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Research Article

A Simple Test for Memristors with High R_{OFF}/R_{ON} Ratio

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Abstract: Semiconductor components must be tested before their usage. Memristors are nonlinear circuit elements, whose existence has been predicted in 1971 and a memristive system behaving as memristor has been found in 2008. It is actually a nonlinear resistor with charge-dependency. In recent years, memristor has become an important research area. In addition to ideal memristors, memristive systems are nowadays also called memristors. However, memristor is not entirely known as a circuit element and there is still research undergoing to model it. Memristor has different models used in literature, nonlinear dopant drift models, linear dopant drift models and threshold-based models. If memristor would become commercially available and start being commonly used in circuits, it will also need testing methods to be used by circuit designers. In this paper, by reviewing some of the memristor models given in literature, a simple test is suggested to be applied for individual memristors with high R_{OFF}/R_{ON} ratio. This test can be done using only a multimeter or an ohmmeter and is able to verify whether the memristor is good or bad.

Keywords: *Memristor, Component test, Thin films.*

Yüksek R_{off}/R_{on} Oranlı Memristörler İçin Bir Test Yöntemi

Özet: Yarı iletken elektronik elemanlar kullanımlarından önce test edilmelidirler. Memristörler varlığı 1971 yılında ortaya atılmış olan doğrusal olmayan elemanlardır ve bir memristif sistem 2008 yılında bulunmuştur. Memristörler son yıllarda önemli bir araştırma alanına dönüşmüştür. Ayrıca memristörlere ilave olarak memristif sistemler de memristör olarak adlandırılmaktadır. Literatürde memristörlere ait lineer iyon sürüklenme hızlı, doğrusal olmayan iyon sürüklenme hızlı ve eşik voltajlı olmak üzere çok sayıda model bulunmaktadır. Bir gün memristörler ticari olarak satıldığında devre tasarımcılarının bir memristör test yöntemine ihtiyaç olacaktır. Bu makalede öncelikle çeşitli memristör modelleri incelenmiş ve yüksek R_{OFF}/R_{ON} oranına sahip memristörler için bir test yöntemi verilmiştir. Bu test sadece bir multimetre ya da ohmmetre kullanılarak yapılabilmekte ve ölçülen memristörün sağlam ya da bozuk olduğunu göstermektedir.

Anahtar kelimeler: *Memristör, Eleman test, İnce filmler.*

1. Introduction

Some thin-film memristive systems are shown to behave as if memristors [1-8]. Such memristive systems are nowadays commonly called memristors in spite of being not ideal memristors. Analog and digital applications of memristor have become hot research topics currently [9-11]. It is the belief of the authors of the paper that, once the element is matured enough, it will be commercially available in the market in the future and memristor-based analog circuit applications such as programmable oscillators, amplifiers and comparators will emerge. In this case, memristor-based circuits or memristors will need test devices or testing methods. A simple test for ideal memristors is given in [12]. Some memristors have high R_{OFF}/R_{ON} ratio (Off-state resistance to on-state resistance ratio) [24-26]. In this paper, considering saturation mechanism of an ionic memristor, a simple test for non-ideal memristors with high R_{OFF}/R_{ON} ratio is suggested in order to learn whether a memristor

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is broken or not. The paper is organized as follows; after the introduction in the second section the model of HP memristor, the TiO_2 nonlinear dopant drift memristor model and the memristor model with threshold voltages are explained; in the third section a simple test for thin-film memristors is given. The paper ended with a conclusion.

2. Memristor Models

In this section, three different models of an ionic memristor which exist in literature are introduced. The models are given to justify the applicability of the memristor test which is suggested in this paper.

