PMMA Stencil Masks for Atom Beam Lithography

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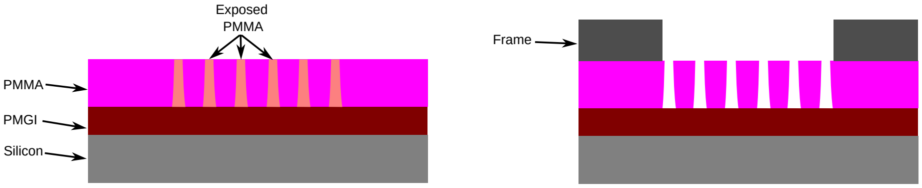
Atom beam lithography (ABL) is a wafer-scale nano-patterning approach where a collimated beam of energetic helium atoms irradiates a large-area stencil mask containing a pattern of openings. Beamlets are formed by atoms that pass through the membrane and these expose a photoresist-coated substrate placed in close proximity. One of the challenges of ABL is the fabrication of the stencil masks with high-resolution openings that can effectively stop atoms in the opaque areas and can remain taught and mechanically stable. Stencil masks have traditionally been fabricated from silicon and silicon nitride, and require a number of pattern transfer steps involving reactive ion etching. In this work, we investigate a mask fabrication process where the membrane itself consists of photoresist and which can be pattered directly by electron beam lithography. We show that 600 nm thick PMMA can be used to form stable masks with 1 cm^2 areas.

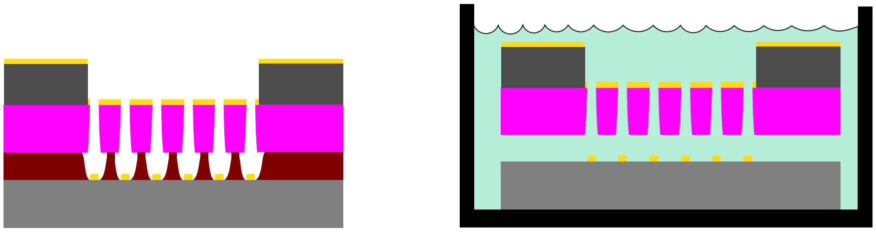
Figure 1 shows a schematic of the mask fabrication process. First, a silicon wafer is coated sequentially with a 250 nm PMGI sacrificial layer and a 600 nm thick PMMA layer by spin-casting. A pattern is written using a 50 keV electron beam system (JEOL JBX-5500 FS) and is then developed in a 1:3 solution of MIBK:IPA for 30 seconds. Next, a laser-cut, 3 mm thick acrylic frame is bonded to the wafer using a double-sided adhesive. The patterned regions of the PMMA are then undercut by a brief PMGI wet etch using a 2.3 % TMAH solution in water, and a 100 nm thick layer of gold is thermally evaporated onto the substrate. Finally, the patterned area and frame are released from the wafer by dissolving the remaining PMGI in TMAH. Figure 2(a) shows a photo of a mask mounted using wax onto an aluminum holder. The patterned area consists of 16 1 mm^2 regions containing 190 nm openings on a 1 µm pitch. The acrylic frame contains protrusions for safely handling the mask. Figure 2(b) shows 190 nm patterns printed in PMMA using ABL and a PMMA stencil mask.

With these stencil masks, we are able to rapidly pattern a full 4-inch diameter wafers using step-and-repeat printing. We found that PMMA thicknesses below 500 nm result in fragile and difficult-to-handle masks. When optimizing the mask design, we have to consider forward scattering electrons as a function of resist thickness. For a 50 keV e-beam voltage and a resist thickness of 600 nm, the forward scattering blur for our 50 keV system is expected to be less than 50 nm (FWHM). To substantially reduce the forward scattering blur and allow for thicker membranes, larger electron beam energies can be used.



a) Spincoat PMGI, PMMA, and pattern expose PMMA

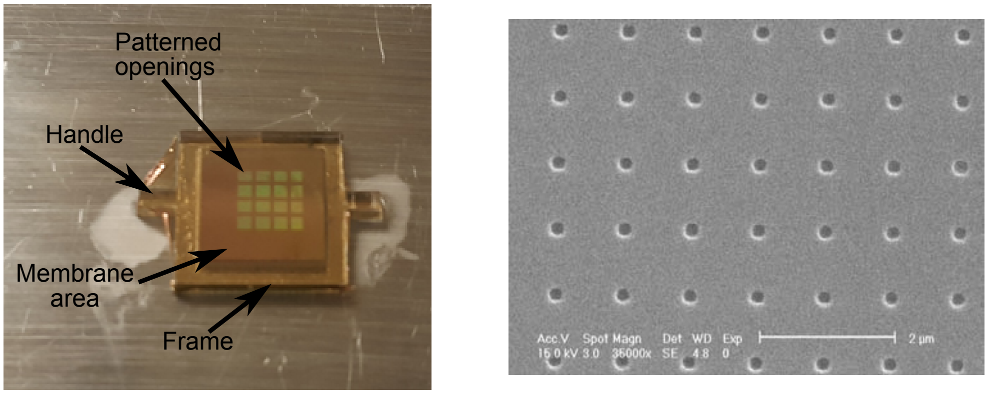
b) Develop PMMA and attach frame



c) Etch and undercut PMGI, thermal evaporate Au

d) Wet etch remaining PMGI

Figure 1: PMMA Membrane mask process flow.



(a) **(b)**

Figure 2: PMMA membrane mask, where (a) is a photo of the mask waxed onto an aluminum holder and (b) is a micrograph of 190 nm diameter patterns with a 1 µm pitch printed in PMMA using ABL.