Influence of the development process on ultimate resolution Electron Beam Lithography using ultra-thin HSQ resist layers

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When writing sub-10 nm structures using electron beam lithography, the ultimate resolution is strongly influenced by the following three factors: the lithography machine, the resist material and the development process. In the past decade, Hydrogen Silsesquioxane (HSQ) has become known as a high resolution negative-tone inorganic electron beam resist. Minimum line edge roughness, high etch selectivity and the small molecular size make HSQ a very good candidate for high resolution electron beam lithography [1,2]. All the experiments on HSQ reported in literature were done with 50-400 nm resist layers and by using tetra methyl ammonium hydroxide (TMAH) based developer. Also, most of the structures written in HSQ were isolated structures [3] and it is still a challenge to achieve closely spaced patterns with high resolution. By using ultra-thin resist layers and an optimisation of the development process, we proved that a very high resolution can be achieved when using HSQ (Flowable Oxide, FOx-12 from Dow Corning) in electron beam exposure experiments. The best results are shown in the figures below. The test patterns consisted of dots and lines with different widths that were written with different pitches and various exposure doses. The structures were all written with a fixed beam step size (BSS) (the distance between two adjacent exposures) of 1.25 nm. Depending on the designed linewidth, line exposure is performed by linearly scanning the beam once (1-exel line) or by scanning n adjacent lines (n-exel line). Dots were realized by writing a design with the smallest possible pattern: squares measuring 1.25 nm x 1.25 nm (1x1 BSS), each representing a single, isolated exposure. Using 100 keV electron beam lithography, we achieved 6 nm dots (see Figure 1) with a pitch of 125 nm in the x direction and 100 nm in the y direction in a 20 nm HSQ layer on silicon substrates. The sample was developed by manual immersion at 20°C in TMAH developer (MF-322 from Rohm and Haas) for 60 s. Other experiments were performed in which a sodium hydroxide based developer (Microposit 351) was used. We observed that with this stronger developer (with a normality five times higher than MF-322), the sensitivity of the resist decreases. Also, for such thin resist layers we suspect that the development time plays an important role. For long development times, the smallest designed structures might be washed away. In order to overcome these problems, the developer was diluted with de-mineralised water in 1:5 ratio and the development time was decreased from 60 s to 30 s. The result of the first experiments in a 10 nm thick HSQ layer using a development time of 30 s is shown in Figures 2 and 3. From these figures it is seen that the linewidth is 5-6 nm with a pitch of 20 nm. It should be noted that this is the smallest pitch (20 nm) achieved to date using HSQ resist. Currently we are trying to decrease the pitch below 20 nm.