2.1. HP Memristor Model or Linear Drift Modeling of Memristor

A memristor can be modeled with two constitutive relationships as either current or voltage controlled [1,7]. The terminal equations of the current-controlled memristor is given as

$$v(t) = \mathrm{M}(q)i(t) \tag{1}$$

$$i(t) = \frac{dq}{dt} \tag{2}$$

where M(q) is the memristance of the memristor. Memristance of a memristor can be expressed as,

$$M(q) = \frac{d\varphi(q)}{dq} \tag{3}$$

Memristor charge is the integration of current and memristor flux is the integration of its voltage with respect to time and, respectfully, these are equal to

$$q(t) = \int_{-\infty}^{t} i(\tau)d\tau \tag{4}$$

and

$$\varphi(t) = \int_{-\infty}^{t} v(\tau)d\tau \tag{5}$$

Memristance function is linearly dependent on memristor charge in linear dopant drift TiO_2 memristor model [1] and is given as

$$M(q) = \frac{d\varphi}{dq} = R_{OFF}\left(1 - \frac{\mu_V R_{ON}}{D^2}q(t)\right) \tag{6}$$

In (eq. 6), D is the length of the TiO_2 thin film, μ_v is mobility of oxygen ions in memristor, and R_{ON} and R_{OFF} are low and high resistance levels respectively. Function of memristance can be simplified as in following;

$$M(q) = \frac{d\varphi}{dq} = M_0 - K_q q(t) \tag{7}$$

where $M_0=R_{OFF}$ is the maximum memristance, K_q is the charge coefficient of the memristance, and $q(t)$ is the instantaneous memristance charge.

Therefore, the following is always true for the resistance of a memristor:

$$R_{OFF} \geq M(q) \geq R_{ON} \tag{8}$$

2.2. Nonlinear Ion Drift Memristor Model

Memristor models with nonlinear ion drift or current dependency exist in literature [13-15]. They have window functions to have nonlinear drift speeds within the TiO_2 region. The window function shows how a memristor deviates from being an ideal memristor. Their resistance value starts varying when the window function is different from zero. The memristor model in [13] is given as,

$$v(t) = R(x)i(t) \tag{9}$$

$$\frac{dx}{dt} = \frac{\mu_v . i(t) R_{ON}}{D^2} f(x,i) \tag{10}$$

where w is the memristor's oxidized length, $x=w/D$ is the length of normalized oxidized area, $f(x,i)$ is the window function, $R(x)$ is the memristance or resistance of memristor, and the rest of the parameters are the same as those given in the previous section.

The window function for the memristor model in [13] and in Eq. 9 is given as,

$$f(x,i) = 1 - \left(x - stp(i)\right)^{2p} \tag{11}$$

For all the nonlinear dopant drift models, the memristor resistance is given as

$$R(x) = R_{ON}x + R_{OFF}(1-x) \tag{12}$$

Its resistance stays between the minimum and the maximum value, R_{ON} and R_{OFF} respectively.

$$R_{OFF} \geq R(x) \geq R_{ON} \tag{13}$$

2.3. Nonlinear Dopant Drift Memristor Model and Threshold Voltages

A memristor model with nonlinear drift and has threshold voltage is can be found in [16]. The model has two independent window functions and its memristance value can be changed with the voltage level higher than its threshold voltage.

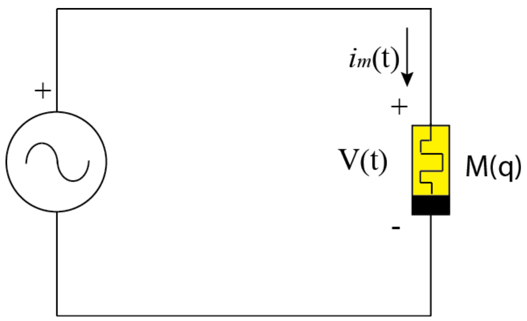

Figure 1. AC-supplied memristor.

The memristor model in [16] is given as,

$$v(t) = R(x)i(t) \tag{14}$$

$$\frac{dx}{dt} = \begin{cases} \frac{\mu_v i(t) R_{OFF}}{D^2} f(x,i) & , \quad V_{TH} \le V \\ 0 & , \quad V_{TH} \le V < V_{TH} \\ 0 & , \quad -V_{TH} \le V < V_{TH} \\ \frac{\mu_v i(t) R_{OFF}}{D^2} f(x,i) & , \quad V_{TH} \le V < -V_{TH} \\ 0 & , \quad V \le V_{TH} \end{cases} \qquad (15)$$

where $f(x,i)$ is its window function, V_{TH} is its threshold voltage, and the rest of the parameters are the same as those given in the previous section.

