Scanning Helium Ion Beam Lithography

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Scanning electron beam lithography (SEBL) has been the leading technology in low-volume, high-resolution nanofabrication for over three decades. Unfortunately inherent limitations of the technology, such as electron beam scattering, have made improvement in SEBL resolution past the 10 nm limit problematic. Recent advances in resist contrast enhancement have mitigated this somewhat, but reliable patterning of dense, sub-10-nm features remains nontrivial on even the most high-end SEBL tools.

One of the key advantages of patterning using a helium ion, rather than an electron beam, is the substantial reduction in beam scattering as it travels through the resist. High-energy electrons undergo significant scattering due to their low mass, both as the primary beam travels through the resist (forward scattering) and as stray electrons scatter out of the substrate (backscattering). Helium ions, with a comparatively higher mass, are affected much less by atomic collisions when traveling through a material and exhibit only minimal scattering in normal resist materials. Figure 1 shows the results of a Monte Carlo simulation of a 50 KeV helium ion beam traveling through a PMMA layer; at a depth of 50 nm (a typical resist thickness for many applications) the point-spread function of the beam is only 2 nm wide, narrower than even 100 KeV electron beams under similar conditions. This reduction in beam scattering should help reduce the proximity effect that makes patterning dense, high-resolution features difficult with SEBL.[1]

Experimentation with helium ion beam lithography has recently been made possible by the development of a scanning helium ion beam microscope by Alis Corporation.[2] Their commercial-grade microscope has achieved resolutions on the order of 1 nm, making it a promising candidate as a lithography tool. Basic experimentation with their lower-resolution "proof-of-concept" system has demonstrated that patterning and successful transfer of features is possible using standard SEBL processes. Figure 2 shows a field of Ti-Au dots patterned with the system using a film of PMMA on silicon and standard metallization and liftoff.

While issues such as vibration, pattern generation, and process control remain to be addressed, further experimentation with helium ion beam lithography may lead to a tool that meets or exceeds the performance of modern SEBL systems.

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[1] E.H. Anderson, D.L. Olynick, W. Chao, B. Harteneck, E. Veklerov, J. Vac. Sci. Technol. B **19**, 2504-7 (2002).
[2] B.W. Ward, J.A. Notte, N.P. Economou, J. Vac. Sci. Technol. B **24**, 2871 (2006).

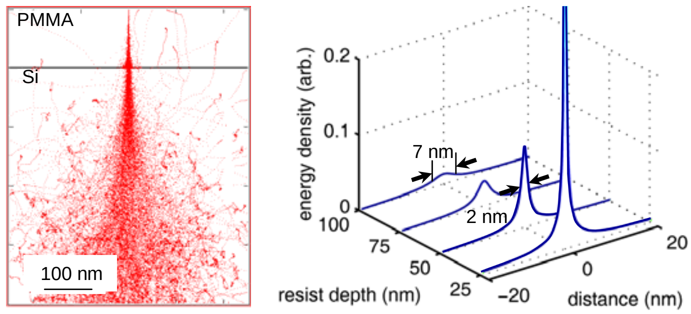

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Figure 1: Simulation of He ion scattering in resist. (a) Result of SRIM-based Monte Carlo simulation of ion-scattering for 50 keV He ions traveling through 100 nm of PMMA into a Si substrate (b) Analysis of the data from (a) showing how the distribution of deposited energy widens as a function of resist depth. After 50 nm of resist (a practical thickness to work with), the beam width is only 2 nm. Note that this model does not take secondary electrons generated by the ion beam into account, as the details of the ion-secondary electron interactions are not fully understood.

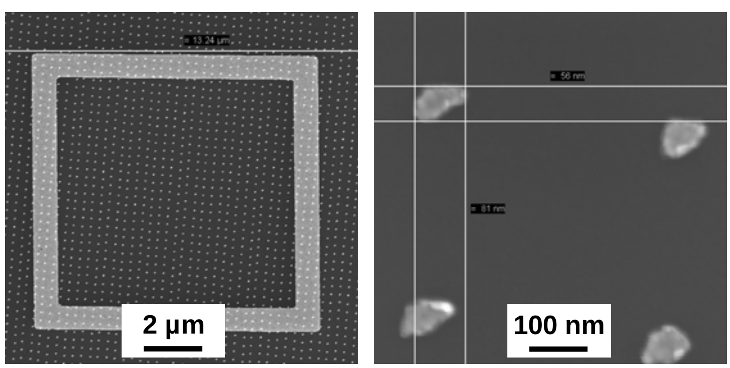

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Figure 2: Scanning electron micrographs of a field of Ti-Au dots at two magnifications, fabricated by exposing 90 nm PMMA on a Si substrate to a single raster-scan of a helium ion beam and performing metal evaporation and liftoff on the resulting pattern. The consistently irregular dot shape in (b) is thought to be the result of vibrations in the system. The large square in (a) is a previously-fabricated fiducial mark