been observed that high aspect ratio HSQ nano-lines will collapse or break after resist development and/or after etching. Here, we present a comprehensive study of the stability of HSQ nanolines with different pitch, line width, aspect ratio (AR), exposure doses, and temperature, etc. Such understanding provides useful information, such as process window, for nanodevice fabrication using HSQ and EBL.

In this study, HSQ (Fox-12) with 60-180 nm thickness was spincoated on Si and Si on insulator (SOI) substrates. EBL was performed at 30 keV beam energy and 26 pA beam current. After the exposure, the samples were developed in a 25 wt% tetramethyl-ammonium hydroxide solution at 51 °C. As shown in Fig.1a, 12 nm HSQ lines with aspect ratio greater than 10 were obtained. Chlorine based inductive coupled plasma etching was used to transfer the HSQ nanolines into a 70 nm thick Si layer of the SOI wafer for a Si nanowire biosensor (Fig. 1b). It is observed that lines with larger pitches are less sensitive to dose variation compared to smaller pitches. For varying pitch and AR, HSQ lines appear several different stability modes, e.g. stable, clustering, wavy, and collapsed states, as shown in Fig. 2. The width and AR of the lines at the boundary of stable and clustering states are defined here as critical width and critical AR, respectively. As shown in Fig. 3a, the critical width strongly depends on the pitch and film thickness. Interestingly for pitch smaller than 75 nm, it is found that thicker films can actually enable smaller and taller stable lines. One possible reason is that the close neighboring lines help the high aspect ratio thin lines survive the capillary forces during the hot development process. Fig. 3b quantifies the effect of grating pitch on the critical AR. Such behavior closely relates to local distribution of the capillary forces between the lines and internal stress in the lines [1][2]. In the paper, we will further discuss theoretical modeling to understand these stability issues, which are important for making stable HSQ nanolines.

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[2] M.P.Stoykovich, K.Yoshimoto, P.F. Nealy, Appl. Phys. A 90, 227 (2008)

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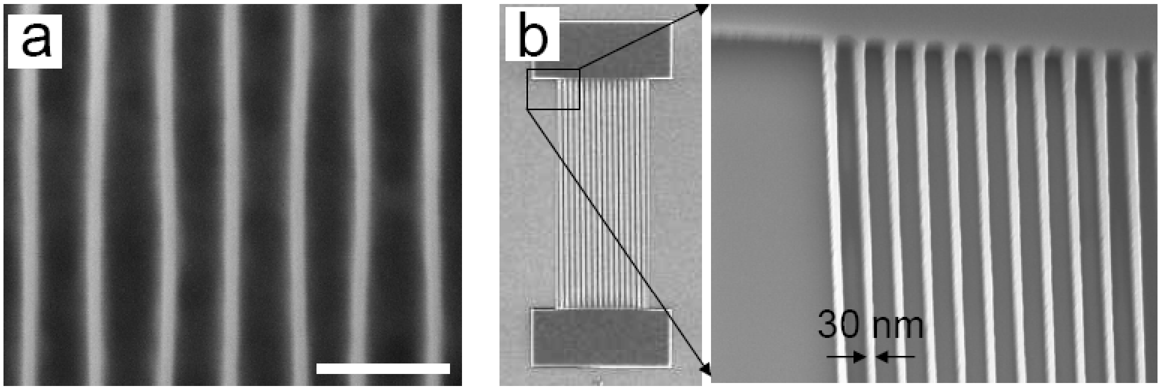

Fig 1: a) SEM of 12 nm HSQ lines with aspect ratio of 12 and 50 nm pitch; 2) a Si nanowire transistor with backgate configuration on an SOI substrate.

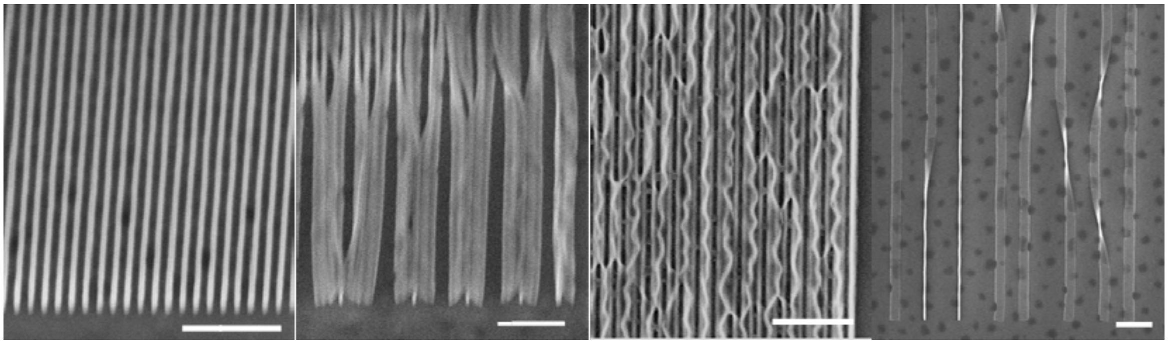

Fig. 2: SEM 45 deg. side view of HSQ nanolines in four typical stability states: a) stable, b) clustering, c) wavy, and d) completely collapsed, forming HSQ ribbons on the surface. Scale bar in the images is 500 nm.

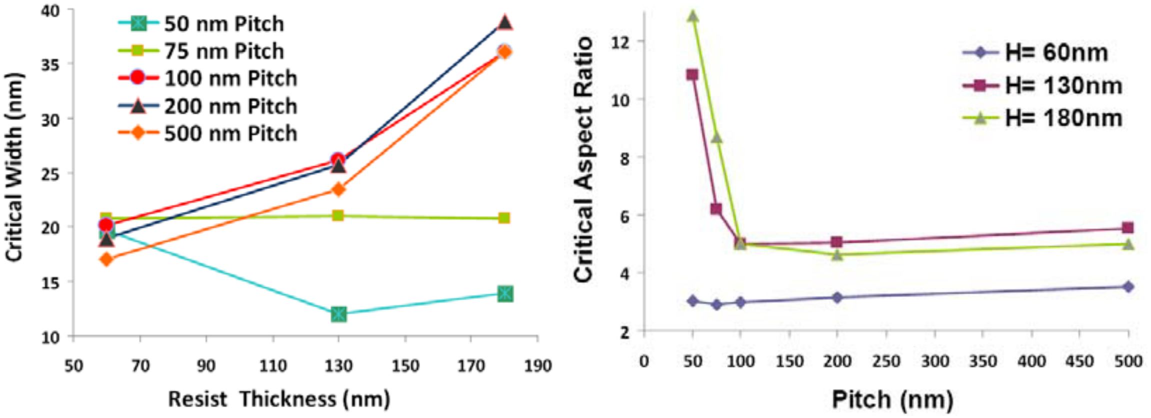

Fig. 3: a) Critical width of HSQ lines as a function of resist thickness for varying pitch of 50-500 nm; b) Critical aspect ratio as a function of pitch for resist thicknesses of 60-180 nm.