The memristor resistance does not vary under threshold voltage in this model. The window function of the memristor, f(x,i) in eq. 15 is given as

$$f(x,i) = 1 - (x - stp(i))^{2p} \qquad (16)$$

The memristor resistance is still given as

$$R(x) = R_{ON}x + R_{OFF}(1-x) \qquad (17)$$

Again, the following is true:

$$R_{OFF} \ge R(x) \ge R_{ON} \qquad (18)$$

3. Memristor Saturation and a Simple Test for Memristors

Tests are commonly used for semiconductor circuit elements. For example, the test for a diode is well-known and also every good quality multimeter has a "diode check" function. A diode conducts well showing a low resistance when the voltage across its anode-cathode is positive. A diode does not conduct well revealing a high resistance when the voltage across its anode-cathode is negative. A similar test can be easily adapted to a memristor. The topology and the equivalent circuit of a TiO_2 memristor are shown in Figures 2 and 3, respectively, displays a similar property and, according to all models given in the previous section. When a signal with regular voltage higher than its positive threshold voltage is applied to the memristor for a time longer than its resistive switching time [17, 18], the oxygen vacancies are fully doped and its memristance takes its minimum value, R_{ON}, as shown in Figure 4.a. When a voltage that higher than its negative threshold voltage is applied to the memristor in a negative manner for a time longer than its switching time, the oxygen vacancies are not doped in TiO_2 and its memristance takes its maximum value, R_{OFF}, as shown in Figure 4.b.

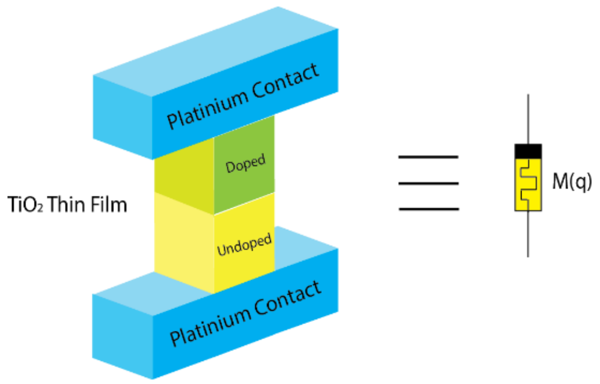

Figure 2. TiO_2 Memristor topology.

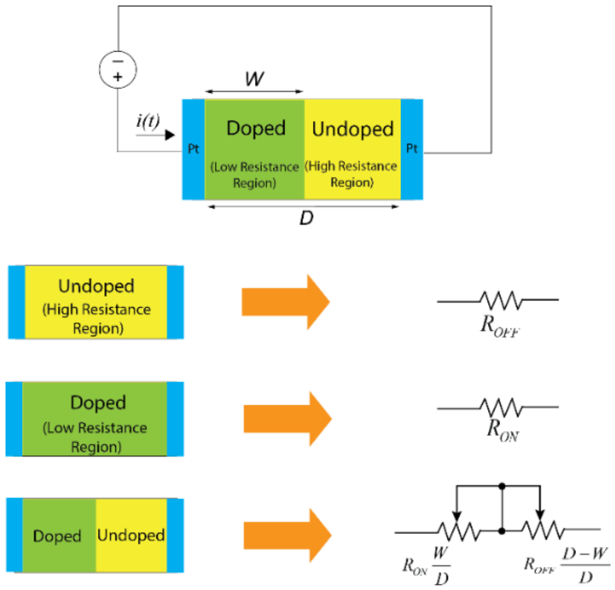

Figure 3. TiO_2 memristor and its equivalent circuit model [1].

