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Research Article

The Impact of the Different Voltages and Frequencies on Resistivity of the TiO_2-based Memristors with 3D Observation in MATLAB

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Abstract

Memristor is the fourth fundamental element that was theoretically discovered about 40 years ago by Professor Leon Chua and was introduced alongside three other existing elements (resistor, capacitor and inductor) in the electronic world. Until recently, however, the construction of a physical example of this had not yet taken place. Finally, in 2008, HP introduced a nanometer-sized TiO_2 structure with predictable memory behavior and hysteresis. In this paper, after introducing the general characteristics and structure of the memristor, a 3D MATLAB model with nonlinear ion deflection for the titanium dioxide memristor made by HP with current or voltage control capability is presented. By setting the model parameters for the specifications of this memory, some simulations are performed and the results are displayed.

Keywords: Memristor, TiO_2, 3D Matlab simulations

1. Introduction

Memristor or memory resistor are two dual terminal elements of circuits. The memistor is made in nanoscale dimensions and its resistance depends on the amplitude, polarity, and duration of the applied voltage. The hysterical current-voltage curve in the memristor allows this element to act as a non-volatile resistor and to remember information until a voltage of different magnitude and polarity is applied to it, even up to a year later [1-3].

RAM is inherently completely erased after a power outage. However, in 1971 the idea of memory conservation was put forward in theory, and this phenomenon came to fruition in 2008 [4].

Memoristor or Memory Resistor an electrical member has two terminals in which a functional connection is established between an electric charge and a magnetic flux. When the current enters the same device from one direction, the electrical resistance increases, and when current flows in the opposite direction, the resistance decreases. But when the current stops, this component of the circuit maintains the last resistance it has, and when the load current starts again, the resistor will be at the last time of operation. It is a resistance actuator with almost linear resistance as long as the current diagram remains in a certain range over time [5-6].

Memristor was formally formulated and named by Chua in an article published in 1971. In 2008, a team in the HP Laboratory officially announced the production of a variable-layer, thin-film memory. This means that the memristor can be used for nanoelectronic memory and computer neuromorphic structures.

In the 1971 article, Shen Chua received a concept between the resistor and the inductor-capacitor and was inspired by a simple, basic idea similar to that of a device such as a memristor. Although the relationship between voltage and current in a memristor is not as linear as that of a varistor, other scientists have previously described nonlinear relationships for electric charge flux, but Chua's theory was more pervasive. The resistance of the memristor depends on the correct input port given to the terminal (unlike the varistor, which depends on the amount of instantaneous input). This component of the circuit inflates the amount of current it emits, which was discarded by Chova as a memristor. In other words, the memristor is a neutral member of the circuit and has two terminals that can maintain the relationship between the function of current in time and voltage in time. The graph of this function is called memory; And is similar to the variable resistance. Batteries also have a memristor but are not a neutral member. The definition of a memristor is specifically based on the main variables of the circuit, namely current and voltage, and their relationship to time. Just like resistors, capacitors, and inductors.

Unlike these three circuit components (resistor, inductor, and capacitor) which can have constant values with respect to time, the memristor relation is nonlinear and can be expressed as a function of the circuit variable, ie net load current. There is no such thing as a standard memristor. Instead, any device that plays a functional role in expressing voltage in terms of current or vice

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versa. A type of memristor is a simple resistor. Like other two-circuit components (capacitor, resistor, and inductor), there is no ideal memristor. Rather, it has a small amount of resistance, capacitance, and induction [7-10].

Obtaining a pure model for the memristor helps to predict the behavior of this component and features of the memristor need understanding the reaction of this element under different voltages, currents and frequencies. In this way, generating a 3D model to show the specifications of this component under voltage-current-frequency will be very useful. This paper shows the reaction of the model of the TiO2-based memristor generated by Chua under different window functions.

