Resistive Switching in Ag/Cu Doped Methyl-Silsesquioxane for Future Memory Applications

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Introduction:

Increased scaling of current memory devices will soon reach a limit due to the complexity of their design and the required architecture for implementing them. Furthermore, no current technology simultaneously allows for high speed, high density, and non-volatile memory. Resistive random access memory (RRAM) offers a possible solution to fulfill all three of these requirements [1]. One such RRAM cell uses a symmetric design consisting of two inert electrodes with a methyl-silsesquioxane (MSQ) thin film in between. This symmetric metal-insulator-metal design allows for high density integration by using nano-crossbar arrays capable of being stacked in multiple layers [2]. Recently, a cell with a similar device structure demonstrated fast switching speeds of less than 10 ns, showing great promise for future memory applications [3]. However, the reliability of these devices must first be improved and the performance optimized before high density integration can be achieved.

Experimental Procedure:

The resistive switching devices used in this study were based on MSQ thin films doped with either silver (Ag) or copper (Cu). Under strong electric fields, Ag and Cu atoms within the MSQ are ionized and become mobile. The proposed mechanism for resistive switching is that the mobile ions form a filament within the MSQ film, through which is a low resistance path for current to flow. This filament can then be broken and reformed repeatedly to achieve memory function. The primary variable affecting performance in such a device then is the concentration of dopant metal within the film. In order to study the effects of doping on device performance, a total of eight samples were fabricated with different doping concentrations; four samples each for Ag and Cu.

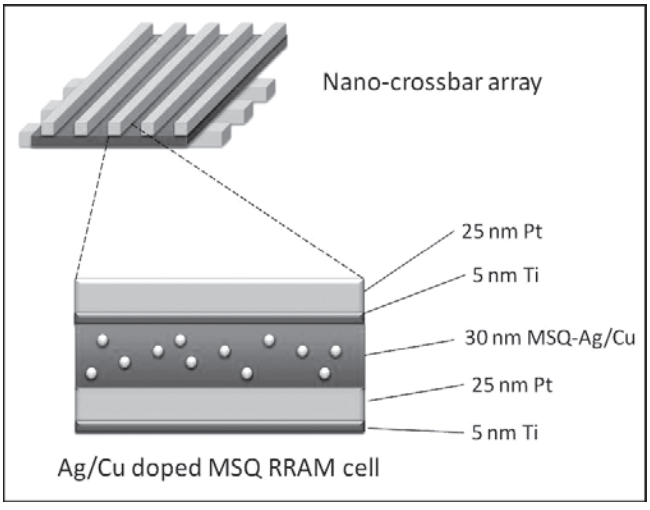

Figure 1: Diagram depicting the device structure and integration in a nano-crossbar array.

The device structure (Figure 1) was fabricated with junction areas ranging from 1 μm^2 to 150 μm^2 using standard micro-fabrication techniques. Both the top and bottom electrodes were deposited by sputtering 5 nm Ti and 25 nm Pt, and then patterned using photolithography. Prior to the fabrication of the top electrodes, the MSQ film was doped by first depositing 15 nm of either Ag or Cu and then diffusing the metal by annealing the sample at temperatures of 450, 500, 550, and 600°C for 20 minutes for each of the samples and their respective dopant.

Electrical characterization was carried out using an Agilent B1500 semiconductor. The analyzer was programmed to test the devices by repeatedly switching them and measuring the resistances as well as their I(V) response during switching. Each device was switched a total of 100 times and the results were compiled to show the effect of device performance due to doping concentration. Figures 2 and 3 show the I(V) characteristics of the Ag doped samples for the turn on and turn off voltage sweeps, respectively.

The devices were first switched on by sweeping the voltage from 0 to 2 V and back. Between 0.25 and 0.75 V, a filament was formed and the cell entered a low resistance state. During switching the current was limited to a maximum of 250 μA to prevent the immediate destruction of the filament due to joule heating. To check that the filament was stable, a small forward bias of 10 mV was applied while the leakage current was measured. The device was then switched off by sweeping the voltage from 0 to 5V with no current limit, and the resistance was checked again.

