Resistive switching and impedance spectroscopy in metal-oxide-metal trilayers with SiO_x and ZrO_2: a comparative study

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Abstract

The ReRAM, acronym of resistive (switching) random access memories, are candidates to lead the new generation of non-volatile memories and are based on a phenomenon known as resistive switching (RS) [1]. The research on this phenomenon, known since the 1960’s [2], was boosted by the link to the memristor, a passive fundamental circuit element proposed by Leon Chua in 1971 [3], demonstrated by a group of the HP Labs in 2008 [4]. Although the titanium dioxide is considered a prototypical memristive material [5], research on RS in structures containing materials that are compatible with the CMOS technology, nowadays the leading technology in the fabrication of integrated circuits, such as silicon oxide or zirconium oxide, may favour the future market introduction of RS-based devices.

In this work, Au/oxide/TiN structures, obtained by RF-magnetron sputtering deposition of 40 nm thin films of silicon and zirconium oxides, were investigated by means of current-voltage (*I*-*V*) characteristics and impedance spectroscopy and compared based on the results obtained.

In the SiO_x structure, the *I*-*V* characteristics exhibit bipolar-like RS, with a ratio between the resistances of the high resistance state (HRS) and the low resistance state (LRS) bigger than 10^2, at 1 V read voltage. The observed RS is sensitive to the Au electrode exposure to the atmosphere, which enhances the RS (see Fig. 1). A decrease in the voltage application time leads to an increase in the voltage required to induce the transition from HRS to LRS. The two different states show a very distinct behaviour as the temperature is varied: whereas the LRS's resistance has a very weak temperature dependence and decreases with decreasing temperature, in the HRS the resistance increases as the temperature drops. The latter state's resistance temperature dependence is described by a thermal activation of charge carriers, with activation energies of 0.46 and 4.3 meV in the 6 to 130 K temperature region. The weak dependence of the resistance with the Au electrode area and the invariance of the structure's capacitance between the states suggest a filamentary mechanism for the observed RS. Due to the oxygen's influence on the RS, the creation and disruption of the filaments should involve redox reactions.

The ZrO_2 structures also exhibit bipolar-like RS, with a ratio of ca. 10^2 between the resistance of the HRS and of the LRS, read at 1 V. However, the atmospheric exposure decreases the above mentioned ratio, having the opposite effect on the RS, relatively to the SiO_x case (see Fig. 2). The increase in this ratio via pulsed measurements evidences the existence of at least two competing processes in the RS. The impedance spectra show a similar behaviour between these structures and the SiO_x ones, even though there is a bigger dependence on the electrode area, behaviour that deviates from a single filament model. The addition of a germanium oxide (GeO_x) layer between the Au electrode and the ZrO_2 film enhances the repeatability of the *I*-*V* characteristics.

References

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Figures

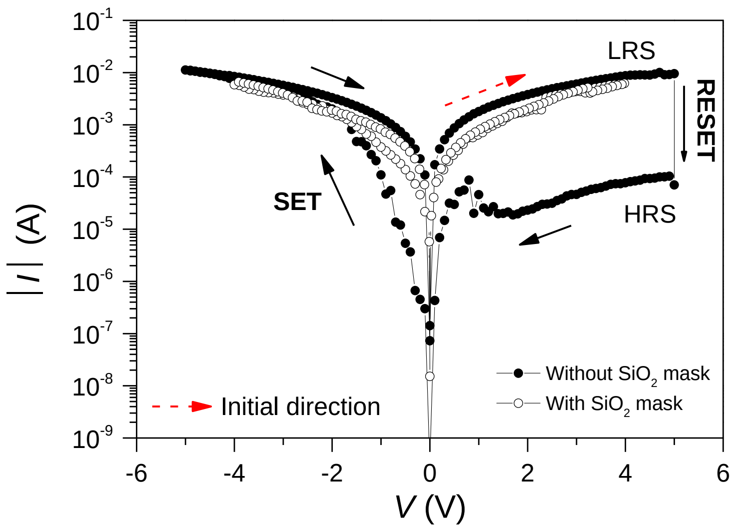

Fig. 1: Typical *I-V* characteristics obtained for the Au/SiO_x/TiN structures with a voltage sweep rate of ca. 1 V/s. The data displayed with the empty symbols was measured with a 300 nm-SiO_2 mask covering the Au electrode, evidencing the importance of the atmospheric exposure for the RS process in increasing the resistance ratio between the high resistance state (HRS) and the low resistance state (LRS). The red dashed arrow indicates the initial direction of measurement.

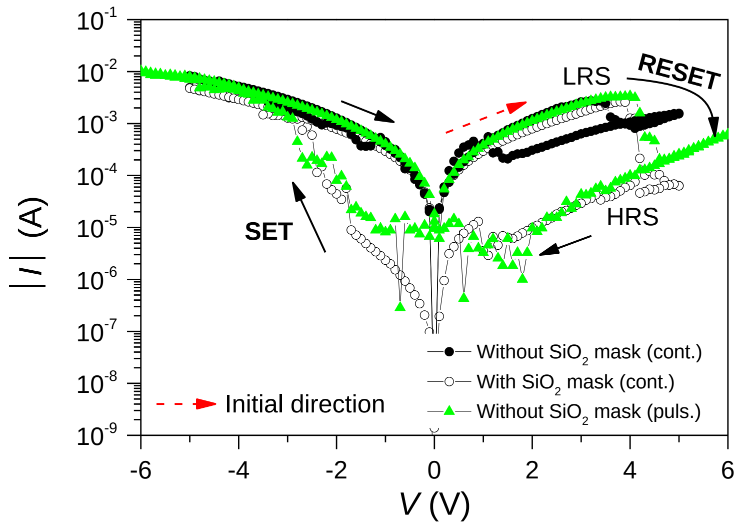

Fig. 2: Typical *I-V* characteristics obtained for the Au/ZrO_2/TiN structures with a voltage sweep rate of ca. 1 V/s (for the data shown with the circular symbols). The data displayed with the empty symbols was measured with a 300 nm-SiO_2 mask covering the Au electrode, evidencing the impact of the atmospheric exposure for the RS process, in this case decreasing the resistance ratio between the high resistance state (HRS) and the low resistance state (LRS). The data displayed with the triangular symbols were measured in a pulsed regime (with a voltage sweep with 500 μs pulses for each voltage level, intercalated with a time interval where there was no applied voltage), which enabled a higher resistance ratio even without the mask. The red dashed arrow indicates the initial direction of measurement.