TiO₂ Memristor Modelling with LabVIEW

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Abstract

The fourth fundamental circuit element-Memristor, was mathematically modelled by Prof. Leon Chua in 1971. After about four decades, researchers at the Hewlett–Packard (HP) laboratories submitted the development of a new basic circuit element that completes the missing link between charge and flux linkage, which was suggested by Chua. Though a physical memristor device was not discovered then, many unique simulation applications are executed to take advantage of memristor feature which is different from other circuit elements by many researchers. In this paper, we use TiO₂ memristor model on account of its simplified expressions and the same ideal physical behaviors. Firstly, we obtained the mathematical equations of TiO₂ memristor. Then, these equations are created with LabVIEW and results are submitted. Finally, results of this system's behavior and stability analysis of are submitted.

Keywords: LabVIEW, Memristor, modelling and simulation, physical behavior.

LabVIEW ile TiO₂ Memristör Modellemesi

Özet

Dördüncü temel devre elemanı olan memristor, 1971'de Prof. Leon Chua tarafından matematiksel olarak modellendi Yaklaşık kırk yıl sonra. Hewlett-Packard (HP) laboratuvarlarındaki araştırmacılar, Chua tarafından keşfedilen, akı ve yük arasındaki eksik bağlantıyı tamamlayan yeni devre elemanını geliştirdi. Fiziksel memristör keşfedilmemiş olsamasına rağmen, birçok araştırmacı tarafından diğer devre elemanlarından farklı olan memristor özelliklerinden yararlanmak için birçok benzersiz simülasyon uygulaması gerçekleştirilir. Bu makalede, basitleştirilmiş ifadeler ve aynı ideal fiziksel davranışlar nedeniyle TiO2 memristor modelini kullanıyoruz. Öncelikle, TiO2 memristorun matematik denklemlerini elde ettik. Ardından, bu denklemler LabVIEW platformunda oluşturulmakta ve sonuçlar sunulmukatadır. Son olarak, bu sistemin davranış ve kararlılık analizinin sonuçları sunulmaktadır.

Anahtar Kelimeler: LabVIEW, Memristör, modelleme ve benzetim, fiziksel davranış.

1. Introduction

Leon O. Chua published his work where the fourth passive two-terminal electrical component memristor was described in 1970s [1]. Current, voltage and magnetic flux are the basic elements in circuit theory. There is a relationship between them. Three of them define the three basic devices which are resistor, capacitor, inductor. They showed that memristor should represent the relation between electric, charge (q) and magnetic flux (φ),

$$d\varphi = Mdq \qquad (1)$$

Herewith Memristor was developed for several times, but the scientists did not realised, that they developed a new component–memristor [2]. R. S. Williams who is leader of HP team invented this item, while they have been searching for a device which is a resistor with a state and not for a device, which has charge – magnetic flux relation. This work was published and it include the first relations for memristor modeling [3].

Memristor has drawn the worldwide attention after HP released its invention. After then many researchers focus on this element. Owing to different properties, memristors are being found out for many potential applications in the areas of nonvolatile memory very-large-scale integrated (VLSI) circuit, digital image processing, artificial neural networks, and pattern recognition and signal processing [4].

In this paper, we focalize the memristor modeling with LabVIEW. We submitted memristor model with different mathematical statement. Similar works have not founds up to, thus we assume that this is a different publications of the models and simulations described below. In methods, our nonlinear model of the memristor is presented and a formula is given in order to infer model parameters used physical parameters. In methods, measurements of simulation are defined. Final part of methods contributions of this paper are summarized.

2. The Memristor

In 2008, R. Stanley Williams of Hewlett Packard was submitted an experimental solid state version. It has TiO2 and TiO2-x sandwiched in between platinum electrodes. TiO2 is resistive and TiO2-x conductive and the ratio of these two layer varies with the application of current. They had designed a cross-bar structure with a layer of platinum dioxide, a layer of switching molecules and a thin film of titanium sandwiched between two platinum electrodes.

