Mitigating Etch-Induced Fencing of Platinum with Sacrificial Layers

CNF Fellows Program

Principal Investigator(s): Vince Genova[1], David Lisham[2]

CNF Fellow: Kyle J. Dorsey[3]

Affiliation(s): 1. Cornell NanoScale Science and Technology Facility, 2. Plasma-Therm LLC,
3. School of Applied and Engineering Physics, Cornell University
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Contact: genova@cnf.cornell.edu, kjd96@cornell.edu
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Abstract:

Lithographic patterning of platinum is challenging because platinum does not readily form volatile etch products. Most approaches toward patterning platinum rely on physical etch mechanisms. Low-energy sputtered platinum has a short mean-free path and high surface mobility, so it readily redeposits on the sidewalls of etch masks. When the etch mask is removed, the sidewall-deposited platinum remains adhered to the wafer in a phenomenon known as "fencing." We describe a lithographic approach to mitigate the effects of platinum etch fencing by utilizing sacrificial layers to lift off the residual fences during etch mask stripping. The central elements of the process are described schematically in Figure 1. A sacrificial layer is prepared with considerable undercut underneath the etch mask as shown in Figure 1(a). The redeposition of platinum from the edge of the feature can be considered a point source. The flux of platinum should then vary as cos θ. Therefore, very little platinum is redeposited underneath the resist, enabling it to be lifted off in solvent.

Summary of Research:

Platinum films were prepared on silicon wafers by DC sputtering (AJA International). *In situ*, the wafers were cleaned with an Ar plasma, then sequentially coated with 2 nm Ti adhesion layer and 100 nm Pt at 3 mTorr. The sacrificial layer (to be described in subsequent sections) was deposited or spin-coated. The etch mask was patterned by photolithography (GCA AS200 i-line stepper, 5x) in SPR700-1.2 photoresist. The pattern consists of lines and spaces at equal pitch ranging from 0.5 µm to 20 µm. The platinum was etched in an argon ion-milling system at normal incidence with 600V bias. Etching proceeded in 15 second increments with 30 second cooldowns between bursts to prevent overheating. Eight etch/cool cycles were needed to clear through 100 nm of Pt.

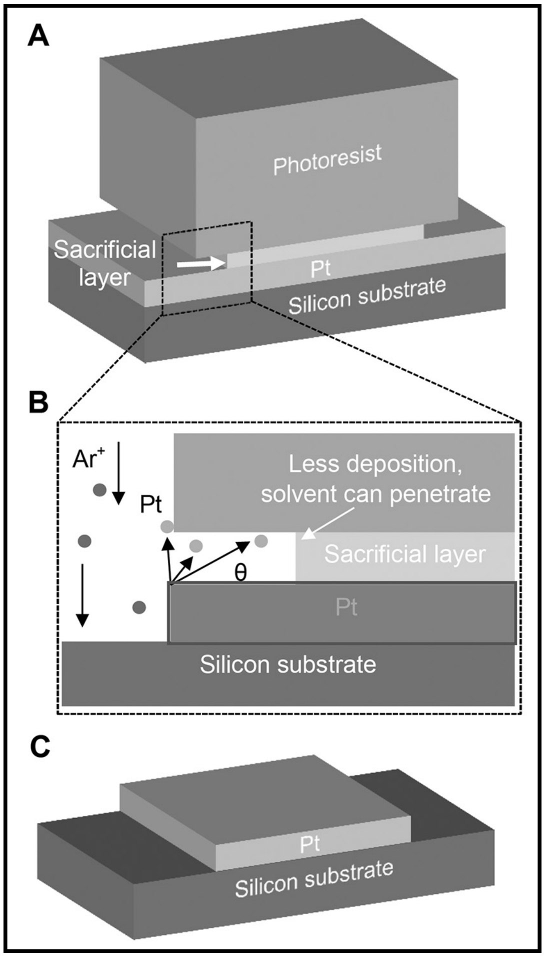

Figure 1: Central elements of the process are described schematically.

The primary sacrificial layer investigated is Microchem LOR resist. This material dissolves in developer solution, producing an undercut profile concurrently with the lithography process. The thickness is controlled by spin-coating and viscosity, and the undercut rate is controlled by soft-bake temperature. After etching, the photoresist was dissolved in heated 1165 stripper (~50°C) with ultrasonic agitation for 30 minutes, followed by rinsing in acetone, isopropanol, and DI water.

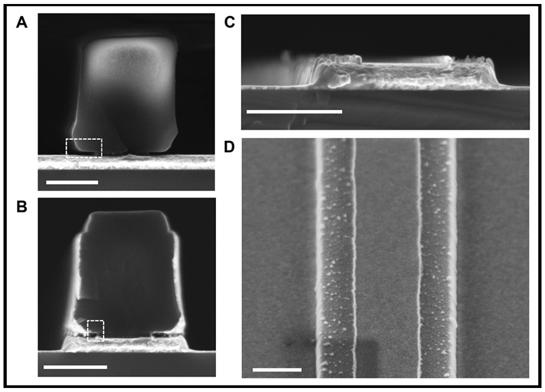

Figure 2: Complete process flow.