2. The Structure, Properties and Formulas of the Memristor

2.1. General Features of the Memristor

Memristor stands for Memory Resistor. In terms of hardware, it is a microscopic instrument that can maintain its previous electrical condition, and with this trick, it is possible to preserve temporary memory even after a power outage.

If we consider resistance as a water pipe, and water as electric charge. The amount of resistance will be proportional to the diameter of the tube. So far, the resistors have had a fixed pipe diameter, but the memristor is like a pipe whose diameter changes with the amount and direction of flow. If the flow is in the right direction, the diameter of the pipe is more. The current remains constant. These unique features have prompted the construction of the Memorial to promise a greater transformation than the transformation of the twentieth-century transistor invention.

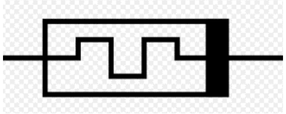

Figure 1. Memristor

2.2. Titanium dioxide memorizers:

Spintronic Memristor:

Xin Chen and Xiobin Wang, two researchers in hard disk drive technology at Seagate Technology in Bloomington, Minnesota, described three possible examples of magnetic memristors in March 2009. In one of the three samples, the resistance created by the rotation of the electrons in one part of the device's pointer in a different direction than the other parts creates a boundary "wall wall" between the two states. Electrons moving towards the device have a special spin that causes a change in the magnetic state of the device. The magnetic change, in turn, causes the field wall to move and change the resistance of the device. This work has received a lot of attention in the electronic press, including interviews on the IEEE spectrum.

Magnetic resistance of rotational torque transmission:

MRAM Spin torque transmission is a well-known instrument that shows memristive behavior. The resistance depends on the relative rotation between the two sides of the magnetic tunnel connection. This, in turn, can be controlled by the torque induced by the current through the connection. However, the duration of the current through the connection determines the amount of current required, for example, the electric charge charged in this way is the main variable.

In addition, as reported by Krzysteczko et al., The MgO tunnel connections based on MgO show the mammoth behavior based on the discharge of oxygen vacuum inside the MgO layer of insulation (resistance change); Thus, the combination of torque and resistance switching naturally results in a second-order master system with W = (WI, W2) in which WI represents the magnetic state of the magnetic tunnel connection and W2 represents the resistance state of the MgO barrier. Note that in this case the current is controlled in the WI switch (torque is due to the high current density) while in the W2 switch the voltage is controlled. (Oxygen discharge is high due to high electric fields).

Magnetic Memory System:

Although the use of the word "memristor" has not been described, a study of two-layer manganese-based oxide layers for non-volatile memory was conducted by researchers at the University of Houston in 2001. Some diagrams show the tunable and adjustable resistance based on the number of voltage pulses applied, similar to the effects of titanium dioxide on memristor materials.

Wavy tunneling diode memristor:

In 1994, FABoyt and E.K. Rajagopal at the U.S. Naval Research Laboratory demonstrated that the "current-voltage" bow-like (IV) feature in AIAs / OaAs / AIAs quantum diodes involved the design of a specific doping layer of separating layers in Agree with published experimental results. This characteristic of the bow-current voltage (like I-V) is characteristic of a memristor, although the term memristor is not explicitly used in the articles. There is no magnetic interaction in the analysis of Hyperion features such as I-V [10-12].

3. MATLAB Codes and Results

In this section for the mentioned doped (TiO_2) and undoped (Ti) blocks, different types of the input voltages under Memristor Parameters: Ron = 100, Ro = 4k condition are given are results are reported. Different window functions with P=1, 2, 5, and 10 are presented and the results are presented.

MATLAB simulation for Ti and TiO_2 blocks was carried out by means of the following codes, and the applied voltage, current, and current-voltage curves were obtained. The important detail is that, for applying the voltage to the structure, two thin layers of the platinum is considered.

