Fabrication and Characterization of Cu-WO_3-Pt and Pt-WO_3-Pt Switching Devices

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Abstract/Introduction:

Due to fundamental barriers that prevent further scaling of metal oxide semiconductor (MOS) field effect transistor technology, novel devices are sought as the foundation for next generation memories and processors [1]. Resistive random access memory (RRAM) offers a promising solution to further scaling of memory technology. The building block of RRAM is a device that has multiple resistance states that can be reached depending on the history of current or voltage application.

Metal-insulator-metal (MIM) structures with transition metal oxide (TMO) insulators are typically used to implement resistive switching devices [2]. The specific structures studied in this paper are copper-tungsten oxide-platinum (Cu-WO_3-Pt) and platinum-tungsten oxide-platinum (Pt-WO_3-Pt). The devices were characterized in the virgin state through capacitance-voltage (CV), current-time (It), and current-voltage (IV) curves. A constant voltage forming method was used to induce repeatable resistive switching behavior. Stable bipolar and unipolar switching was observed in devices with Cu top electrodes and Pt top electrodes respectively.

Experimental Procedure:

The devices (Figure 1) were fabricated on sputtered 100 nm Pt substrates with a Pt/ZrO_x/SiO_2/Si structure. 60 nm of WO_3 was deposited using a WO_3 target in an oxygen atmosphere at 1 mbar. Both Cu and Pt top electrodes were deposited using a Cu and Pt target, respectively. 100 nm of each was sputtered in an inert environment of argon at ~ 1×10^{-3} mbar. The top electrodes were patterned using a shadow mask with circular openings of diameter 100 nm and 200 nm. However, the exact dimensions of the electrodes are uncertain due to shadowing.

A Keithley 2611 System SourceMeter was used for IV and It characterization of the chips. CV measurements were carried out using a 100 mA 10 KHz signal superimposed on a DC sweep from -1V to +1V. The capacitance was extracted by modeling the resulting data by a capacitor in parallel with a resistor. After a constant voltage forming step, a voltage sweep was used to switch the devices between multiple resistance states. For certain devices, millisecond constant voltage pulses were used to change resistance state of the device.

Results:

The IV curves of the pristine devices showed asymmetric behavior with respect to positive and negative bias for both types of devices (Pt and Cu top electrode). This was expected, due to the difference in the interface between the top electrode and bottom electrode because of fabrication methods. However, the value of the leakage current could not be reliably extracted from the IV curve due to time dependent current sources such as dielectric relaxation. The leakage current at

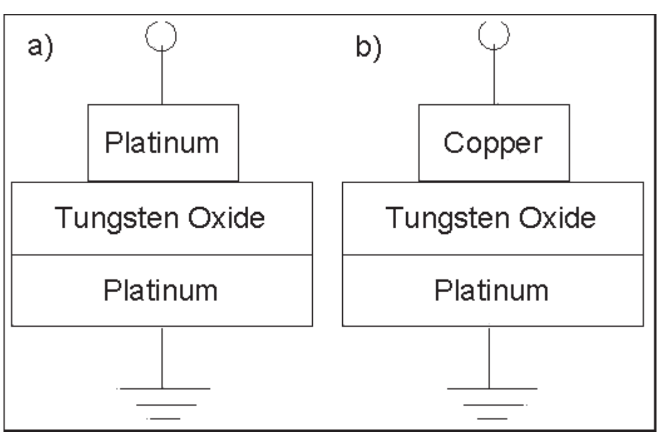

Figure 1: Cross sectional view of device structure.

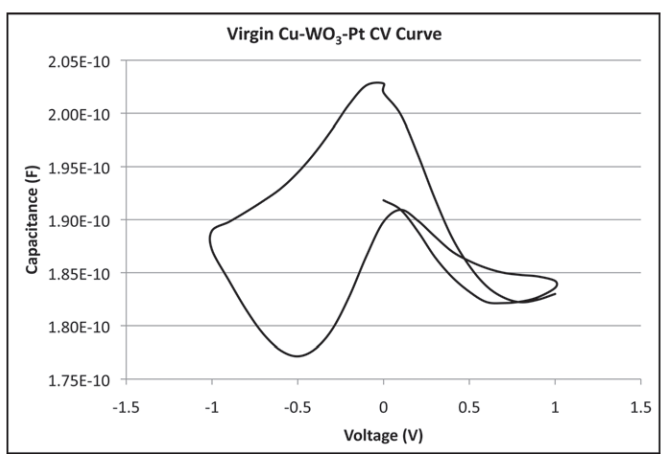

Figure 2: CV curve of devices with copper top electrodes.

0.1 V, obtained from It curves, was ~ 10^{-7} A for devices with Cu top electrodes, and ~ 10^{-9} A for Pt top electrodes.

