Dynamical Resistive Switching of a Generic Memristor Model : Analysis and Simulation

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Abstract—**The memristors was theorized by Leon O. Chua in 1971 as a passive two-terminal electronic device that changes its resistive state depending on the current or voltage history through the device. Since the first fabrication of the memristor by HP Labs in 2008, it has been extensively studied for wide electronic applications. Thus, many SPICE models have been proposed to describe the behavior of memristor. All these models are focused on the pinched hysteresis loop phenomenon, which takes various shape, depending on their different properties.**

In this paper, we study the dynamical behavior of memristor. We use a simple and flexible SPICE memristor model to demonstrate that this model accounts for four different types of a memristor: the bipolar memristor behavior, the unipolar memristor behavior, the bipolar with forgetting effect and the reversible process between the bipolar and the unipolar behavior.

Keywords—Memristor, Bipolar, Unipolar, Forgetting effect, Reversible

I. INTRODUCTION

The nanoscale memristor device has been postulated by Leon Chua as the fourth basic memory circuit element besides resistor, inductor, and capacitor in 1971 [1]. Since the first fabrication of the TiO2 memristor structure in 2008 by Hewlett-Packard laboratory [2], there have been increasingly strong demands to produce new memristor devices with different methods and materials. This device is defined as a memory with a varying state of resistance, it has the capability of changing its resistance based on the charge that passes through the device. This type of device thus exhibits an inherent memory effect with a pinched hysteresis loop in the I-V characteristics curve [1-2]. The device structure comprised of two layers, one is doped with low resistance state Ron and the other is undoped with high resistance state Roff. A positive voltage pulse applied to the device, the resistance state is lowered, and the opposite effect occurs when negative pulses are applied.

Due to its particular I-V characteristics flowing through it, its excellent scalability and its low energy dissipation, the memristor has been attracted as a promising candidate for the next-generation high-performance technology [3].

In particular, it has attracted increasing interest as a suitable alternative to complement transistors [3-5]. In recent years, many models [6-12] have been proposed to describe the behavior of memristor. It differs in their complexity, materials, and accuracy. Thus, all these models are based on the pinched hysteresis loop phenomenon, which has a different shape from one model to another, due to its different properties [12].

In the literature, different models have been published which define different types of memristor's behavior; the bipolar memristor behavior [13-14], the unipolar memristor behavior [13-14], the bipolar with forgetting effect [14-15], and the reversible effect between bipolar and unipolar behavior [16]. Here in this paper, we demonstrate the four types of memristor behavior within a SPICE memristor model that has been published in [17-19].

This paper is organized as follows: Section II describes a brief description of the SPICE model. Section III displays the memristor I-V characterizations analyzing the four type of the memristor behaviors of the bipolar, the unipolar, the bipolar with forgetting effect memristor, and the reversible process between the bipolar and the unipolar. Section IV concludes this paper.

II. DESCRIPTION OF THE MEMRISTOR MODEL

To model the memristor device in SPICE, a previously published memristor models [7-10] have very good representations of the theoretical memristor, but they do not match other published memristor device characteristics very accurately. In this work, we use a SPICE memristor model [17-19] that correlates well the characteristic data published in [20], the used subcircuit is described in Fig. 1.

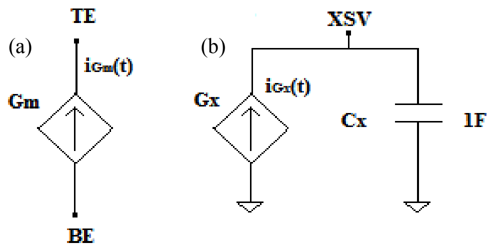

Fig. 1 SPICE subcircuit.

This model is based on three different characteristics spotted in memristive devices that match the published I-V data [12]:

- A metal-insulator-metal junction, generated by the first part (a), between TE and BE two terminals of the subcircuit.
- A threshold voltage and a dopant drift function, generated by part (b), between the XSV electrode and the ground, which is responsible for state variable motion and the nonlinear ion movement into the device.

The simulation analysis of this model is based on a set of adjustment parameters. A precise description of the parameters used in our simulation results revealed in Table 1.

