Resistive Switching in Tantalum Oxide with Varying Oxygen Content

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Abstract:

Silicon based non-volatile memory is nearing its practical limit and several other possibilities are being examined more closely as potential replacements. One of these possible replacements is resistive switching. Resistive switching is a phenomenon in which a metal-insulator-metal (MIM) structure can change to a low resistance state (LRS) at the application of a set voltage and then be switched back to a high resistance state (HRS) by the application of a reset voltage [1]. Much about resistive switching is still unknown in regards to which materials switch and why. Our group examined how the various set and reset voltages of tantalum oxide (TaO_x) changed when prepared with different oxygen to argon ratios during sputtering. By performing electrical characterization of the samples with a basic probe station, we were able to determine the set and reset voltages of each sample, each with differing oxygen contents during formation. Ultimately it was found that the oxygen content during sample preparation changed the initial resistance as expected but did not change the set or reset voltages.

Introduction:

Resistive switching is an interesting phenomenon of certain metal-insulator-metal (MIM) devices where, when a threshold voltage, called the forming voltage, is applied to them, the resistance changes by orders of magnitude. This switching may then be undone by the application of another voltage, called the reset voltage, in the opposite direction, or it may be redone by applying a slightly lower threshold voltage in the original direction and is called the set voltage. This set-reset action can then be cycled. It is thought that the mechanism behind resistive switching is filamentary switching in which a controlled breakdown of the MIM device, caused by the forming voltage, allows for the creation of a conductive filament through the insulator [2]. This filament is then partially destroyed when the reset voltage is applied and is repaired when the set voltage is applied as shown in Figure 1.

Methodology:

In this project, we examined TaO_x, which is a very stable resistive switching material [2]. More specifically we aimed to discover how the switching characteristics of TaO_x (forming, set, and reset voltages) changed when the ratio of argon to oxygen was changed during the initial preparation of the samples. This oxygen to argon ratio was manipulated during the reactive sputtering of the TaO_x and was done in steps of 5% oxygen starting from 10% oxygen to argon all the way to 25% oxygen to argon. The full process of sputtering and device fabrication is outlined in Figure 2.

After the devices were fabricated, characterization was done with an automatic IV probe station. The probe station characterized the 1.5 μm pad size probe and

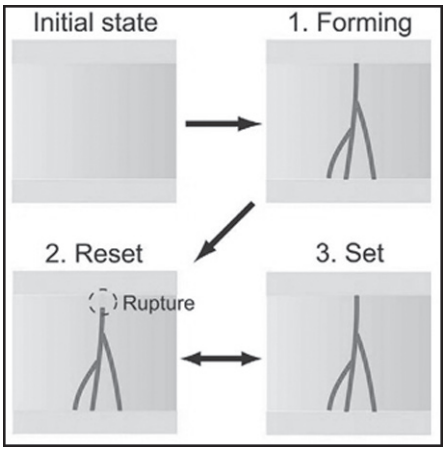

Figure 1: Simple model of the filamentary mechanism [3]. A conductive path is created that provides a low resistance path and then is reset to the original resistance.

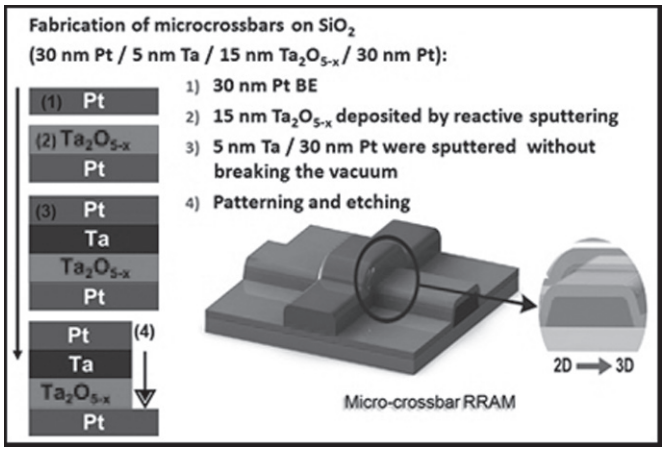

Figure 2: Outline of the device fabrication process for TaO_x devices.

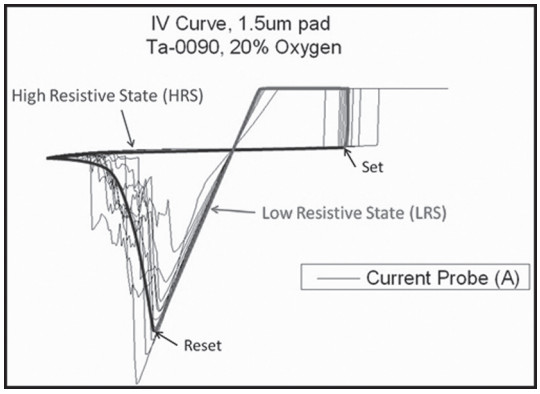

Figure 3: Quasistatic IV curve of a specific trial. Note the two resistive states as well as the set and reset voltage for this stable switching. The plateau arises from the current compliance of the system.

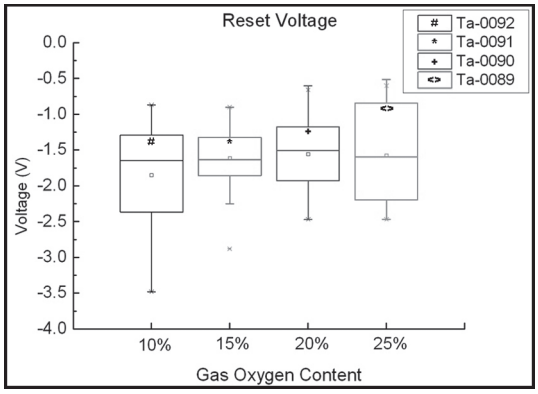

Figure 4: Reset voltage versus oxygen content during sputtering. No apparent relationship between the two.

ran one forming cycle from 0 to 4 volts with a step size of 30 mV, a hold time of 30 ms and a current compliance of 0.2 mA. Then ten set-reset cycles were run with a max voltage of 3.5V, a minimum voltage of -2V, a step size of 30 mV, hold time of 30 ms and a 0.2 mA current compliance up and 20 mA current compliance down. This process was then done on each possible device on the sample totaling about 100 devices per sample depending on availability of the autoprobe.

Results:

Overall there was stable switching of the TaO_x devices. One device example is shown in Figure 3. This allowed for median set, reset and forming voltages to be gathered from the data sets. Ultimately there was no overall trend with set, reset or forming voltages and the changing oxygen contents of the devices as shown in Figure 4. The median set voltage was about 2V, the median reset voltage was about -1.75V and the median forming voltage was about 2.5V with only minor changes with different oxygen content.

Discussion and Future Work:

In the end, the oxygen content during sputtering and sample preparation had no effect on the switching characteristics, which shows that the filamentary mechanism is fully independent of different oxygen content during deposition. In the future, examination of other materials may be worthwhile such as TiO_x in order to see if this oxygen independence during sample deposition is specific to TaO_x or is due to the filamentary mechanism.

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