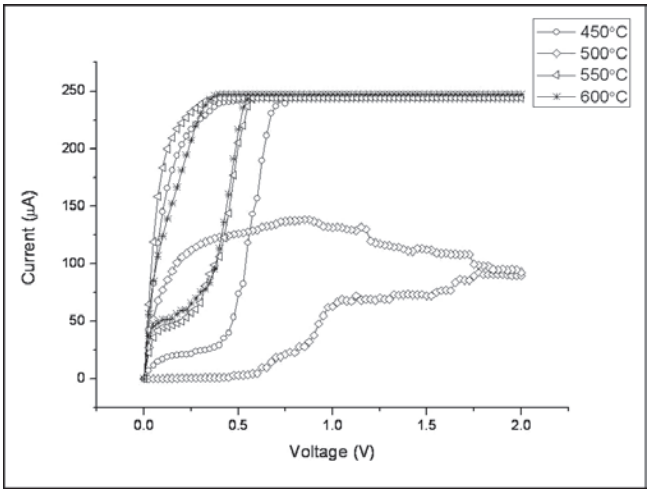

Figure 2: I(V) curves for the various Ag doped MSQ devices showing the switch from high to low resistance states.

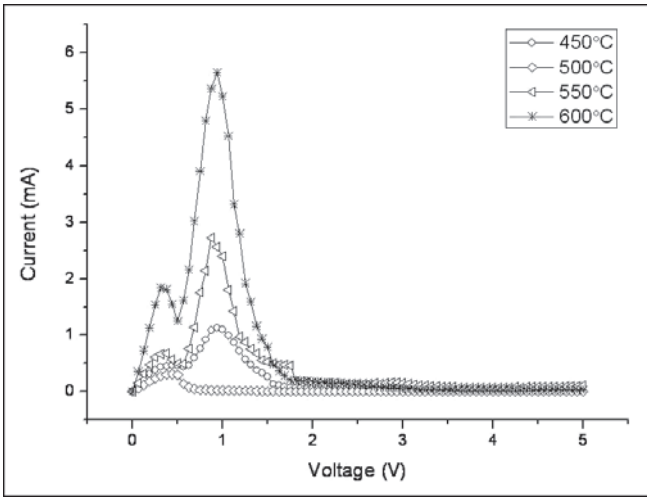

Figure 3: I(V) curves showing the switch from low to high resistance states.

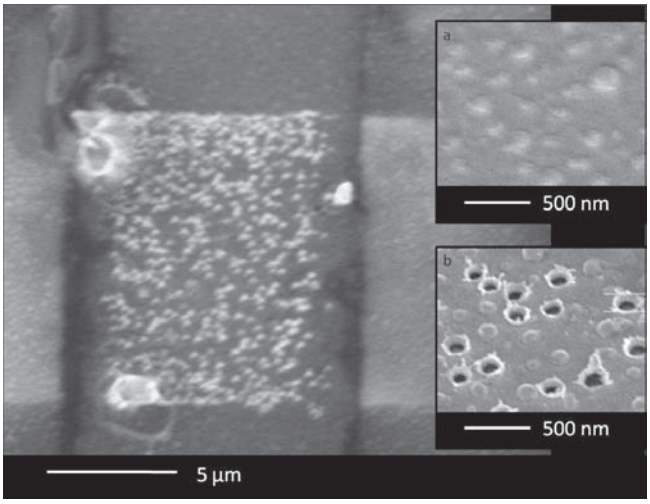

Figure 4: SEM images showing in situ switching and destruction of a device.

In addition to the repeated sweep measurements used to investigate the switching characteristics and device reliability, scanning electron microscopy (SEM) was performed while switching a device *in situ* in order to directly observe the switching effects.

Figure 4 shows an image from this experiment, where the filament breaking points can be seen as bright spots in the center of the junction. The insets show images of the top electrode at a 45° viewing angle before (a) and after (b) the device was damaged from high currents.

Results and Future Work:

Of the devices tested, only those doped with Ag showed consistent switching from less than 1 kΩ to greater than 1 MΩ. Measurements taken on the Cu doped devices indicated that the samples were under-doped. Further work will need to be done to determine whether or not Cu can be used as an effective dopant.

Comparisons were also made between Ag doped devices with different junction areas in order to observe potential scaling effects, showing a decrease in the required erase current with area. This fact, combined with an endurance test resulting in over 3000 successful on/off cycles before failure, are a strong indicator that Ag doped MSQ resistive switching devices are a promising candidate for future memory applications.

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References:

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[3] Meier, M, et al.; IEEE Electron Device Letters, 30(1), 8-10 (2009).