Point spread function analysis of dense high resolution nanodots in hydrogen silsesquioxane

D. K. Brown, C. Chapin, E. Kim
Georgia Institute of Technology, Atlanta, 30332, USA
devin.brown@mirc.gatech.edu

G. Lopez, N. Unal, U. Hofmann
GenISys GmbH, D-82024 Taufkirchen, Germany

In previous work we studied the patterning of 20 nm dots at pitches of 40, 50, 60, and 80 nm, in a 100 um square array in 15 nm thick hydrogen silsesquioxane (HSQ) resist on silicon substrates.[1] This previous work showed that a process space was not possible to simultaneously print dots at the center and corner of the array unless proximity effect correction was applied. Furthermore, our work demonstrated that the Monte Carlo simulators used did not anticipate the required dose. As shown in Figure 1, the predicted required dose adjustment was 1.2 to 1.5 times the base dose at center and corner for the various pitches. However, the observed required proximity correction was much higher at 2 – 5 times the base dose and a process blur parameter was required for accurate correction.

We now present new data to seek to explain these observations, by examining single point exposures at beam currents of 100 pA, 600 pA, and 2 nA to determine an empirical point spread function. HSQ is spun coat to a thickness of 15 nm on silicon substrates with a post apply bake of 80 C on a hot plate for 4 minutes. Samples are exposed on a JEOL JBX-9300FS electron beam lithography system at 100 kV at the stated beam currents using isolated single point exposures for a range of doses from 2E5 to 3E7 uC/cm^2. The samples are developed by immersing in an aqueous solution of 25% TMAH for 30 sec at 21 C and rinsed thoroughly in DI water for 90 sec. Samples are then evaluated without further treatment by using a Zeiss Ultra 60 thermal field emission SEM.

A few demonstrative SEM results for the single point exposures are shown in Figure 2 at 100 pA, 600 pA, and 2 nA beam currents. Diameter measurements from SEM's such as these are plotted in Figure 3 for the entire range of exposure doses. The minimum diameter dot for any beam current is 9 nm; below that dots collapse or are missing due to lack of adhesion. Furthermore, although beam diameter reduces with beam current, it is not responsible for the higher than expected correction values. From this data, a comparison can be made to Monte Carlo generated point spread functions[2]. In Figure 4, dot radius is plotted on the x axis, and the normalized reciprocal of the exposure dose is plotted on the y axis. This is compared directly to the normalized deposited energy as calculated by two Monte Carlo programs Sceleton, and Penelope convolved with beam diameter. As can be seen from the slope of the single point exposures, the energy spread is much broader than predicted. The Penelope model accounts for secondary electron exposure, while the Sceleton model used did not. The empirical data suggests that either a more accurate electron simulation model is needed or other process effects need to be considered.

---

[1] D.K. Brown, C. Chapin, E. Kim, G. Lopez, N. Unal, U. Hoffman, 37th International Conference on Micro and Nano Engineering, 2011 (presented at conference, submitted for publication)
[2] H. Duan, V. Manfrinato, J. Yang, D. Winston, B. Cord, K. Berggren, J. Vac. Sci. Technol. B **28**, 6, (2010)

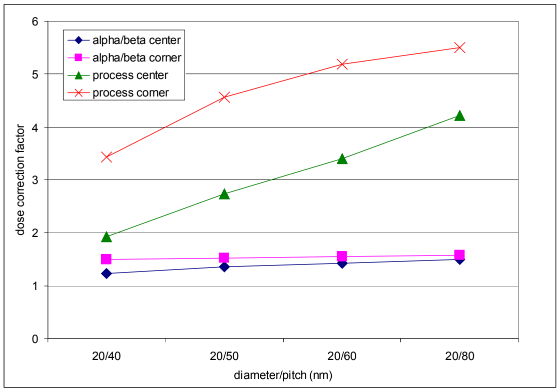

Figure 1: Comparison of predicted ("alpha/beta") proximity correction values to actual ("process") for 20 nm dots at 40, 50, 60, and 80 nm pitches.

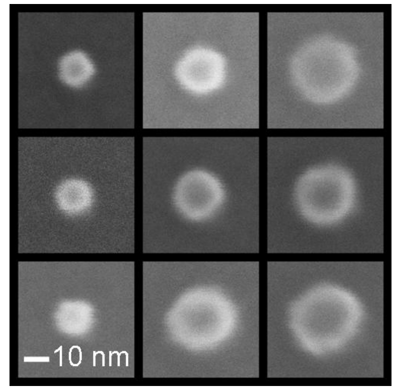

Figure 2: SEM images of single point exposures in HSQ resist. Top, middle, and bottom rows are 100 pA, 600 pA, and 2 nA beam currents, and left middle and right columns are doses 1.3E6, 4.3E6, and 1.8E7 uC/cm^2 respectively.

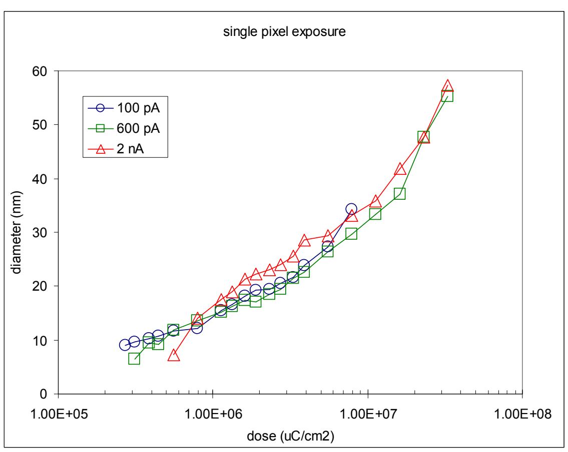

Figure 3: Diameter of single point exposures in HSQ at 100 pA, 600 pA, 2 nA beam current versus exposure dose. Measurements taken from SEM images as in Figure 2.

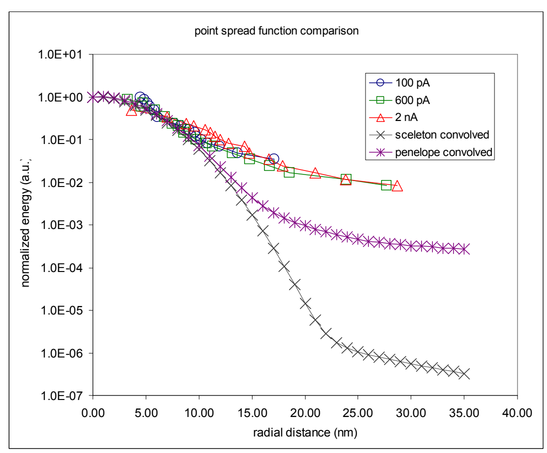

Figure 4: Single point exposure actual data versus Monte Carlo simulation data. Simulation y axis is normalized energy convolved with beam diameter. Single point exposure y axis data is the reciprocal of the exposure dose normalized.