Scanning-neon-ion-beam lithography

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A commercially-available scanning-helium-ion microscope of high source brightness[1] has been modified for operation with neon gas. This neon system has been evaluated for nano-machining[2], but not for resist-based lithography as has been done with helium systems[3,4]. The neon system may enable a lithography process with higher resolution than any scanning-particle system to date. This possibility is due to the combination of the high-brightness source and the expected reduction of secondary-electron (SE) range relative to electrons or helium ions. In addition, the expected increase in SE yield relative to electrons or helium ions may lead to a lithography process with high sensitivity. This high sensitivity could allow critical doses below substrate-damage thresholds.

We exposed test structures in 18-nm-thick hydrogen silsesquioxane (HSQ) resist on bulk silicon to measure both (1) the critical dose-to-print and (2) the spatial distribution of deposited energy, or point-spread function (PSF). The neon system and its internal pattern generator were used with a 20 kV beam, 0.3 pA current and 0.3 µs minimum dwell time per step (1-nm step size) for the exposures. We found the critical dose to be 130 ions/dot for isolated single-pixel dots, 26 ions/nm for single-pixel lines, and 2 ions/nm^2 for area structures. Figure 1(a-b) shows critical-dose structures. Figure 1(c) shows doughnut structures, which may be used to determine the PSF (assuming radial symmetry)[5]. Figure 1(d) shows the reciprocal of dot dose versus dot radius, i.e. a non-parametric and non-normalized plot of the PSF. While we were not yet able to achieve sub-10-nm feature dimensions, this result may not reflect a fundamental limitation of the neon system. Further investigations will clarify the limits of this system.

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1 B. W. Ward, J. A. Notte and N. P. Economou, J. Vac. Sci. Technol. B **24**, 2871-4 (2006).
2 S. Tan, R. Livengood, D. Shima, J. Notte and S. McVey, J. Vac. Sci. Technol. B **28** C6F15-C6F21 (2010).
3 D. Winston, B. M. Cord, B. Ming, D. C. Bell, W. F. DiNatale, L. A. Stern, A. E. Vladar, M. T. Postek, M. K. Mondol, J. K. W. Yang and K. K. Berggren, J. Vac. Sci. Technol. B **27**, 2702-2706 (2009).
4 V. Sidorkin, E. van Veldhoven, E. van der Drift, P. Alkemade, H. Salemink and D. Maas, J. Vac. Sci. Technol. B, **27**, L18-L20 (2009).
5 L. Stevens, R. Jonckheere, E. Froyen, S. Decoutere and D. Lanneer, Microelectronic Engineering **5**, 141-50 (1986).

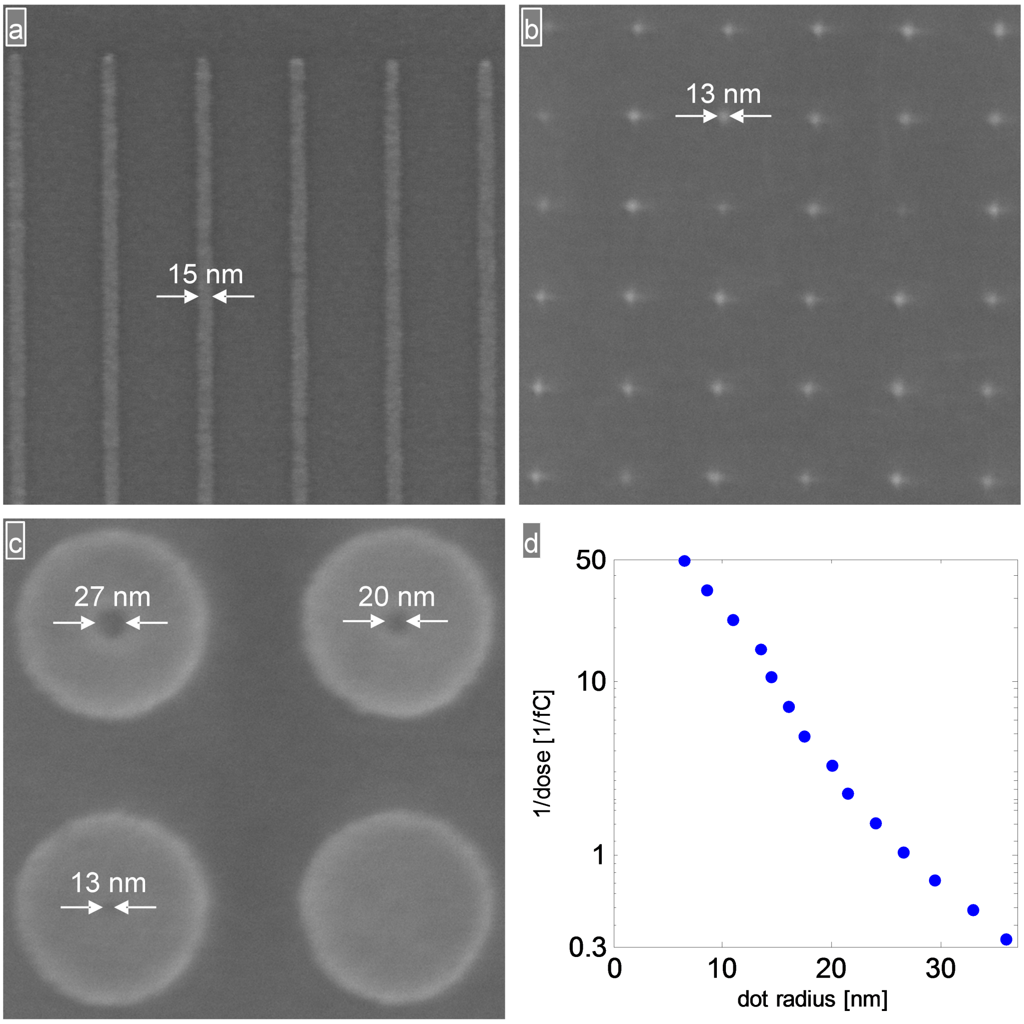

Figure 1: (a-c) Scanning electron micrographs (SEMs) of developed patterns in 18-nm-thick hydrogen silsesquioxane (HSQ) resist on silicon, exposed by scanning a 20 kV focused neon-ion beam. *(a)* Single-pixel lines using 26 ions/nm at a pitch of 100 nm. 100 nm is greater than the expected lateral scattering range of neon at 20 kV. *(b)* Single-pixel dots using 130 ions/dot at a pitch of 100 nm. Fluctuation of dot dose is observable. *(c)* Doughnut structures using 2 ions/nm^2 and with specified inner diameters of 40 nm (top left), 30 nm (top right), 20 nm (bottom left), and 10 nm (bottom right). *(d)* The reciprocal of dot dose versus dot radius, estimated from SEMs of 6×6 dot arrays similar to *(b)*.