These multiple parameters make it possible for this device to be adaptable to a variety of characterization data of memristive devices.

For the resultant I-V characteristics displayed in Fig. 2, we use a sinusoidal voltage 0.46V and 100Hz.

Table 1
Description of the implemented parameters.

Parameters	Name	Description
a_1 and a_2	Magnitude parameters	These parameters vary according to the value of the input polarization.
b	Control parameter	This parameter controls the conductivity of the device.
A_p and A_n	Magnitude parameters	These parameters control the speed of the ion motion.
V_p and V_n	Threshold voltage parameters	These parameters responsible for the change of the value of the state variable.
x_0, x_p, and x_n	Physical parameters	These parameters control the movement of the dopants and responsible of the linearity of the device. x_0 represents the initial value of the state variable.
α_p and α_n	Fitting parameters	These parameters control the linearity of the movement of the state variable x.
η	Fitting parameter	This parameter responsible for the change of the state variable movement depending on the polarity of the input voltage.

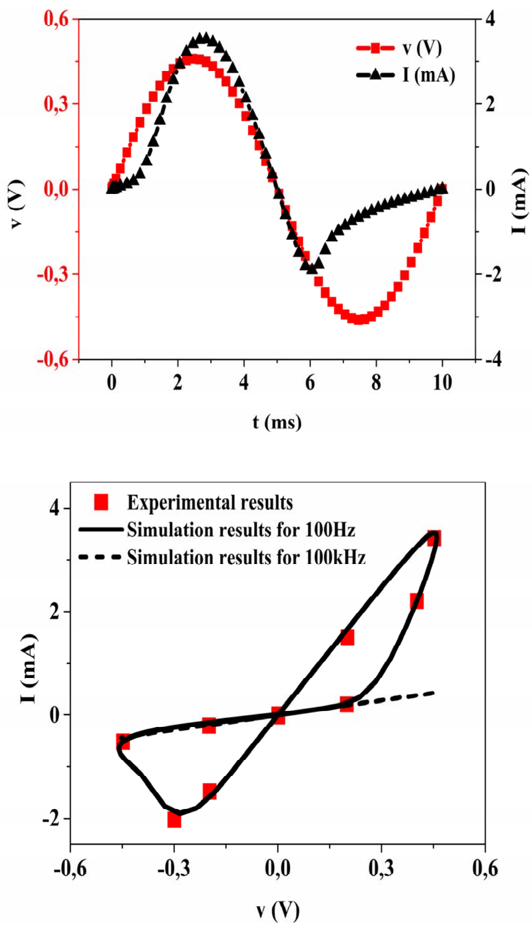

Fig. 2 Curve of I and V applied to the terminals of the memristor, and the resultant hysteresis loop at 100Hz and 100kHz.

Both the shape of the I-V characteristic and the value of each of the current peaks shows an agreement with experimental results described in [17]. We simulated the device for a higher value of frequency 100kHz, to confirm the basic property of a memristor, which it acts like a regular resistor for a higher value of frequencies.

Also, the model represents well the complex switching operation of the memristor's behavior displayed in Fig. 3, describes the memristive switching within the variation of the state variable in function of the input polarization. It depends on the bias of the applied voltage across the device. As an initial state, the memristor is considered in an Off state, i.e. high resistance level, switching the device to On state, requires a positive bias across the device. While switching it to Off state requires negative bias.

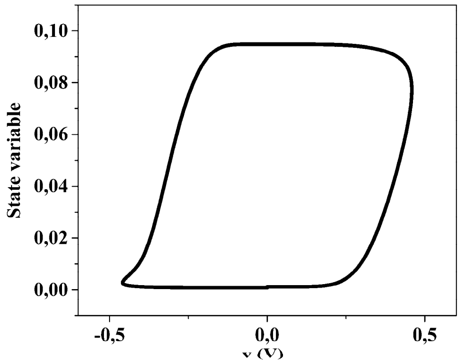

Fig. 3 Response to the state variable motion at memristor boundaries according to the applied voltage.