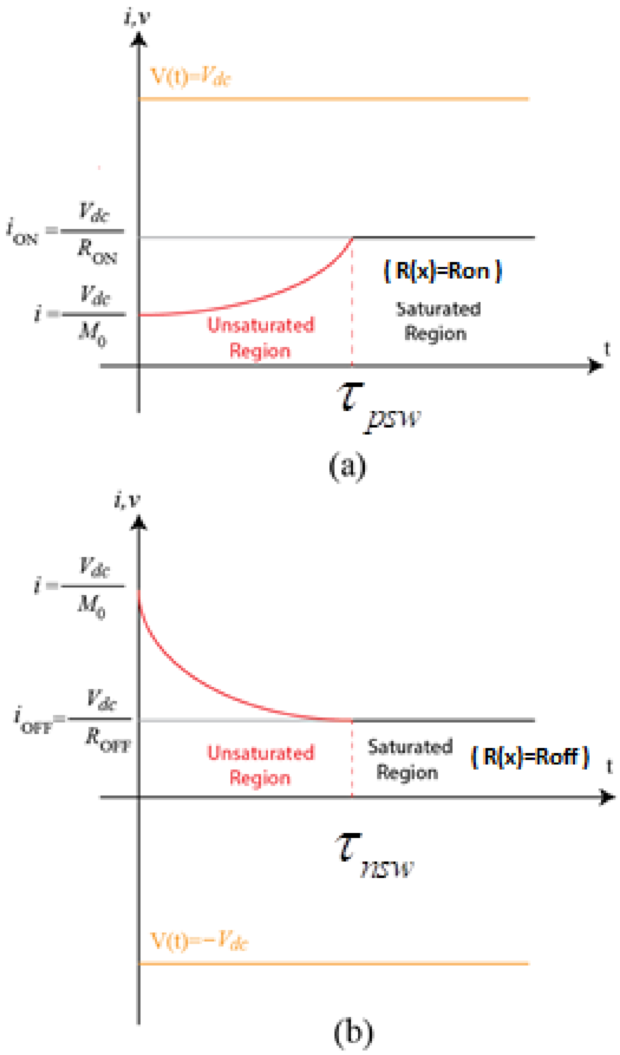

Figure 4. a) Saturated and unsaturated regions when a positive DC voltage applied to the memristor, when the level of the memristance decreases in value and the memristor saturates at R_{ON} b) when a negative DC voltage applied to, memristance level raises and the memristor saturates at R_{OFF}.

In [17], a memristor emulator of HP memristor model designed in [19] is used to give a memristance calculation methodology. The saturation phenomena of the memristor emulator using a square-wave with frequency low enough to show memristive switching for both positive and negative polarities is shown in Figure 5. If an ionic memristor to or the memristor emulator excited with a DC long enough, as shown in Figure 5, the memristor saturates, which means that its memristance would take minimum or maximum values. For a memristor with threshold voltages to switch its state, the memristor must be supplied a voltage higher than its polarity-dependent threshold voltage. The switching time of the memristor, which is the time expectation for the saturation under a constant DC voltage, was examined in [18]. The pulse half-cycle's duration must be a bit longer than the switching time in order for the saturation phenomena to occur.

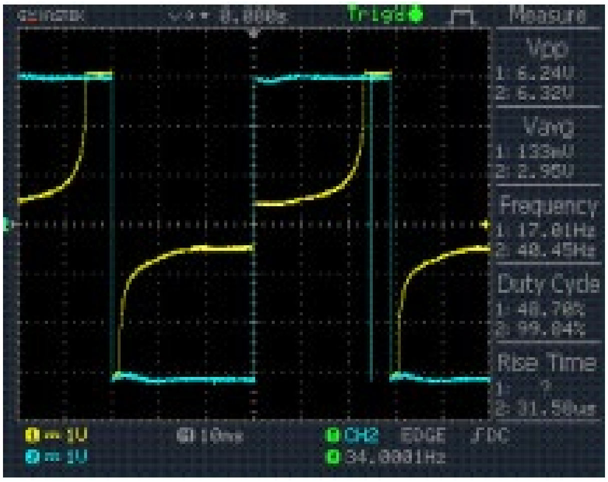

Figure 5. The memristor emulator voltage and current are shown in turquoise and yellow respectively. Negative and positive saturation phenomenon can be seen in current of the memristor.

If a memristor with high R_{OFF}/R_{ON} ratio becomes commercially available and out in the market, the following test can be done to learn whether it is good (working) or bad (failed).