Results:

We investigated ultra-thin layers of LOR, which simplifies process by having easier to prepare films, eliminating an etch step, and remaining easy to remove. The LOR was prepared by mixing LOR 1A in a 1:1 volumetric ratio with cyclopentanone. This mixture was mixed on a magnetic stir plate for an hour prior to coating. The wafers were spun with this solution at 3500 RPM for 30 seconds and baked at 185°C. At this temperature, the LOR produces an undercut rate of 4 nm/sec in 2.38N developer. The complete process flow with this sacrificial layer is described in Figure 2.

Figure 2a shows the completed structure. The LOR thickness is 40 nm, and the development time produces a 200 nm undercut. After milling, the sidewalls are coated in Pt, as shown in Figure 2b. However, the corners of the completed feature are not coated. This enables separation of the sidewall from the substrate. After removal, the finished structures are shown in cross section in Figure 2c and in angled imaging in Figure 2d. There is some residual platinum, but none of it is thicker than the LOR thickness. Moreover, there are no large regions of retained sidewall as there were for the silicon nitride case.

The remaining Pt particles can be removed by inserting an additional sacrificial layer in between the platinum and the undercut resist, as shown in Figure 3a. The thickness of this additional layer should be very thin as to avoid generation of new, larger fences. It should also not dissolve during photolithography development or resist coating. We investigated two extra sacrificial layers, 10 nm of chromium (sputtered, 3 mTorr) and 10 nm of PMMA.

Figure 3 reports the results of the platinum features after removing the extra sacrificial layer. Figures 3b and 3c show the effects of removing the 10 nm of Cr post-milling with Cr etchant CE-200. There are small additional fences remaining, but fewer large residues compared to the approach without the extra layer. Figures 3d and 3e show the effects of using ultra-thin PMMA films as the extra layer. Compared to the Cr layer, the PMMA films simplify the process since it is removed concurrently with the photoresist in the 1165 bath. This approach has improved residues compared to the Cr-based approach and the process without any extra layers at all.

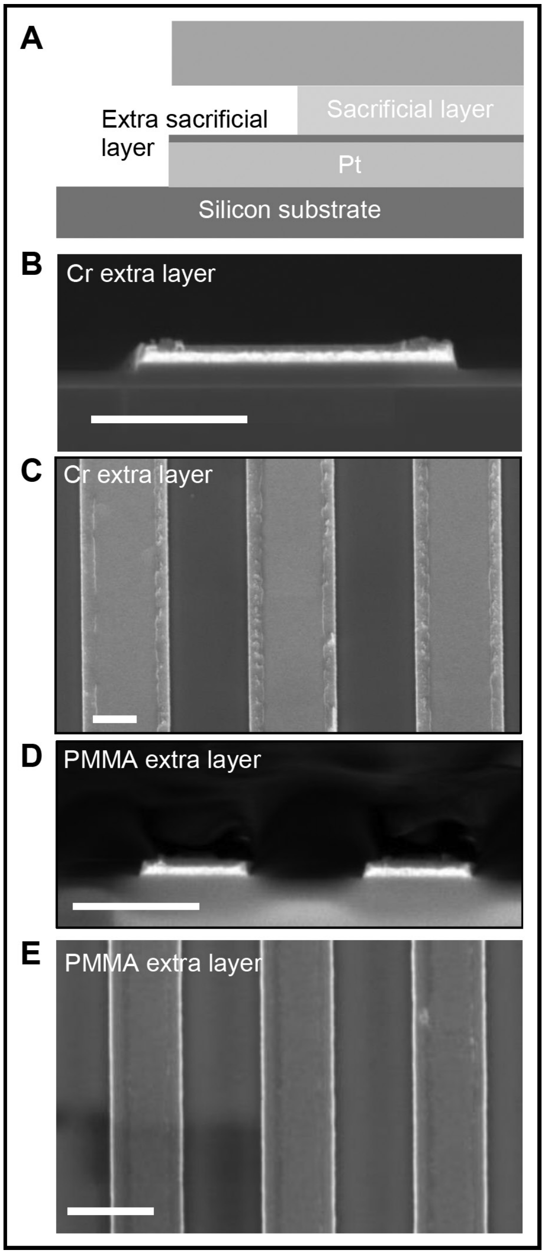

Figure 3; Results of the platinum features after removing the extra sacrificial layer.

Future Work:

Future work will focus on further refinement of the sacrificial underlayer approach. It shows promise as a simple route to fence-free platinum etching. An additional interesting experiment involves conformal sacrificial layers deposited over the imaging resist. This conformal layer covers the entire sidewall of the resist pattern. If chosen appropriately, it can lift off the sidewall fences in a single process step. Work is ongoing using ALD-deposited aluminum oxide, which can be deposited conformally at low temperatures and is readily dissolved in TMAH-based photoresist developer.