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Regular paper

A versatile window function for linear ion drift memristor model – A new approach

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A B S T R A C T

The memristor is a nano-scaled resistive switching device which is widely investigated in analog and digital applications. We report here our success in formulating a new window function as applicable to linear ion drift model. Accordingly, this paper identifies the demerits of other existing window functions and the requirement of a versatile window function to mimic the current-voltage characteristics of a physical memristor device. The proposed new window function overcomes the demerits of existing window functions such as boundary effect, boundary lock (with respect to frequency of operation), and the scalability. The main significance of proposed model is to facilitate the nonlinearity in linear ion drift memristor model that produces the pinched hysteresis loop (a signature of a memristor) for any typical applied voltage within the frequency range ($0.05 \leq f < 2$ Hz). The validation of which has been verified in a memristor based op-amp circuitry. It exhibits a high gain compared to other existing models and produces low power dissipation compared to CMOS based op-amp.

1. Introduction

Memristor is a missing fourth fundamental passive circuit element which is conceived by Leon Chua in 1971 [1]. Memristive device based on TiO_2 was apparently first demonstrated by Strukov et al. [2]. Considering the resistive properties of memristor, it has become an element of surprise for various analog applications such as chaotic circuit, oscillators, filters, programmable analog circuit, sensors, cellular neural networks and alike [3–5] as well as digital applications viz., fuzzy processor [6] and non-volatile memory devices [4,5]. To throw more insight into memristors, various models have been proposed in the past focusing on obtaining Pinched Hysteresis Loop (PHL), a typical indicator of memristive characteristics. Hitherto, modeling of memristor is being carried out by using Linear Ion Drift Memristor Model (LIMM) [2], Non-Linear Ion Drift Memristor Model [7], Simmon Tunnel Barrier Model [8] and Team Model [9].

Each of these models has its own pros and cons. In LIMM, nonlinearity is very less and assumes two conditions which are (i) uniform electric field and (ii) the average mobility of ions [13]. To mitigate this problem, window functions play an important role in LIMM such as Jogelker [10], Biolek [11], and Prodromakis [12]. In view of various setbacks in using these revealed models with respect to LIMM, we introduce a new window function which overcomes the boundary lock issues pertaining to low frequency which was not thought of before according to our best knowledge. Accordingly, we have proven the versatility of our window function and compared its performance with respect to other existing window functions with respect to LIMM.

2. Linear ion drift memristor model

Memristor is defined as the rate of change of flux with respect to charge [1], which is represented in Eq. (1)

$$d\phi = M(q)dq \tag{1}$$

where $M(q)$ is the memristance.

The memristor consists of a bilayer of titanium-di-oxide which is sandwiched between two platinum electrodes [2,13] as shown in Fig. 1. The bilayer consists of two layers, one is oxygen deficient titanium-di-oxide (TiO_{2-x}) layer, which offers On State Resistance (R_{ON}) and another is perfect titanium-di-oxide layer (TiO_2) which offers Off State Resistance (R_{OFF}).

In memristor, the initial state of the memristance is high, which is shown in Fig. 2(a). When the positive voltage is applied across the memristor, the positively charged oxygen vacancies are drifted from TiO_{2-x} to TiO_2.Hence, the width of the defected titanium-di-oxide increases, simultaneously total memristance decreases and current conductivity increases. Therefore, the memristor switches from OFF state to ON state, which is illustrated in Fig. 2(b). This process is termed as the completion of growth of the conducting filaments [14]. At this stage the polarity is reversed, that is the negative voltage is applied at the Top

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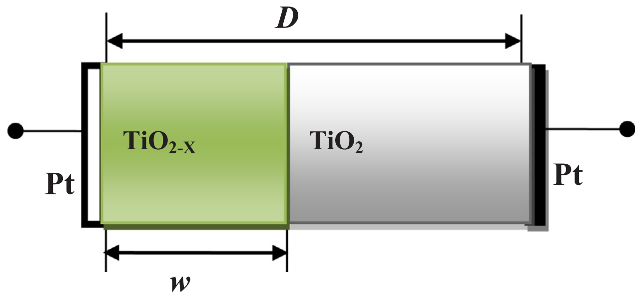

Fig. 1. Schematic structure of a bilayer memristor.

Electrode (TE) with respect to the Bottom Electrode (BE), the positively charged oxygen vacancies are repelled from TiO_2 to TiO_{2-x}, the process is termed as rupturing of the conducting filament [14]. As a result, the width of the defected titanium-di-oxide decreases consequently affecting the total memristance to increase and the current decreases. Thus, the memristor switches from ON state to OFF state as illustrated in Fig. 2(c).

The above said behavior is mathematically described in Eq. (2) for a linear ion drift memristor model,

$$V(t) = \left(R_{ON}\frac{w(t)}{D} + R_{OFF}\left(1-\frac{w(t)}{D}\right)\right)I(t) \tag{2}$$

where $w(t)$ is the width of the non-stoichiometric region, $V(t)$ is the applied voltage, $I(t)$ is the current flow through the memristor, and D is the distance between the two platinum electrodes.

