A definitive demonstration that resistance-switching memories are not memristors

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***Abstract*—There are claims in the literature that all resistance-switching memories are memristors, namely, resistors whose resistance depends only on the charge that flows across them. Here, we present the first experimental measurement unambiguously showing that such claims are wrong. Our demonstration is based on the recently suggested "ideal memristor test" which exploits a duality in a capacitor-memristor circuit. This duality requires that for any initial state of the memristor (its initial resistance) and any form of the applied voltage, the final state of the memristor (its final resistance) must be identical to its initial state, if the capacitor charge finally returns to its initial value. We have applied the test to a Cu-SiO_2 electrochemical metallization cell, and found that the cell is not a memristor: it does not return to the initial state when the circuit is subjected to a voltage pulse. Since the response of our electrochemical metallization cell is typical of most common bipolar resistance-switching memories, we can conclude that resistance-switching memories are not memristors.**

I. Introduction

Memristors were introduced by Leon Chua in 1971 as hypothetical resistive devices with memory whose resistance depends on the charge that traverses them from an initial moment of time [1]. It was shown that when memristors are subjected to time-dependent bias, their current-voltage curves have the form of pinched hysteresis loops [1]. Although this property has been widely used to identify physical "memristors" [2], [3], such an identification is clearly *not exclusive*: there are so many more general dynamical systems (such as memristive systems [4]) that are not memristors and still show pinched hysteresis loops.

Very recently two of us (YVP and MD) suggested an *exclusive* memristor test [5] that can distinguish between ideal memristors and all other resistance switching devices that are not memristors. The idea is the following. Consider a circuit comprised of a capacitor and the device to be tested (e.g., the Cu-SiO_2 electrochemical metallization cell in Fig. 1(a)) subjected to a time-dependent voltage $V(t)$. When the device to be tested is a memristor characterized by a memristance $R(q)$, then there is a correspondence (duality) between the capacitor charge q and the state of the memristor since the capacitor conserves the charge that flows through the memristor.

Clearly, for any initial state of the memristor (its initial resistance) and any form of $V(t)$, the final state of the memristor (its final resistance) must be identical to its initial state, if the capacitor charge finally returns to its initial value [5]. To prove that the device tested is a memristor, the test [5] verifies the duality in a wide enough range of initial states of the memristor and forms of the applied voltage (corresponding to the device operating region). To prove the opposite, however, a single measurement (or several measurements within the operational range of the device) showing the lack of duality is enough.

This contribution reports a recent *experimental* implementation [6] of the memristor test [5] proving that the resistance-switching memories are not memristors.

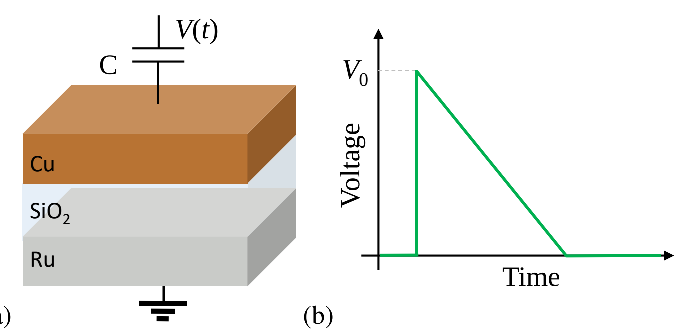

Fig. 1. (a) Schematics of the memristor test circuit. (b) Voltage pulse profile used in our experiments.