• If the memristor is not broken, when used with an ohmmeter or multimeter, as shown in Figure 6, and the memristor is forward-biased, i.e. with positive DC voltage applied for a sufficient time for resistive switching to occur in this direction. A value almost its minimum resistance value, R_{ON}, is measured considering its manufacturing tolerances. Perhaps provided with its catalog in the future. For a memristor with threshold voltages to switch its state to minimum resistance, the memristor must be supplied with a voltage which higher than its positive threshold voltage.

• If the memristor is not broken, when used with an ohmmeter or multimeter,, as shown in Figure 6, and the memristor is reverse-biased, i.e. with negative DC voltage applied for a sufficient time for resistive switching to occur in this direction, a value almost its maximum resistance value, R_{OFF}., It is measured considering its manufacturing tolerances. For a memristor with threshold voltages to switch its state to maximum resistance, the memristor must be supplied with a negative voltage whose absolute voltage level is higher than its negative threshold voltage.

• It should be stated that such memristor with a high R_{OFF}/R_{ON} ratio is broken or useless if readings are the same in both directions.

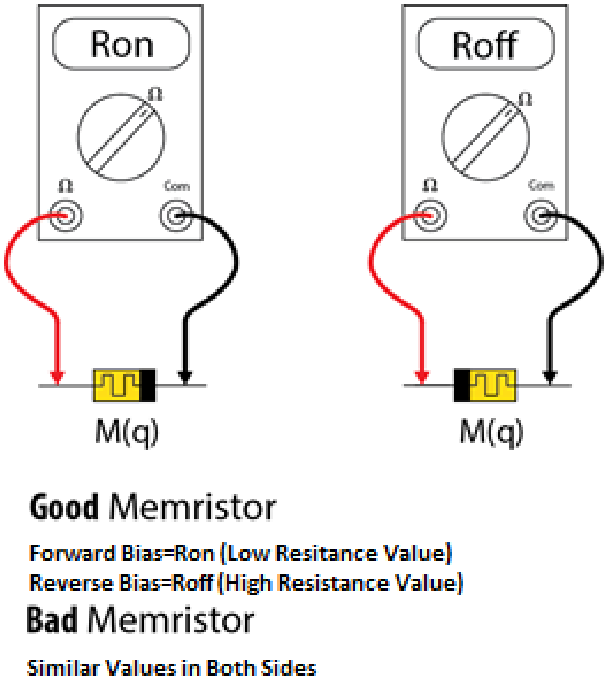

Figure 6. Memristor test with an ohmmeter.

4. Conclusion

In the future, the circuit designers or repairmen will require test methods to verify whether a memristor works properly or not. In this study, a simple robustness test for an ionic memristor with a high R_{OFF}/R_{ON} ratio is suggested. The test is easy to apply and requires just an multimeter or ohmmeter. It can also be used easily in the microcontroller-based measurement and test systems. In the future, the authors hope that memristors as newly circuit elements will be in the market for analog circuit applications and the suggested test can make application of memristor easier. Such a test, perhaps after some modification, can also be used in memristor emulator circuits such as the ones given in [20-22]. Unfortunately, such a test cannot be used to test memristive systems with bipolar resistive switching [23] or complementary resistive switches [16].

References

[1] D. B. Strukov, G. S. Snider, D. R. Stewart, and R. S. Williams," The missing memristor found," Nature (London), Vol. 453, pp. 80-83, 2008.

[2] Vongehr, Sascha, and Xiangkang Meng. "The missing memristor has not been found." Scientific reports 5, 2015.

[3] L. O. Chua," Memristor - The Missing Circuit Element," IEEE Trans.Circuit Theory, Vol. 18, pp. 507-519, 1971.

[4] L. O. Chua and S. M. Kang," Memrisive devices and systems," Proc.IEEE, Vol. 64, pp. 209-223, 1976.

[5] T. Prodromakis, and C. Toumazou. "A review on memristive devices and applications." 17th IEEE International Conference on Electronics, Circuits and Systems, 2010.