The LIMM is simulated in Cadence® software with virtuoso tool for the applied voltage of ± 2 V at 0.5 Hz. It produces the bow-tie like loop the so-called PHL with less nonlinearity as shown in Fig. 3. In LIMM, it is understood that boundary effect and boundary lock are the two main prevailing problems. When the virtual boundary reaches to the metal/oxide interface, the rate of change of width (dw/dt) is suppressed to zero. Consequently, the memristance is fixed to either of the resistance states. That is, it is fixed either at minimum on-state resistance or maximum off-state resistance. This effect is known as boundary effect.

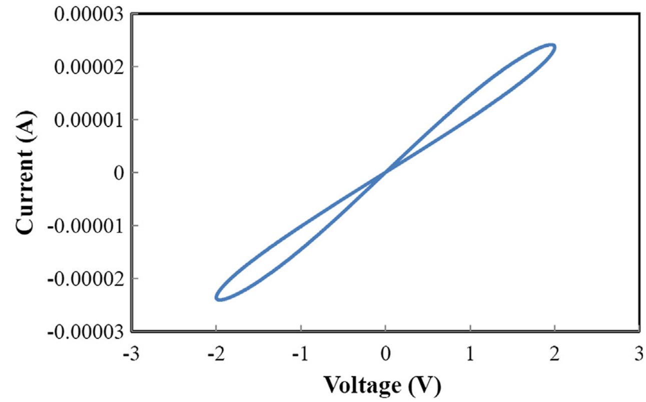

Fig. 3. The pinched *I-V* loop obtained for linear ion drift memristor model, a characteristic signature of a bilayer memristor.

On the other hand, if the applied voltage is large enough, then internal state variable (x) might reach the terminal boundaries faster and fixed at the boundary (+) as stated before. This phenomenon is known as boundary lock.

3. Different types of window functions

Window functions are used to retain the ions within the boundaries and mimic the properties of the physical memristor device. By computing the parameters of the available window functions, it is possible to use memristor model in different electronic applications.

3.1. Jogelker window function

The Jogelker window function [10] is represented in Eq. (3)

$$f(x) = 1-(2x-1)^{2p} \tag{3}$$

where $f(x)$ represents the window function, p is the positive integer and x is the internal state variable.

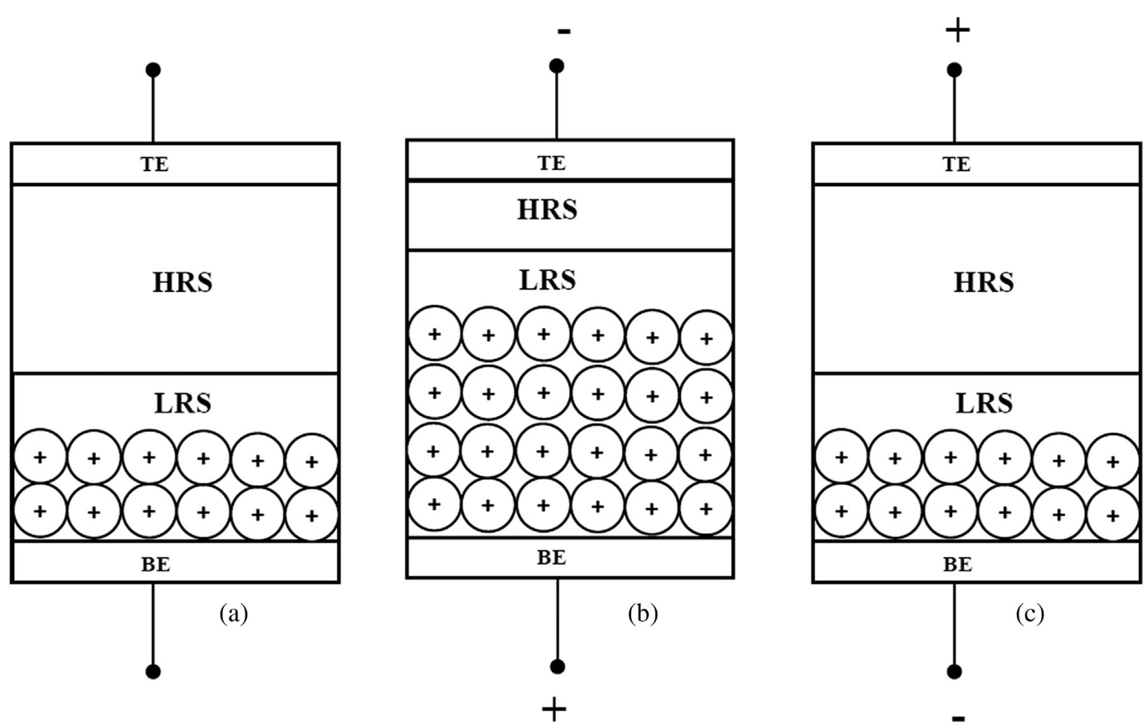

Fig. 2. Different bias conditions of a memristor (a) Before bias (b) Positive bias and (c) Negative bias.