III. SWITCHING BEHAVIOR OF THE SPICE MODEL

In this section, we demonstrate four different responses to the switching behavior of various memristor devices within a simple model. We use a simple and flexible SPICE memristor model, comprises a number of implemented parameters, which makes it adaptable and adjustable easily. We here prove that this model is able to capture all of the four types of memristor switching behavior, i.e. bipolar, bipolar with a forgetting effect, unipolar and reversible behavior between the bipolar and the unipolar memristor.

In the literature, memristive devices with bipolar behavior [13-14] are defined by its memristance which increases and decreases by different polarities.

The unipolar switching behavior [13-14] can be defined by its memristance, which can increase and decrease by the same voltage polarity.

Memristor models that show a bipolar with forgetting effect [14-15] are defined by its memristance, which can make a change increases or decreases with different voltage polarization, but also it can spontaneously decrease at the same time, even with no voltage applied.

In addition, memristor models that show the reversible bipolar and unipolar switching behavior [16], can behave like a bipolar memristor for the first cycle of switching and after it will turn to behaves like an unipolar memristor behavior.

Furthermore, in our simulation results we different types of polarizations, either sinusoidal or repetitive DC sweeping voltage in order to present the different switching states of the memristor and thus it shows the behavior of the four different types of a memristor, i.e. bipolar, unipolar, bipolar with forgetting effect, and the reversible bipolar and unipolar switching behavior.

Thus, those results reveal the richness of memristor's dynamical behavior. So at first, we employed a sinusoidal excitation with a set value v = +/-1.8V, in order to demonstrate the bipolar switching behavior, represented in Fig. 4 (a).

The correspondent pinched hysteresis loop shown in a semi-log scale Fig. 4 (b), which represents the typical fingerprint of a bipolar resistive switching. The response of the conductance is illustrated in Fig. 4 (c) it shows a closed switching cycle in the bipolar switching behavior for a maximum value of 25mS.

These characteristics show the functionality of the model as a bipolar memristor. It is obvious that the On and Off switching behavior of the device needs a different polarity of the voltage.

We can conclude that our simulation results are consistent with the results already published in [21].

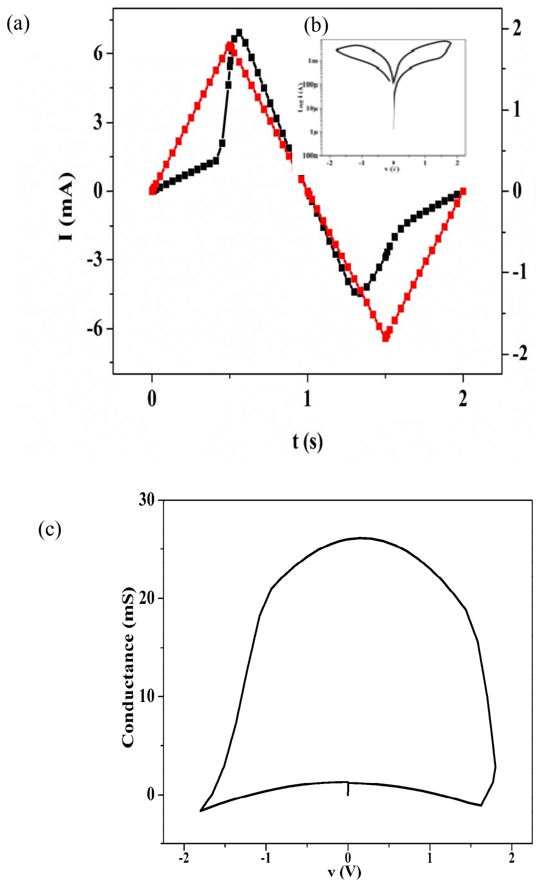

Fig. 4 characteristics of a bipolar switching behavior.

In another hand, we employed a triangular excitation for a single polarity 2V, in order to exploit the unipolar behavior of memristor, which is represented in Fig. 5.

In this case, we confirm another switching behavior characterized by our SPICE work model, we can notice a slight accumulation of the current on each pulse, and the conductance curve shows three switching cycles related to voltage pulses for a maximum value of 80mS.

