Optimization of Switching Layer for Retention in Tungsten Oxide Memristive Devices

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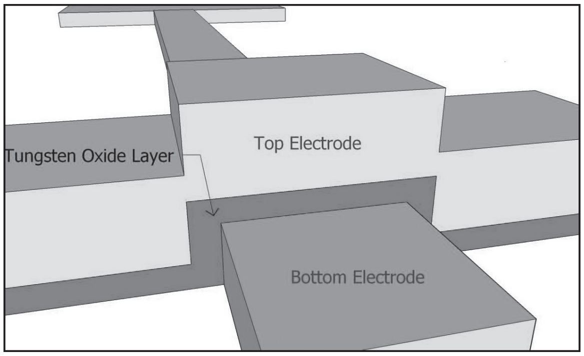

Figure 1: Schematic of the device structure.

Abstract and Introduction:

The memristor, essentially a resistor with memory, has generated much interest as a newly accessible circuit component that is dependent on nanotechnology. A switching layer between two electrodes can change the resistance of the device as oxygen vacancies, acting as a dopant in the oxide, redistribute when exposed to high electric fields. The film composition, specifically the oxygen concentration gradient, therefore has a significant impact on device performance. Reactive sputtering was employed for the tungsten oxide switching layer, and the process was characterized using differing oxygen flow rates and substrate temperatures during sputtering, which can be fine-tuned to change the retention, or the ability to remember a resistance when voltage is removed, based on device application. One application used by our group is as "synapses" in neuromorphic circuits: memristors' ability to connect in large networks can be used to emulate neuron/synapse connections, and the memory component of the memristors simulates learning in the brain [1, 2]. For neuromorphic circuits, retention should be high, so this project aimed to fabricate memristors that demonstrate good resistance retention at a photolithography-compatible scale.

Experimental Procedure:

All tungsten oxide thin films in this study were reactively sputtered using differing gas flow rates and substrate temperatures. Thin films deposited on silicon substrates with a silicon dioxide insulating layer were characterized using x-ray photoelectron spectroscopy (XPS) to determine the oxygen and tungsten concentration. The memristive devices themselves were prepared using photolithography for patterning and liftoff for both electrodes and gold probing pads.

Fabrication began with a 40 nm layer of palladium evaporated onto the patterned wafer and lifted off to form the bottom electrode. The switching layer, 30 nm of tungsten oxide, was sputtered onto the device, and then after patterning again, a 65 nm layer of either palladium, or titanium and platinum for an asymmetric device, was evaporated onto and lifted off of the wafer. The top electrode was then used as an etch mask and the tungsten oxide was etched through to reveal the bottom electrode via plasma etching. Finally, gold probing pads 100 nm thick were patterned and evaporated, along with an adhesion layer of 10 nm of nickel-chrome. After a final liftoff, characterization using a probe station was carried out to find the I-V characteristics of the devices. Figure 1 shows a schematic of the device structure.

Results and Conclusions:

It has been documented in the literature that below 30% O_2, flow rate in the sputtering chamber tungsten oxide becomes less stoichiometric and increasingly conductive [3]. This was verified by XPS measurements on samples with 35%, 25%, 15%, and 5% O_2 flow rates. As the flow rate drops, the oxygen concentration in the sample falls from 42% to 31% and the tungsten concentration increases from 37% to 53%. The remaining percentage of the sample surface is carbon, since every sample had been exposed to air. Two XPS survey scans for films deposited with 35% and 5% O_2

flow are shown in Figure 2. A flow rate around 25% was ultimately deemed best for controlled memristive effects, as a flow rate close to 15% resulted in too many oxygen vacancies and the devices simply showed a linear I-V characteristic, which is just a resistor with no memory; while flow rates above 30% would make the film too stoichiometric to allow resistance changes, having high oxygen concentrations and therefore very few oxygen vacancies.

Figures 3 and 4 show I-V characteristics of devices fabricated with 25% O2 flow. Figure 3 exhibits the well-defined pinched-hysteresis loops expected from a memristor. Repeated positive voltage sweeps result in a continued increase in device conductance, demonstrating good retention. Figure 4, however, while exhibiting pinched-hysteresis loops, shows poorer retention than the device in Figure 3; repeated positive voltage sweeps do not result in much change in device conductance. The different behaviors between devices may be related to differences in tungsten oxide film quality because of non-uniformity during film fabrication. Asymmetric devices were also fashioned, because the symmetry of earlier devices made their polarity unpredictable.

Future Work:

Since only limited flow rates and substrate temperatures were tested, it could behoove the lab to continue characterization of the films at temperatures near 350°C with added flow rates, especially if finer control of retention is needed. There are also plans to test devices using two layers of tungsten oxide sputtered with different flow rates, or to sputter films with gradients of oxygen concentration, to see if these arrangements can make the polarity still more predictable, and the devices useable as fabricated without a forming sweep.

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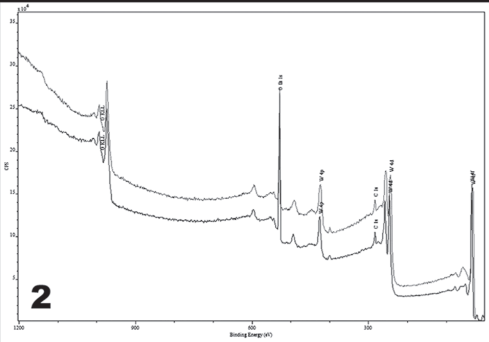

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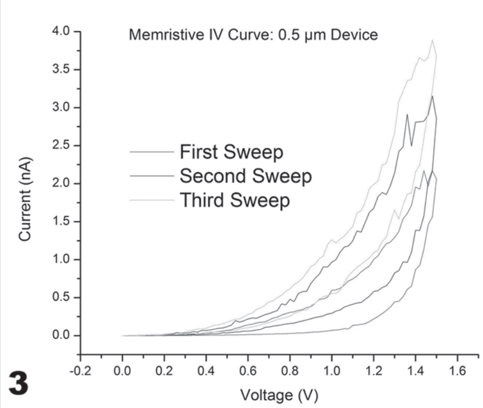

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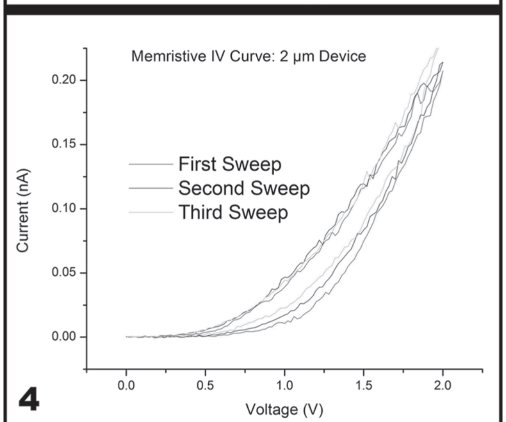

Figure 2, top: Two XPS survey scans for films deposited with 35% and 5% O_2 flow.

Figure 3, middle: Well-defined pinched-hysteresis loops expected from a memristor.

Figure 4, bottom: Repeated positive voltage sweeps do not result in much change in device conductance, showing poorer retention than the device in Fig. 3.