3.1 Resistance of memristor respect to different votages:

In this step, different voltages from -3 to 3 volts by 0.01V steps are imposed to output terminals of the memristor, and the resistivity of this component is analyzed. Below the MATLAB codes are presented and the Resistance-Time-Voltage cure is shown in figure 2:

```
clear all
t=0:0.01:2;
v=-3:0.01:3;
Ri=6000;
f=1;
Ron=100;
Roff=16000;
```

```
D=0.0000001;
DDM=0.00000000000001;
k=DDM.*Ron^2./D^2;
for ii=1:length(t);
for jj=1:length(v);
R(ii,jj)=sqrt(Ri.^2-((2.*v(jj).*k*(Roff-
Ron))./(pi.*f)).*sin(pi.*f.*t(ii)).^2);
end
end
mesh(real(R))
ylabel('Time')
xlabel('Voltage')
zlabel('Resistance')
```

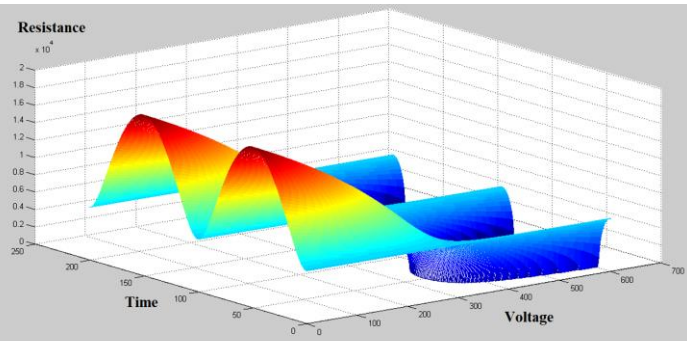

Figure 2. The Resistance-Time-Voltage cureve for Chua TiO_2 Memristor

3.2 The resistance cureve respect to different voltages and frequencies:

This subsection presents the Resistance-Voltage-Frequencu curve under different window function coefficients from P=1 to P=10. The general MATLAB codes can be written as follows:

```
clc;
clear all;
close all;
p=0.7;
v_d(1)=0;
f_p=[];
L=[];
F=5:-0.01:0.5;
for ii=1:length(F)
    f=F(ii);
t = 0:0.01./f:1./f;
v(:,ii)=-3*sin(2*pi*f*t);
d = 10^(-8);
j=2;
u_v=10*10^-15;
r_on=100;
r_off=16000;
r_i=4000;
w(1)=((r_off-r_i)/(r_off-r_on))*d;
```

```
x(1)=w(1)/d;
m(1)=r_on*(w(1)/d)+r_off*(1-w(1)/d);
% f_p(1)= 1 - (2*x-1)^(2*p);                  %Joglekar window
 f_p(1)=j*(1 - ((x(1)-0.5)^2+0.75)^p);         %Prodromakis window
for index=2:length(t)
    i(index,ii)=v(index)/m(index-1);
    v_d(index)=(u_v*r_on*i(index)*f_p(index-1))/d;
    w(index)=v_d(index)*(t(index)-t(index-1))+w(index-1);
    x(index)=w(index)/d;
%     f_p(index)=1 - (2*x(index)-1)^(2*p);              %Joglekar window
     f_p(index)=j*(1 - ((x(index)-0.5)^2+0.75)^p);   %Prodromakis window
    m(index,ii)=r_on*(w(index)/d)+r_off*(1-w(index)/d);
    if m(index)<r_on
        m(index)=r_on;
    end
    if m(index)>r_off
        m(index)=r_off;
    end
    x(index)=w(index)/d;
end
end
F1=repmat(F,101,1);
mesh(v,F1,m)
xlabel('Voltage')
ylabel('Frequency')
zlabel('Resistance')
```

Figures 3, 4, 5, and 6 presents the results for window function coefficients from P=1 to P=10 respectively.