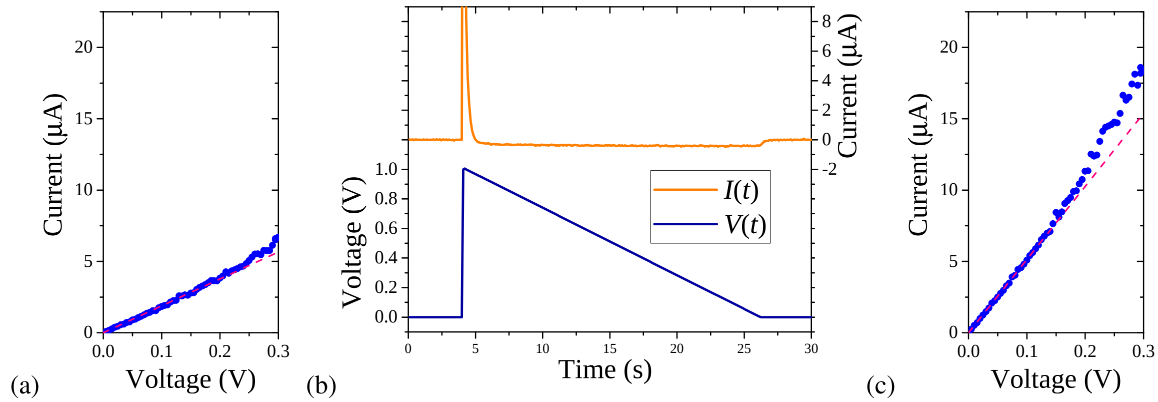

Fig. 2. Ideal memristor test performed at $V_0 = 1$ V. (a) A low-amplitude sweep is used to test the initial memristance (the capacitor is shunted). (b) Voltage and current versus time, when the testing voltage from Fig. 1 is applied. (c) A low-amplitude sweep is used to test the final memristance (the capacitor is shunted). The fitting line in (a) corresponds to $R_M = 53$ kΩ, while in (c) to $R_M = 19.5$ kΩ. From [6].

II. Experimental details

The devices we studied consist of a stack of thin films formed by sputtering deposition technique. The bottom ruthenium electrode (30 nm) was deposited on the Si substrate with the help of a 5 nm thin Ti adhesion layer. On top of the bottom electrode, 30-nm-thick SiO_2 insulating layer was grown using a shadow mask with 10 mm × 10 mm size square openings. The top electrode (Cu) of the thickness of 30 nm thickness was deposited using a mask that has openings of various sizes and shapes. Moreover, the Cu layer was covered with 5 nm CoCrPt (through the same mask) to prevent its oxidation. Finally, the wafer was thermally treated in He at 580 °C for one hour to diffuse some Cu atoms into SiO_2 [7].

To perform the test, several memristive devices showing stable bipolar resistance switching were selected. We have verified that their current-voltage curves are typical of resistance-switching memories. The circuit shown in Fig. 1(a) was enhanced with a reed relay connected in-parallel to the capacitor. The relay was controlled by an external signal. This modification facilitated the access to the electrochemical metallization cell for the purposes of initialization and measurement. A triangular voltage pulse (Fig. 1(b)) was applied with a precision source-measure unit, which was also used to measure the current.

III. Results

Fig. 2 exemplifies implementation of the test [5]. The test sequence consisted of i) device initialization and verification of its state, ii) application of the voltage pulse using Fig. 1(a) circuit, and iii) reading the final device state. These steps are represented in Fig. 2(a)-(c), respectively. We note that the relay was closed to initialize and read the device state, and open when the pulse was applied.

The data shown in Fig. 2 were obtained using a device with ∼0.7 V positive and ∼-0.8V negative switching thresholds. Fig. 2(a) shows that the initial resistance of the device was about 53 kΩ. Fig. 2(b) demonsrtates the voltage and current profiles. Here, an important point is that the current is zero at the initial and final moments of time. This indicates that at these times the voltage across the capacitor was zero, so that the initial and final capacitor charge was the same. The final state measurement is shown in Fig. 2(c). Based on this plot, we have estimated that the final resistance is about 19.5 kΩ. Since the initial and final resistance of these devices is different they did not pass the memristor test.

Tests repeated on different devices demonstrated similar results.

IV. Conclusion

In conclusion, we have applied the memristor test to Cu-SiO_2 electrochemical metallization cells - an archetypical resistance-switching memory. Our experiments have demonstrated that such devices do not return to the initial state when the cumulative charge flown through them is zero. Importantly, as the deviation of the final state from the initial one is very significant, it can not be taken into account by small corrections to the ideal memristor model. Therefore, we can clearly conclude that resistance-switching memories are *not* memristors.

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