# Mechanical nanostepping for atom beam lithography

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Atom beam lithography (ABL), a derivative of ion beam proximity lithography (IBL), is a process where a broad beam of energetic neutral particles illuminates a stencil mask, a membrane with a fine pattern of open windows, and beamlets of transmitted neutrals transfer the mask pattern to a substrate. This technique provides nanoscale resolution by utilizing all of the benefits of IBL (small diffraction, low resist scattering) along with an inherent immunity to charging artifacts. However, for both techniques, as the pattern density on the stencil mask increases, the strength of the membrane decreases, thereby imposing a mask pattern density limit. To achieve a high pattern density on the substrate using a lower density mask pattern requires multiple exposures offset from each other by an arbitrary step. The goal of this work is to develop a technique to provide this *nanostepping* capability for atom beam lithography.

Nanostepping in IBL has been implemented by shifting the beam incidence angle relative to the mask using electrostatic deflection.[1] Although the neutral particles of the atom beam can not be electrostatically deflected, an identical effect can be achieved for ABL by mechanically tilting the substrate and mask together relative to the incident neutral beam. To accomplish this we have used an external rotary stage, figure 1, to tilt the entire sample chamber, which is isolated from the main beamline by a double bellows assembly. This system has an angular resolution of about 100 μrad, which, for a 5 μm proximity gap, would result in a nanostepping increment of 0.5 nm.

We demonstrated this technique using a stencil mask with a widely spaced array of nanoscale openings. The silicon mask was 300 nm thick and was coated with 150 nm of gold. A 30 keV helium atom beam was used to expose a 60 nm thick film of polymethylmethacrylate (PMMA) resist on a silicon substrate, which was clamped to the mask with a 20 μm proximity gap. For comparison, two samples were exposed, one as a single exposure without nanostepping and one with three nanostepped exposures. After development the samples were coated with 2 nm of iridium for SEM imaging. Figure 2 shows (a) a 20 nm feature in the resist and (b) this same feature printed three times with a pitch of 80 nm. Experimental results with smaller features and higher density will be presented at the conference.

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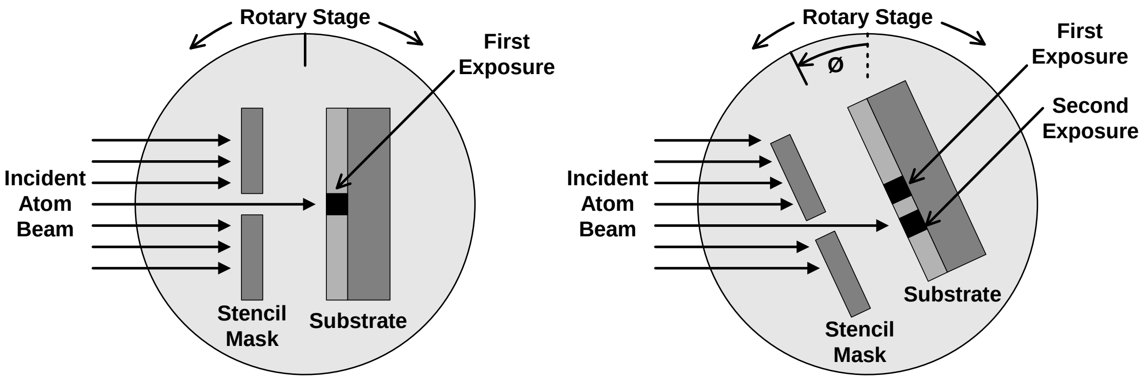
1 Paul Ruchhoeft, J. C. Wolfe, and Robert Bass, J. Vac. Sci. Technol. B 19, 2529 (2001).




(a) (b)

**Figure 1. Concept of nanostepping by tilting a clamped mask and substrate together on a rotary stage to replicate (a) a single exposure (b) multiple times with an arbitrary step size.**

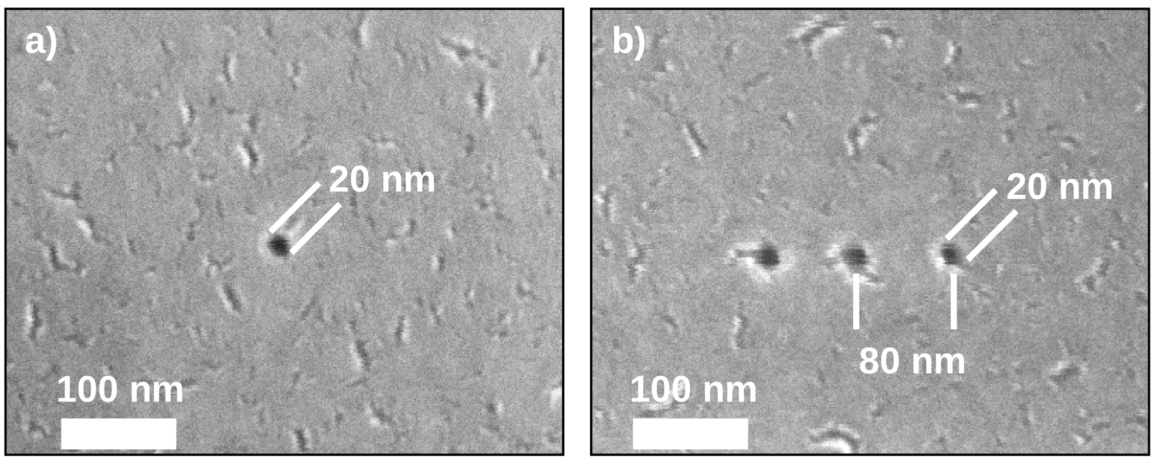



**Figure 2. Preliminary experimental results demonstrating nanostepping capability by comparing (a) a single exposure of a 20 nm feature with (b) a nanostepped triple exposure of the same mask feature with an 80 nm pitch.**