[6] Yu V. Pershin, J. Martinez-Rincon, and M. Di Ventra. "Memory circuit elements: from systems to applications." Journal of Computational and Theoretical Nanoscience 8.3, 441-448,2011.

[7] Y. V. Pershin and M. Di Ventra, "Memory effects in complex materials and nanoscale systems," Adv. Phys., vol. 60, pp. 145–227, Apr. 01, 2011.

[8] L. Chua, "Resistance switching memories are memristors,"

Appl. Phys. A, vol. 102, pp. 765–783, 2011.
[9] M. Roberto, G. Gelao, and A. G. Perri. "A Review on Memristor Applications" International Journal of Advances in Engineering & Technology 8.3, 294, 2015.
[10] S. Shin, K. Kim, and S.-M. Kang. "Memristor applications for programmable analog ICs." IEEE Transactions on Nanotechnology 10.2, 266-274, 2011.
[11] Mohamed E. Fouda, and A. G. Radwan. "Memristor-based voltage-controlled relaxation oscillators." International Journal of Circuit Theory and Applications 42.10, 1092-1102, 2014.
[12] Y. V. Pershin, and M. Di Ventra. "A simple test for ideal memristors." Journal of Physics D: Applied Physics, Volume 52, Number 1, 2018.
[13] Z. Biolek, D. Biolek, and V. Biolkova. "SPICE Model of Memristor with Nonlinear Dopant Drift." Radioengineering 18.2, 2009.
[14] Y. N., Joglekar, and S. J. Wolf. "The elusive memristor: properties of basic electrical circuits." European Journal of Physics 30.4, 661, 2009.
[15] T. Prodromakis, et al. "A versatile memristor model with nonlinear dopant kinetics." IEEE transactions on electron devices 58.9, 3099-3105, 2011.
[16] E. Karakulak, R. Mutlu, E. Uçar, "Reconstructive sensing circuit for complementary resistive switches-based crossbar memories." Turkish Journal of Electrical Engineering & Computer Sciences 24.3 (2016): 1371-1383.
[17] R. Mutlu, and E. Karakulak, "A methodology for memristance calculation." Turkish Journal of Electrical Engineering & Computer Sciences 22.1 (2014): 121-131.
[18] F.Z. Wang, N. Helian, S. Wu, M.G. Lim, Y. Guo, M.A. Parker, “Delayed switching in memristors and memristive systems”, Electron Device Letters, Vol. 31, pp. 755–757, 2010.
[19] R. Mutlu, E. Karakulak, “Emulator circuit of Ti02 memristor with linear dopant drift made using analog multiplier", National Conference on Electrical, Electronics and Computer Engineering, pp. 380-384, 2010.
[20] A. Yeşil, Y. Babacan, and F. Kaçar, “A new DDCC based memristor emulator circuit and its applications”, Microelectronics Journal, 45(3), 282-287, 2014.
[21] Y. Babacan, A. Yesil, and F. Gul, “The fabrication and MOSFET-only circuit implementation of semiconductor memristor”, IEEE Transactions on Electron Devices, 65(4), 1625-1632, 2018.
[22] Ş. Yener, and Kuntman, H., A new CMOS based memristor implementation. In 2012 International Conference on Applied Electronics (pp. 345-348), 2012.
[23] F. Gul, H. Efeoglu, Bipolar resistive switching and conduction mechanism of an Al/ZnO/Al-based memristor. Superlattices and Microstructures, 101, 172-179. 2017.
[24] N. S. M. Hadis, A. A. Manaf, S. H. Herman, S. H. Ngalim, (2015, July). ROFF/RON ratio of nano-well fluidic memristor sensor towards hydroxide based liquid detection. IEEE 15th International Conference on Nanotechnology (IEEE-Nano) (pp. 1078-1081), 2015.
[25] L. Gao, F. Alibart, D. B. Strukov et al., “Programmable cmos/memristor threshold logic,” IEEE Transactions on Nanotechnology, vol. 12, no. 2, pp. 115–119, 2013
[26] A. Mazady, Modeling, Fabrication, and Characterization of Memristors. PhD Thesis, University of Connecticut, 2014.