The conductance initially increases (during each pulse excitation) and subsequently decays towards its original value (between two simultaneous excitations). Thus, its memristance can increase and decrease by the same polarity of the voltage.

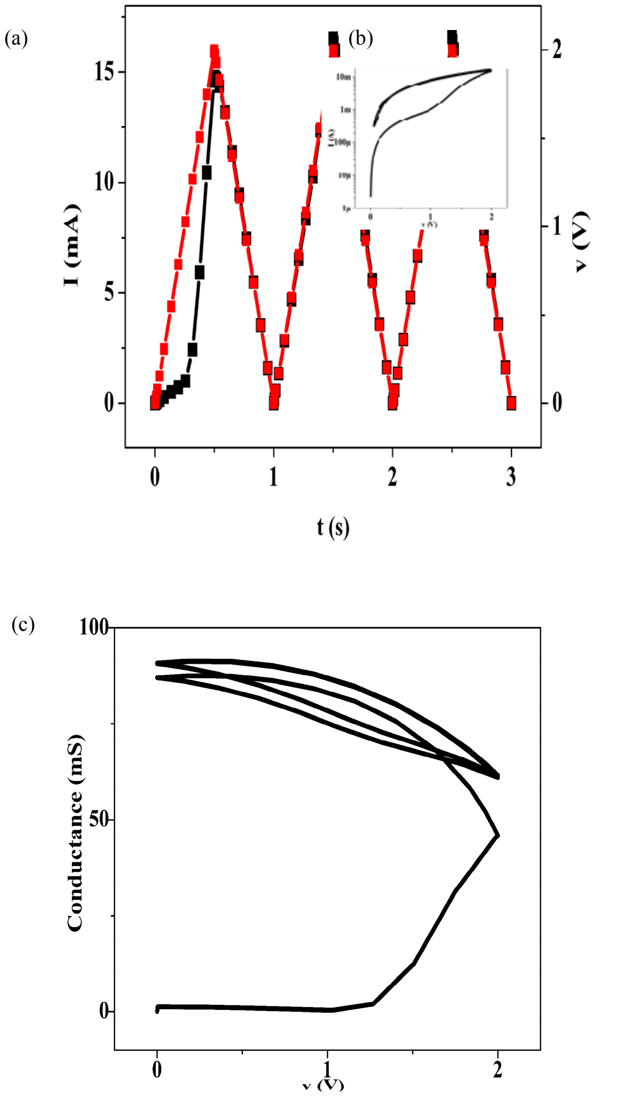

Fig.5 characteristics of a unipolar behavior switching.

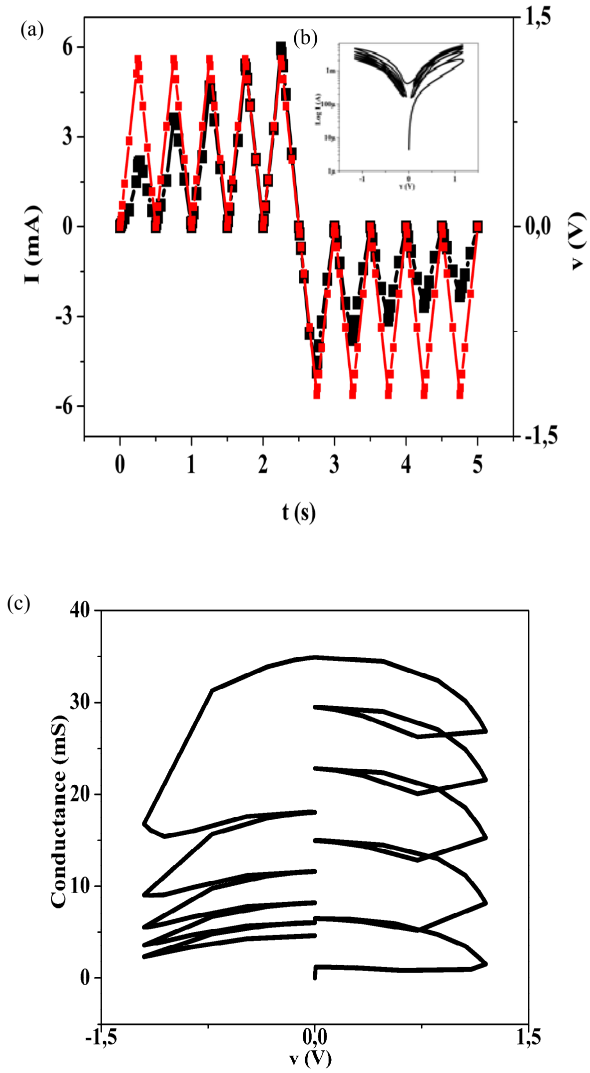

Fig. 6 characteristics of a bipolar with forgetting effect.