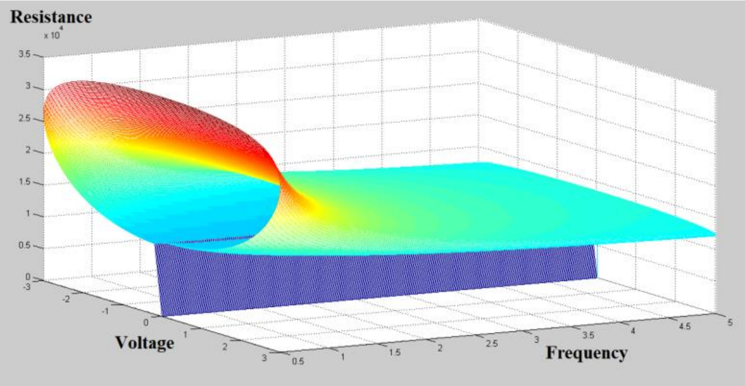

Figure 3. The Resistance-Voltage-Frequency cureve for Chua TiO_2 Memristor with P=1.

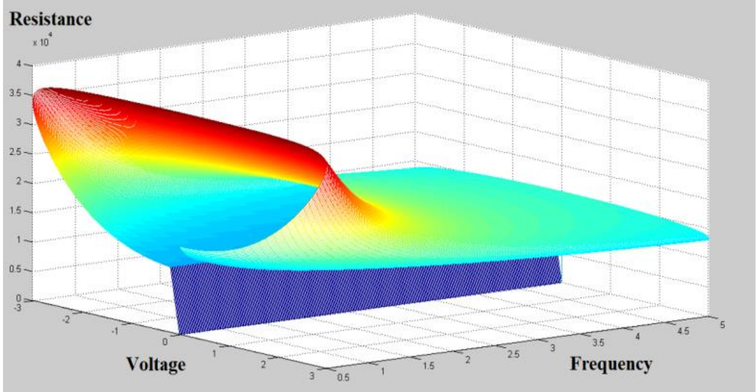

Figure 4. The Resistance-Voltage-Frequency cureve for Chua TiO_2 Memristor with P=2.

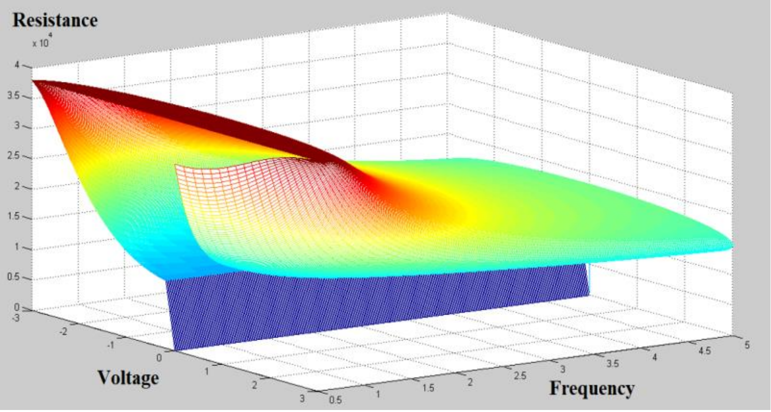

Figure 5. The Resistance-Voltage-Frequency cureve for Chua TiO_2 Memristor with P=5.

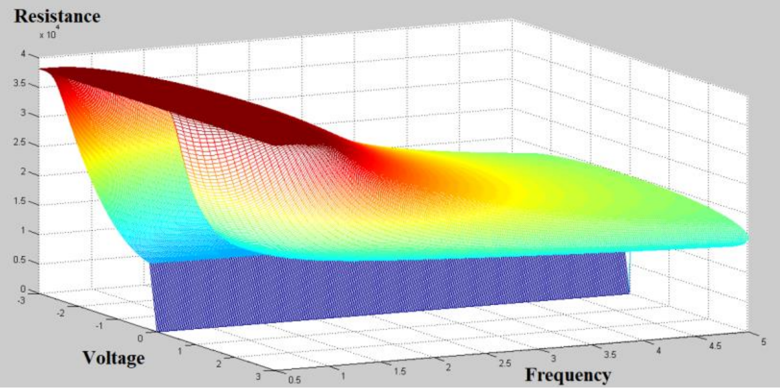

Figure 6. The Resistance-Voltage-Frequency cureve for Chua TiO_2 Memristor with P=10.