A semi-conductor device was either use magmatic field as flux or keeps charge as capacitor, memristor which has memory feature used chemical mechanism. One of the film slide depletion of oxygen atoms. The absence oxygen act as carriers it mean that the depleted layer has lower resistance than the non-depleted layer. Meanwhile the resistance of the film is dependent on how much charge has been went through it, in a particular direction, which is convertible by changing the direction of current [5-8].
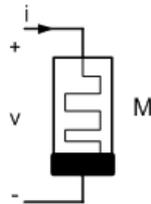
Figure 1. The memristor.

A memristor device is essentially a two-terminal passive electronic element with memory capacity. Its memristance state is affected from amplitude, polarity, and duration of the external applied power. The physical model of the HP memristor from [7], shown in Figure 1, consists of a two layer thin film (thickness $D \approx 10$nm) of TiO2 sandwiched between two platinum electrodes. One of the layers, which is described as TiO2$-x$, is doped with oxygen vacancies and thus it exhibits high conductivity. The width w of the doped region is modulated depending on the amount of electric charge passing through the memristor.
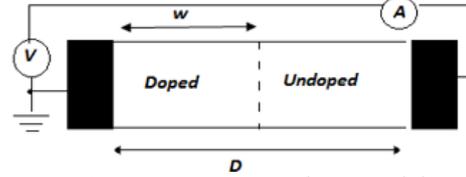
Figure 2. HP's memristor model.

Fig. 2 exhibits HP's memristor model. We see that total memristance is made of w and D regions. The total resistance of the memristor, M, is a sum of the resistances of the doped and undoped regions:

$$M(t) = Ron\left(\frac{w(t)}{D}\right) + Roff\left(1 - \frac{w(t)}{D}\right) \qquad (2)$$

where R_{on} and R_{off} are the limited values of memristance for w=D and w=0. We selected internal state as = w/D [0,1] then we rewritten as

$$M(t) = Roff + (Ron - Roff)x(t) \qquad (3)$$

when t=0, the initial memristance is

$$M_0 = Roff + (Ron - Roff)x_0 \qquad (4)$$

resistance of doped area affects the movement speed of the boundary between the doped and undoped regions

$$\frac{dx}{dt} = ki(t)f(x), \ \ k = \mu_V Ron/D^2 \qquad (5)$$

where $\mu v \approx 10^{-14}$ m^2 s^{-1} V^{-1} is the average ionic mobility parameter. As for a memristive device, these nonlinearities are manifested particularly at the thin film edges, especially at the two boundaries. This phenomenon, called nonlinear dopant drift, can be simulated by multiplying a

proper window function (x) on the right side of (5).
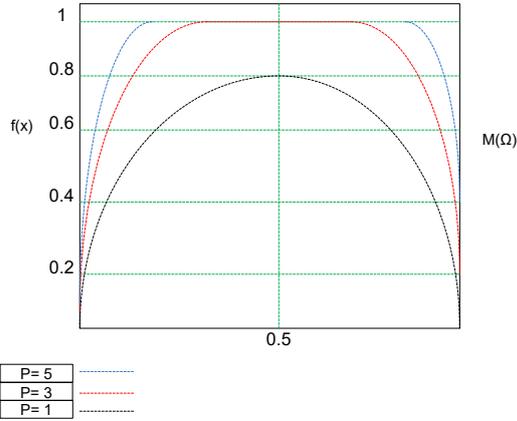
Figure 3. Joglekar window function for $P = 1$, $P = 3$ and $P = 5$.

$$f(x) = 1 - (2x - 1)^{2P} \qquad (6)$$

where P is a positive integer called the control parameter. Fig. 3 shows the behaviour of the Joglekar window function for different values. Nonlinearity changes with value of P integer. As the integer P increases, the model tends to the linear. Based upon this, we selected P=1.

$$f(x) = 4x - 4x^2 \qquad (7)$$

Substituting (7) into (5),

$$\int_x^{x(t)} \left(\frac{1}{x(\tau)} - \frac{1}{1-x(\tau)}\right) dx(\tau) = \int_0^t 4ki(\tau)\, d\tau \qquad (8)$$

where the internal state variable satisfies $x(\tau) \in [x_0, x(t)]$ and the integration time is $0 \le \tau \le t$.