Another type of switching is demonstrated in Fig. 6, the bipolar switching with forgetting effect. We employed a repetitive sweeping voltage with a set value v = +/-1.2V.

We can notice the memory effect in this device with the accumulation of the current for each pulse excitation. Fig. 6 (c) shows the conductance curve varying according to the applied voltage, five simultaneous switching cycles for a higher value of conductance of 35mS.

From this response behavior, we can notice that the memristance increases and decreases by a different polarity voltage, but it also can spontaneously decrease at the same time, even with no voltage applied, and this is a unique switching behavior of memristor.

Thus, these curves show the operation of the SPICE memristor model as a bipolar memristor with forgetting effect.

The fourth type of the switching behavior of memristor device is the reversible state between the bipolar and the unipolar is represented in Fig. 7 (a-c).

The sweeping voltage excitation is shown in Fig. 7 (a) for +/-5V. The pinched hysteresis loop and the conductance of the model are shown in Fig. (b) and (c) respectively.

These curves show the four switching cycles of the device, the first cycle of the switching behavior differs to the other cycles of the switching behavior of the memristor.

In fact, the first cycle shows bipolar operation, but after the second pulse, it turned automatically to unipolar memristor behavior.

Thus, these characteristic curves show the operation of the model as a reversible process between the bipolar and unipolar memristor behaviors.

We can conclude that our simulation results are consistent and in very good qualitative agreement with the results that already has been published in [21].

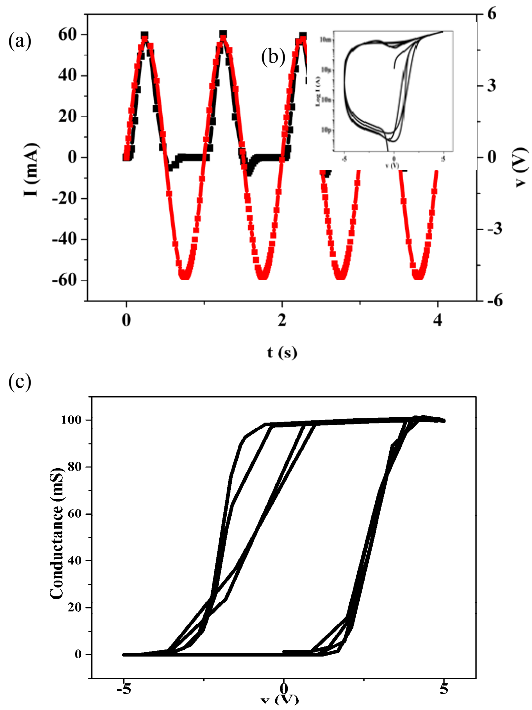

Fig. 7 characteristics of the reversible bipolar and unipolar behavior.

IV. Conclusion

In this paper, we prove the flexibility of the SPICE memristor model in order to be adaptable and adjustable to fit and confirm four different types of switching behavior. We explain the switching behavior of the bipolar, the unipolar, the bipolar with forgetting effect, and the reversible effect between the bipolar and the unipolar effect.

Our simulation results demonstrate a regular hysteresis curve obtained for the bipolar memristor, an increase of the conductance for the unipolar memristor, an obvious overlap between the neighbor loops for the bipolar memristor with forgetting effect, and finally a changing behavior of the device from bipolar to unipolar switching for the reversible process between bipolar and unipolar memristor,

We conclude that this SPICE model has a special advantage on describing various memristors models with an average number of parameters, because its simplicity, flexibility, and low complexity.

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