Sub-5 keV Scanning-Electron-Beam Lithography

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Low-voltage (sub-5 keV) electron-beam lithography has potential advantages over high-voltage lithography, including: (1) lower sample damage; (2) reduced resist dose [1]; (3) lower-cost and smaller-footprint system [2]; and (4) absence of long-range proximity effects [3,4]. However, due to the reduced electron range, ultra-thin resist films are required, necessitating bi-layer or tri-layer processing. The finest pitch reported to date was 60 nm [4]. Here we report higher resolution structures obtained by low-voltage scanning-electron-beam lithography on hydrogen silsesquioxane (HSQ).

Figure 1 shows the point-spread function (PSF) determined at 1.5, 2, and 3 kV acceleration voltages on 13-nm-thick HSQ. The PSF data for the lowest voltages (1.5 and 2 kV) are fit with a triple-Gaussian model whereas the 3 kV results are fit with a double Gaussian model.

To explore the resolution limits of low-voltage electron-beam lithography we wrote test patterns at 2 keV on 13-nm-thick HSQ, and developed them with salty development [5]. Figure 2 shows nested-L patterns in which we observed a resolution limit of 20 nm pitch (10 nm linewidth). Figure 3 shows dot-array test patterns over a 4 µm × 4 µm area, with pitches of 30 nm and 26 nm, corresponding to an area density of 1 Teradot/in^2, a figure of special interest for high-density information storage. The minimum pitch observed was 24 nm, but the quality was poorer. As expected at this low voltage, proximity effect was minimal, as indicated by the fact that the dots at the edges of the arrays showed only minimal deviation in diameter.

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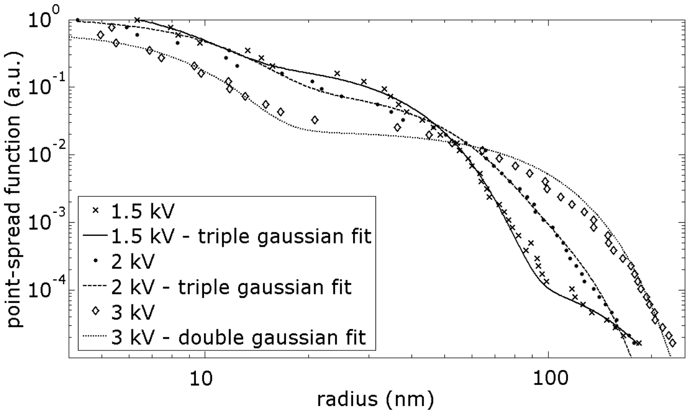

Figure 1. Point-spread function on 13-nm-thick HSQ at 1.5 kV, 2 kV and 3 kV acceleration voltages. For 1.5 kV and 2 kV, we used a triple-Gaussian fitting function and for 3 kV a double-Gaussian fitting function. The point-spread function got broader as the acceleration voltage was increased.

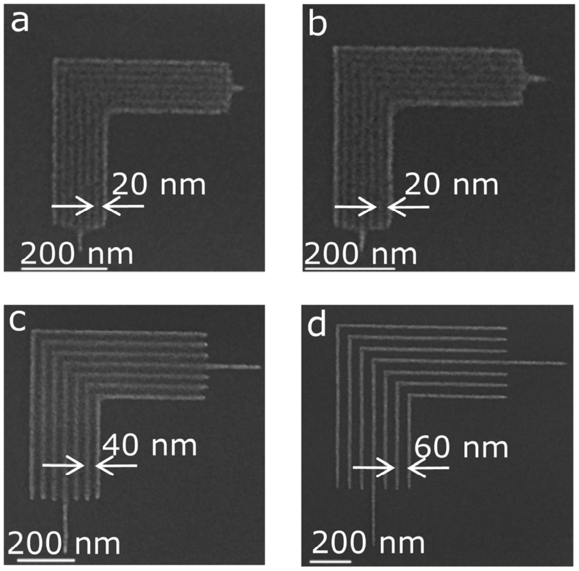

Figure 2. Scanning-electron micrographs of nested L's on 13-nm-thick HSQ exposed at 2 kV. a) and b) are 20 nm pitch with a dose of 0.5 nC/cm (~ 310 electrons/nm) and 0.6 nC/cm (~ 370 electrons/nm), respectively. c) is 40 nm pitch with a dose of 0.9 nC/cm (~ 560 electrons/nm). d) is 60 nm pitch and shows a clearly developed structure with a dose of 1 nC/cm (~ 620 electrons/nm).

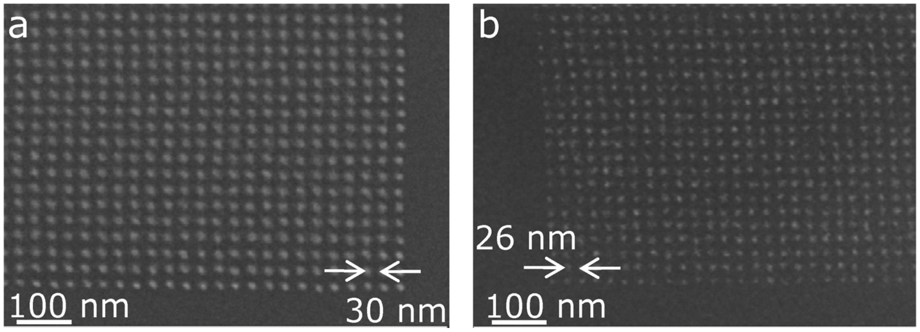

Figure 3. Scanning-electron micrographs of the edge of 4 µm × 4 µm area dot array on 13-nm-thick HSQ exposed at 2 kV. a) 30 nm pitch with a dose of 2 fC/dot (~ 12,400 electrons/dot) and b) 26 nm pitch with a dose of 1.5 fC/dot (~ 9,300 electrons/dot). The very small deviation in dot diameter between the center of the array and the edge validates the presumption of minimal proximity effect.