Assume $q_0 = 0$; we can get

$$\frac{x(t)}{1-x(t)} = \frac{x_0}{1-x_0} * e^{4kq(t)} \qquad (9)$$

then the expression of x(t) can be calculated as

$$x_0 = \frac{R_{off} - R_0}{\Delta R} \qquad (10)$$

then, the expression of $x(t)$ can be calculated as

$$x(t) = 1 - \frac{1}{Ae^{4kq(t)} + 1} \qquad (11)$$

where A is a constant and its value is determined by Roff , Ron, and $R0$:

$$A = \frac{R_{off} - R_0}{R_0 - R_{on}} \qquad (12)$$

This mathematical statements are used for modelling memristor. They are made control and simulation block in LabVIEW.

3. Memristor Modelling with LabVIEW

We developed a behavioral model of a memristor at device level using the LabVIEW programme by following the mathematical equations presented before. The reason of preferring the LabVIEW program is its graphic based structure and the ease provided to user in constituting interface [10].

We examined TiO2 memristor model to make it easy to comprehend and ready to be used in memristive systems.

We used labVIEW programme which is a graphics-based software platform. The usage of program is going up in engineering applications for making this model [11]. We used mathematical equations which are given previous part. Model depicted control and simulation block in labVIEW. Fig.4 shows the memristor model of LabVIEW front panel.
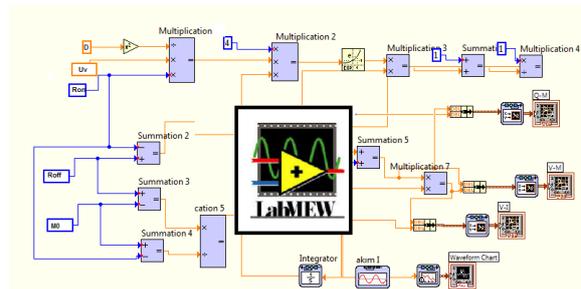

Figure 4. Memristor model of LabVIEW.

The parameters of the model are Ron = 100Ω, Roff = 20kΩ, $M0$ = 10kΩ, D = 10nm and μv ≈ 10-14 m2 s-1 V-1 [7]. Moreover, the simulation results in Figure 6.

$$(8)$$

In order to show memristor characteristics, values of passive elements, and,are chosen to work firstly 0.5mA input current at 5 Hz. Memristor model was simulated to examine the behavior via using LabVIEW program.
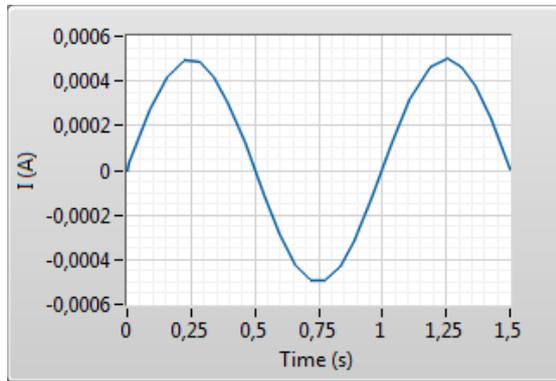
**Figure 5.** Memristor's current graph.

Fig. 5 shows that input current graph to time. The value of this is 0.5 mA sinus flowing through the memristor in this model.
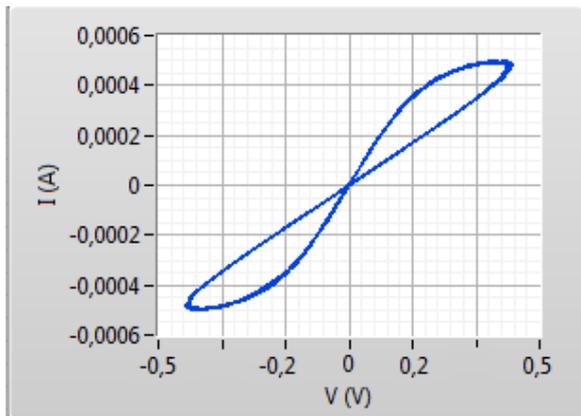
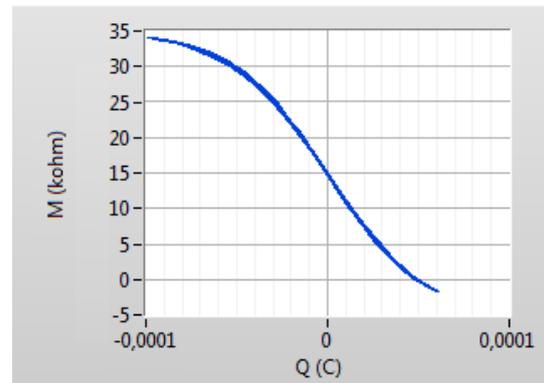**Figure 6.** Relationship between memristor's current (I) and voltage (V).

