Development of Free-standing Membrane-based Electrostatic Lenses for Nanopantography

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Nanopantography is a method for forming large arrays of nano-sized patterns using a broad beam of ions. In this process, a near-monochromatic ion beam illuminates an array of micron-scale electrostatic lenses, and ions entering each lens converge to a small focal point on the substrate, as illustrated in Figure 1. By tilting the substrate with respect to the ion beam, the spot can be moved across the surface to write a periodic pattern. In a previous demonstration, openings as small as 3 nm in diameter were etched into silicon using a lens array containing 300 nm diameter lenses[1], creating a fairly straight-forward path to defining nano-scale patterns from much larger structures.

Lenses previously consisted of a silicon dioxide dielectric layer sandwiched between a metal lens array and the silicon wafer, and so they were not re-useable, and patterns could only be etched into silicon. To make the system more flexible, we are developing removable and reusable electrostatic lenses that are designed to pattern any conducting surface. Our lenses consist of a free-standing epoxy (SU-8) membrane with etched openings and an electrode on one side. Figure 2 shows a schematic of our fabrication approach, where a wafer is coated with PMGI, SU-8, gold, copper, and PMMA, and the pattern is formed by a lithographic step. The frame is attached, the patterns are etched through the SU-8, and the membrane (1 μm thick) is released by dissolving the PMGI layer. The typical membrane area was ~1cm^2 and the 1 μm diameter lens array occupied about 1 mm^2.

The applied potential used to focus the ions also serves to clamp the membrane to the conducting substrate, and the clamping is observed by monitoring the capacitance measured between the lens and the substrate in situ. This force is substantial for these membranes (~7 psi), and we can observe that the membranes flatten against the substrate. Figure 3 shows images of ~100 nm diameter features etched by 99.6eV argon ions focused using a 94V electrode potential in a 4×10^{-5} torr chlorine ambient. The lens array at the top of the image was purposefully torn to demonstrate that the membrane lies flat against the surface, and the larger circles around the etched features are formed by energetic neutrals in the beam that cast a shadow of the lens openings. This is the first demonstration of nanopantography using lenses fabricated from membranes.

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[1] Siyuan Tian, Vincent M. Donnelly, Paul Ruchhoeft, and Demetre J. Economou, *Appl. Phys. Lett.* **107**, 193109 (2015)

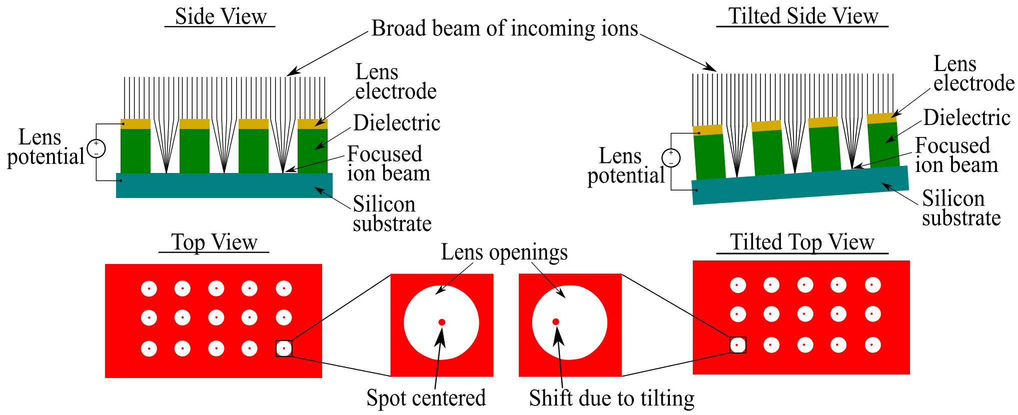

Figure 1: Nanopantography process

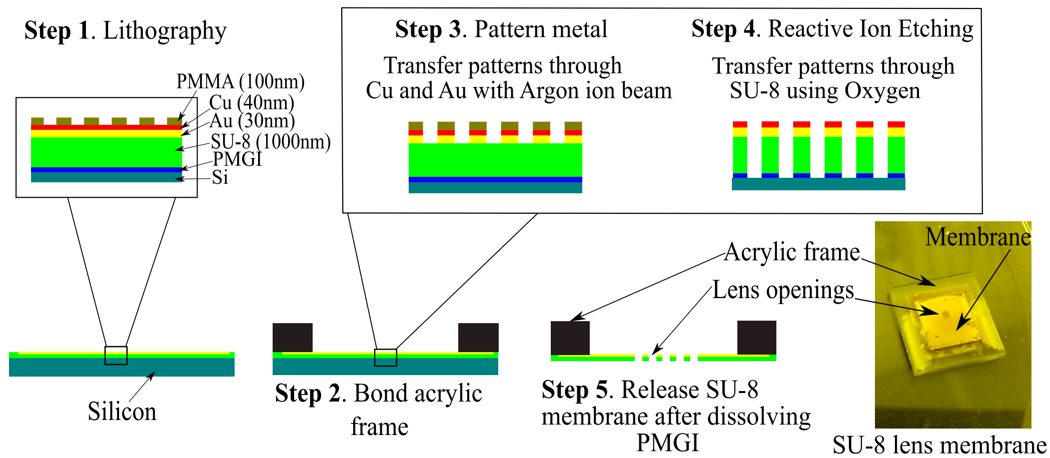

Figure 2: Lens fabrication sequence

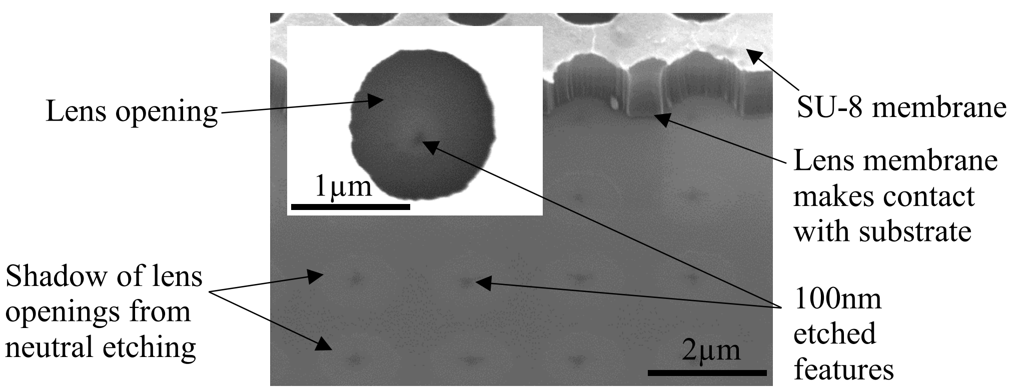

Figure 3: SEM images of the 100 nm features formed at the substrate. The lens array was torn to make it easier to find the pattern and to show that the membrane is clamped to the substrate. A shadow of the lens opening forms due to high energy neutrals in the beam.