Development on an all-wet-etch process chemistry for the patterning of metal conductors in IGZO thin-film-transistors

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Today, metal oxide thin-film transistors (TFTs), specifically those based on indium-gallium-zinc oxide (IGZO), have been established as one of the most promising technologies for leading next-generation flat panel displays due to their attractive electronic properties: low power consumption (~33% vs. *a*-Si TFTs for a 10-inch panel) and high electron mobility (20–30x higher than *a*-Si). Together, these properties allow for scalable and low-cost manufacturing of higher-resolution displays without sacrificing aperture ratio. A transistor's electrical performance, however, is intimately related to its fabrication processes, especially during critical etching steps when shaping both the source/drain (S/D) metal conductors and the semiconductor channel region.

Typically, a dry-etch process is used to define the S/D metal conductors because of its superior selectivity towards metal versus a photoresist (PR) and its high anisotropy which prevents excessive undercutting of metal that's protected by the PR. However, aside from the low throughput and scaling difficulties associated with dry-etching, it has also been shown to degrade a TFT's electron mobility by up to 15% (compared to a wet-etched TFT) due to the structural damage it causes to the semiconductor's surface (through ion bombardment) and bulk structure (via plasma radiation); Additional adverse effects of a dry-etch to the TFT include high threshold voltages, high off-currents, and a divergence of the transfer characteristic curves as a function of applied S/D voltage. Consequently, it could be highly advantageous for key players in display technologies to employ a wet-chemistry approach during critical etching steps, particularly if it encompasses the benefits of dry-etch (*e.g.*, high selectivities) without degrading the electrical properties of the transistor.

Here, we discuss the development of an all-wet-etch process chemistry with high metal selectivity that is capable of shaping the structures of an IGZO TFT (Figure 1a) to customer specifications. Our approach involves a two-step etching process that (i) selectively removes only the metal conductor (Cu) and temporarily stops at the underlying metal adhesion layer (Mo or Ti) (Figure 1b), and then (ii) selectively removes the metal adhesion layer with minimal impact to the IGZO semiconductor and metal conductor (Figure 1c). By pursuing a two-step approach, where each chemistry is designed to target a specific metal with high selectivity, the risk of excessive metal undercutting generally associated with wet-etch techniques can be mitigated.

We found that the metal conductors in IGZO TFTs could be successfully patterned by (i) first exposing the TFT to an aqueous solution consisting of 5 wt. % citric acid and 2.5 wt. % hydrogen peroxide in order to remove Cu, and then (ii) following that with a heated mixture containing 80 vol. % hydrogen peroxide and 20 vol. % tetramethylammonium (TMA) solution to etch the Ti or Mo adhesion layer. Etching rates of Cu, Ti, Mo, and IGZO were calculated based on the amount of metal removed from blanket films, and used to define the total etch time for each chemistry.

The Cu-etch step (citric acid/peroxide) showed impressively high selectivity towards Cu when compared to Mo, Ti (Cu/Mo, Cu/Ti $\rightarrow \infty$), and IGZO (Cu/IGZO > 100) (see for example, Figure 2). Similarly, the TMA-based chemistry used in the adhesion layer etch (2nd step) also revealed high selectivity towards Mo (Mo/Cu $\rightarrow \infty$, Mo/IGZO > 100) and Ti (Ti/Cu $\rightarrow \infty$, Ti/IGZO = 20). With such high etch selectivities towards the Cu and Mo or Ti metal layers, the amount of IGZO remaining in the TFT channel even after a 100% overetch in each of the process steps was more than sufficient for TFT operation (>500 Å).

Further investigation into the TFT channel itself showed that indeed all of the S/D metal not protected by the photoresist is etched away without significantly extending the channel length (Δl < 300 nm). For example, Figure 3 shows an Auger line-scan of elemental Cu and Mo across the length of an IGZO TFT channel, as well as In, Ga, and Zn. The plot represents the intensity of elemental Cu and Mo detected as a function of position along the channel. According to the figure, as the TFT is scanned from left to right, the intensity strength of Cu drops to zero as the position of the beam passes over the channel (signifying Cu is not present), but is quickly restored once the beam strikes the S/D metal contact on the right side of the channel. Similarly, after Cu removal, the unprotected S/D adhesion layer (*e.g.*, Mo in this case) is also removed completely during the etching process, leaving behind a pair of patterned S/D metal conductors with a well-defined and pristine semiconductor channel. Thin-film-transistors that have been patterned using this method are currently being processed to show better performance compared to those TFTs whose S/D metal conductors are shaped using a dry-etch approach.

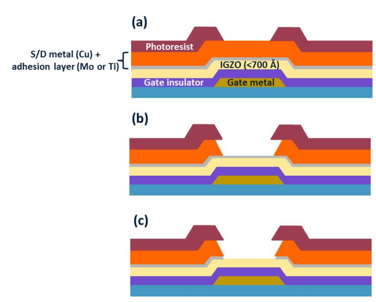

Figure 1. Schematic depicting our wet-etch process approach of (a) an IGZO TFT. First, the metal conductor (Cu) is selectively removed (b), followed by the metal adhesion layer (Mo or Ti), (c).

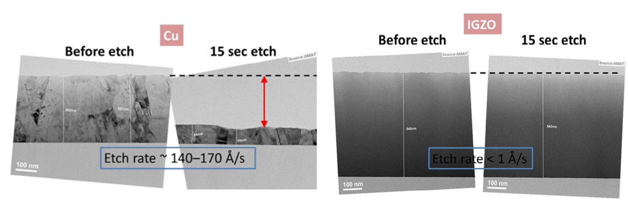

Figure 2. Cross-section TEM images of blanket Cu and IGZO films etched in an aqueous solution of 5 wt. % citric acid and 2.5 wt. % hydrogen peroxide at 50 °C.

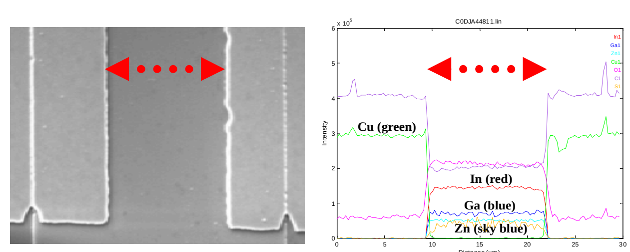

Figure 3. Auger line-scan of an IGZO TFT channel etched in an aqueous solution of (i) 5 wt. % citric acid and 2.5 wt. % hydrogen peroxide at 40 °C, followed by (ii) a 50 °C heated mixture containing 80 vol.% hydrogen peroxide solution and 20 vol.% containing TMA. The intensity of the Cu and Mo signal is zero (noise level) across the entire channel length. Mo signal at the S/D contact is also zero due to the thickness of the Cu metal.