3.3 The Voltage-Current Hysteresis curves respect to different voltages and frequencies:

The I-V characteristics of the TiO2-based memristor are obtained by follows codes and figure 7.

```
clc;
clear all;
close all;
p=1;
v_d(1)=0;
f_p=[];
L=[];
F=2:-0.01:0.5;
for ii=1:length(F)
    f=F(ii);
t = 0:0.01./f:1./f;
v(:,ii)=1*sin(2*pi*f*t);
d = 10^(-8);
j=2;
u_v=10*10^-15;
r_on=100;
r_off=16000;
r_i=4000;
w(1)=((r_off-r_i)/(r_off-r_on))*d;
x(1)=w(1)/d;
m(1)=r_on*(w(1)/d)+r_off*(1-w(1)/d);
% f_p(1)= 1 - (2*x-1)^(2*p);                %Joglekar window
 f_p(1)=j*(1 - ((x(1)-0.5)^2+0.75)^p);        %Prodromakis window
for index=2:length(t)
    i(index,ii)=v(index)/m(index-1);
    v_d(index)=(u_v*r_on*i(index)*f_p(index-1))/d;
    w(index)=v_d(index)*(t(index)-t(index-1))+w(index-1);
    x(index)=w(index)/d;
%     f_p(index)=1 - (2*x(index)-1)^(2*p);            %Joglekar window
     f_p(index)=j*(1 - ((x(index)-0.5)^2+0.75)^p);   %Prodromakis window
    m(index,ii)=r_on*(w(index)/d)+r_off*(1-w(index)/d);
    if m(index)<r_on
        m(index)=r_on;
    end
    if m(index)>r_off
```

```
          m(index)=r_off;
     end
     x(index)=w(index)/d;
 end
 end
 F1=repmat(F,101,1);
 mesh(F1,v,i)
 xlabel('Frequency')
 ylabel('Voltage')
 zlabel('Current')
```

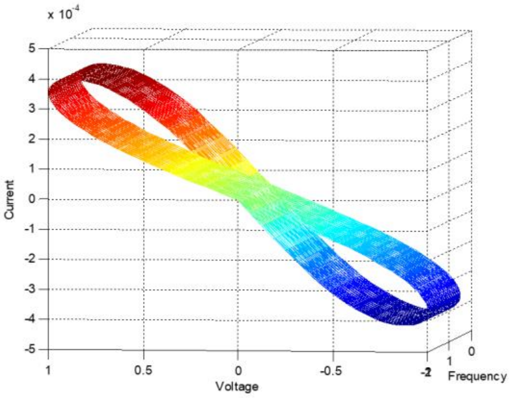

Figure 7. The I-V characteristics for Chua TiO_2 Memristor with voltage from -1 to 1 and frequencies from 0 to 2 Hz.

4. Conclusion

This study presents the MATLAB codes for the estimation of the resistive behavior of the TiO_2-based memristors according to the model that is presented by Leon Chua. Results show that many of the parameters like the function window coefficient, and voltages and frequencies values are important and act as the effective issues for the modeling. Based on the results, for voltages closed to zero, the frequency can not affect the resistivity more, but when the voltage is being larger (V>0) or smaller (V<0), for the lower frequencies, the resistivity is more and for the higher frequency values the resistivity is less. This makes the memristor ready for the higher current feature in higher frequencies. Although the study presents a frequency-based observation, still the reaction of the memristor devices under high frequencies in the kHz domain is a serious concern.

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