The typical hysteresis loop in figure 6 shows its switching characteristic; that is, the memristance can switch between low resistance and high resistance.

One of the most important memristors' observed specialty is the existence of a pinched hysteresis that effect could be represented by the i−v pinched hysteresis loop characteristic, as Chua highlighted that 'If it's pinched, it's a memristor' [12].
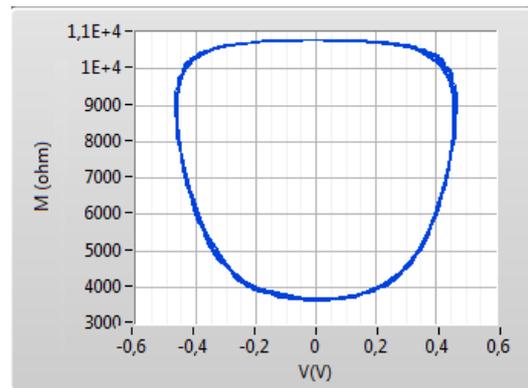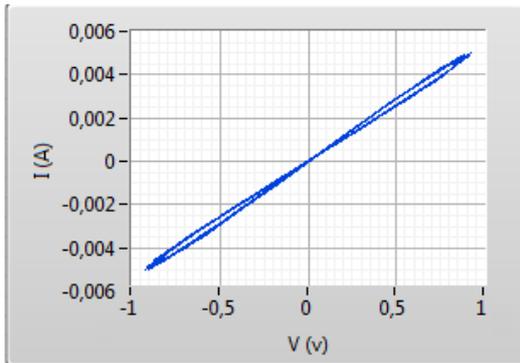

Figure 7. Relationship between memristor's voltage and memristance.

Figure 7 illustrates that the memristance is a nonlinear function of the flow of charge. Figure 8 shows the relationship between the memristance M and the charge q. Especially, in the part of the higher memristance state, the change ratio of the memristance is low, while, in the part of the lower memristance state, the change ratio of the memristance is high.
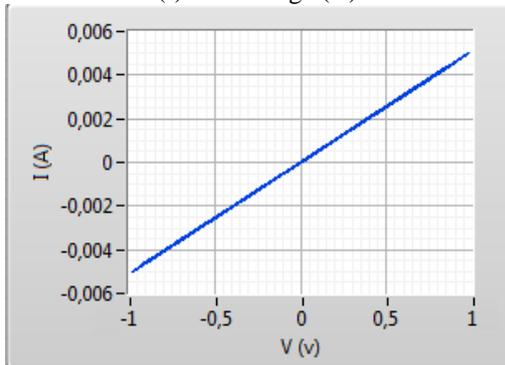

Figure 8. Relationship between memristor's charge and memristance.

If we increase input signal frequency, memristor behave as linear resistor. Fig.9 shows signal frequency is at 20Hz and fig.10 shows that memristor's loop turns the line chart at 200 Hz.

Figure 9. Relationship between memristor's current (I) and voltage (V).

Figure 10. Relationship between memristor's current (I) and voltage (V).

4.Conclusion

Although HP workers has inveted to memristor physically, it is not submitted to the market yet and it will be probably not available for at least some years. Hence, memristor studies are still going on theoretically and based simulation. This paper is one of them. Since memristors have a natural nonlinear behaviour, they can be used in chaotic circuit systems and other different systems such as secure communication and cryptology. The main aim of this study is to show the possibility of application of memristor based circuits.

LabVIEW environments were used to achieve simulation and real time application.

5. References

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