CV curves of the Cu-WO_3-Pt devices (Figure 2) exhibited significant hysteresis, while Pt-WO_3-Pt (not shown) CV curves exhibited essentially none. It should be noted that multiple sweeps from -1 V to 1 V starting and ending at 0 V resulted in similar capacitance values. This could be attributed to copper ion diffusion into and out of the WO_3 film [2]. Since Pt does not diffuse appreciably, no significant hysteresis was observed for Pt-WO_3-Pt devices.

Forming was carried out on the Cu-WO_3-Pt devices using +3 V with current compliances of 0.1 mA and 1 mA. The time required for a device to form (t_f) was a parameter of considerable interest since it is an indicator of the amount of electric stress the dielectric must undergo before repeatable resistive switching is observed. In a sample of 8 identical devices, formed in succession, under exactly the same conditions, t_f ranged from 48s to 2367s. Devices also had t_f's of 62s, 104s, 216s, 362s, 422s, and 1550s. Since these devices were on the same chip, in an area of less than 0.25 cm^2, and were tested in a timespan of under four hours, these changes are thought to be due to microstructural variations. Elucidating the cause of the t_f variation would require materials investigation beyond the scope of this REU project.

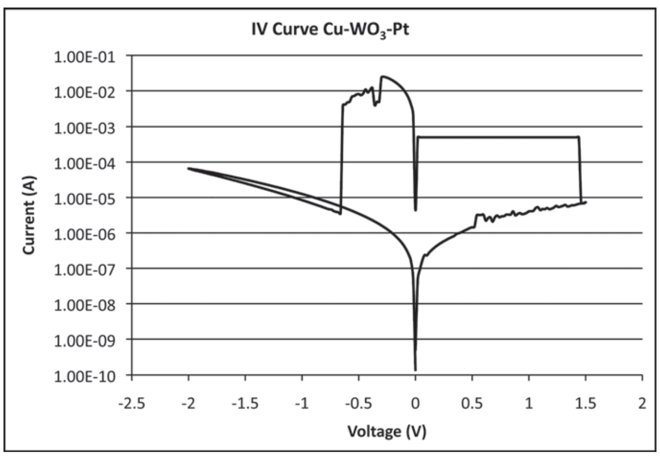

Figure 3: Bipolar switching curve for devices with copper top electrodes.

The bipolar switching for the Cu-WO_3-Pt (Figure 3) device was obtained after a forming at +3 V with a compliance of 0.5 mA. After forming, repeatable on/off switching occurred at +0.9 V and -0.6 V. The *On* state resistance was measured to be on the order of 10 Ω, and the *off* state resistance was on the order of 10^5 Ω. Both states were stable for at least 10 minutes. It is believed this switching arose due to formation of a copper channel between the top and bottom electrode [2].

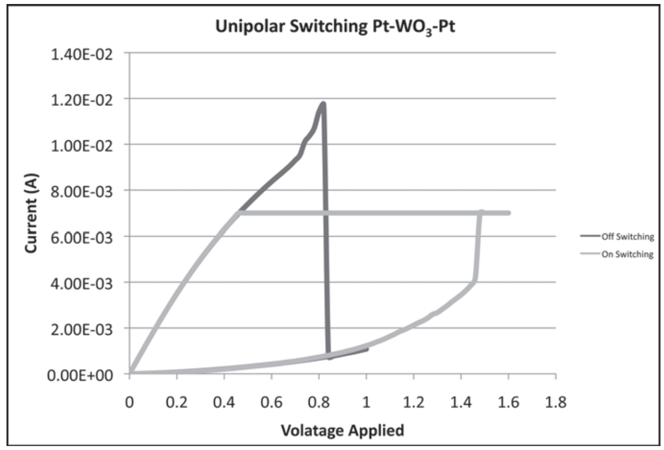

Figure 4: Unipolar switching curve for devices with platinum top electrodes.

The unipolar switching observed for the Pt-WO_3-Pt (Figure 4) device was obtained after 800 seconds of -3 V bias, followed by 1 second of -4 V bias with a compliance current of -1 mA. Figure 4 shows the device switching on at 1.5 V and switching off at 0.85 V with 12 mA current.

Conclusions:

Cu-WO_3-Pt and Pt-WO_3-Pt MIM structures were fabricated, electrically characterized, formed, and switched. The results showed repeatable bipolar switching between stable 10 Ω and 10^5 Ω states with a Cu top electrode. Repeatable unipolar switching was also observed in a Pt-WO_3-Pt device structure. Further work is required to determine possible mechanisms for the unipolar switching behavior.

Acknowledgments:

I wish to thank the the NSF, IREE, the NNIN iREU Program, and the Forschungszentrum Jülich for the opportunity to pursue this research. This research would not have been possible without the time and effort spent to organize the iREU by Dr. Lynn Rathbun and my hosts in Germany, Herr Dr. Prof. Rainer Waser and Dr. Carsten Kügeler. I also wish to thank Robert Weng, Rohit Soni, and Dr. Doo Seok Jeong for their guidance and support.

References:

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[2] Waser, R. & Aono, M. Nanoionics-based resistive switching memories. Nature Mater. 6, 833–840 (2007).