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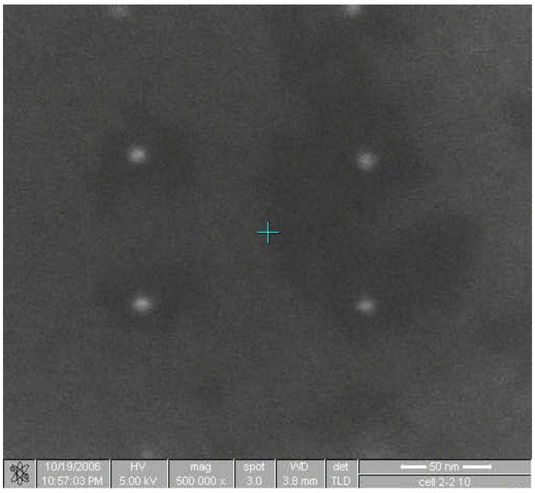
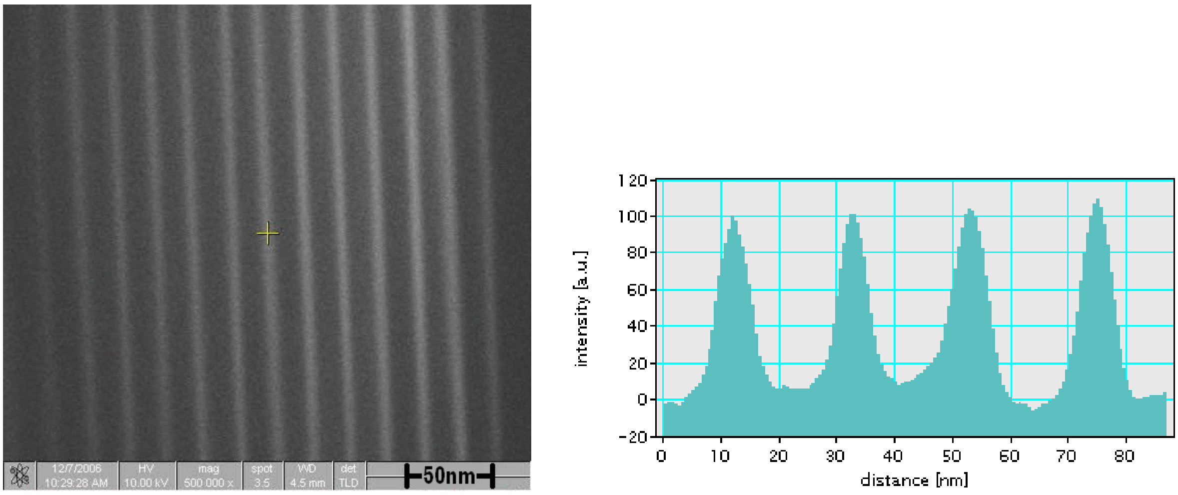
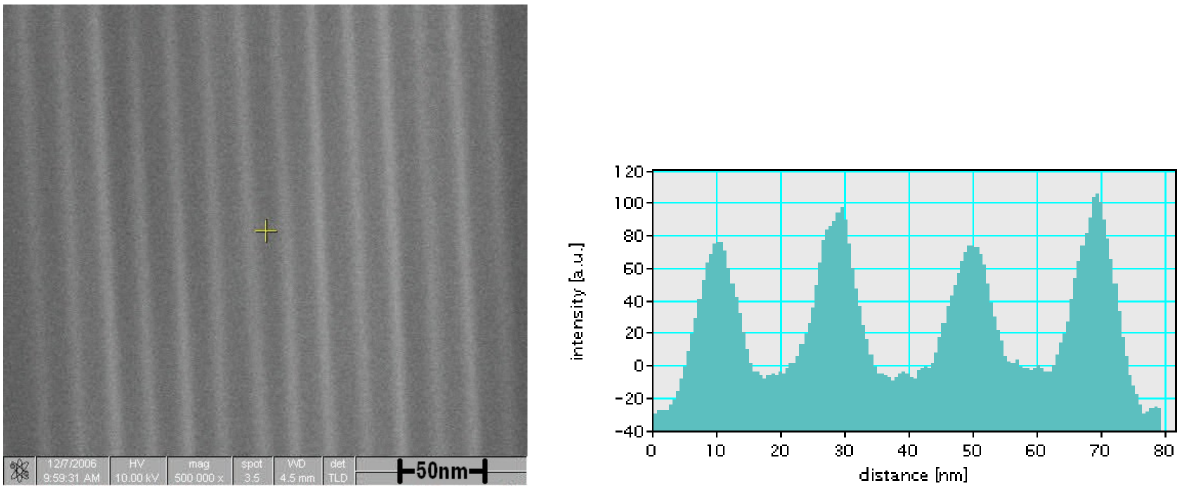


<u>Figure 1</u> 6 nm dots (with 125 nm pitch in the x direction and 100 nm pitch in the y direction) written in a 20 nm HSQ layer; the area dose is 586731 μC/cm^2



<u>Figure 2</u> 1-exel single pass exposure (BSS=1.25 nm) with an area dose of 70812 μC/cm^2 in a 10 nm HSQ layer; the measured linewidth is 5.2 nm and the pitch is 20 nm (SEM micrograph (left) and line profile integrated over 100 nm (right))



<u>Figure 3</u> 4-exel single pass exposure (BSS=1.25 nm) with an area dose of 19054 μC/cm^2 in a 10 nm HSQ layer; the measured linewidth is 5.7 nm and the pitch is 20 nm (SEM micrograph (left) and line profile integrated over 100 nm (right))