Evaluation and Realization of Memristor emulator spice

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Abstract. The fourth missing element of electrical device now are attractive in many applications, memristor is one of the elements which the resistance depends on the historical memory of the current flowing. In this paper, a memristor device were realized, implemented and evaluated using PSPICE package. Where the HP laboratories are manufactured and tests the performance. The relationship between voltage and current characteristics has been measured in different frequencies and voltage to the memristor. The results obtained are compatible with the designed micromodel with the expected performance.

1. Introduction
The Nature on 1st May 2008 Memristor's first experimental concept Hewlet Packard (HP) laboratories have been manufactured the device [1] The interested of the fourth simple passive device was discovered with Leon Chua and predicted in 1971[2].

The name of the memristor, comes from the contraction of memory resistor that is, the function to remember the state of the previous resistance which is depends on the value and voltage polarities addition to the how much time of that voltage has been applied[3]. If the applied voltage is cut-off from the device, the memristor remembers the last resistance value and keep on it until other voltage and current is applied to the memristor element [4]

The memristor is essentially are the relation between the charge and the flux, defined mathematically as the time integral of the voltage, which need not have a magnetic flux interpretation[5]. Implementation and modeling, and realized of the memristor device in SPICE script netlist[6] The paper has the structure, section 2 in background and mathematical implementation of the device, where section 3 is the memristor emulator and simulation and the section 3 are the results of the simulation obtained.[7]

2. Memristor background definition
Basically, there are six different mathematical implementations represent the four fundamental circuit variables, current \( i \), voltage \( v \), flux \( Q \) and charge \( q \) as shown in figure 1
Figure 1. Description of the ideal memristor as the fourth passive fundamental

Circuit component[5], linking charge and flux symmetrically; Where, Current is time integral of charge Voltage is time integration of flux as faraday’s law definition and so, there is four basic circuit elements in relation between the remaining variables which called the missing element or memristor has the value memristance M with mathematical relation between charge and flux.

\[ d\phi = M dq \] (1)

The relation between voltage and current of memristor can be written as

\[ v = R(w)i \] (2)
\[ \frac{dw}{dt} = i \] (3)

Where, \( w \) is the state variable of the memristor device and \( R \) is a resistance which depend on its state variable or charge in this case. If we consider a memristor of semiconductor film with total thickness \( D \) with the boundary of two metal contact then the device is in two terminals as shown in figure 2.

Figure 2a. Doped and Undoped regions of memristor

The device is divided in two regions shown in figure 2a, the left doped region has low resistance and the right undoped has high resistance. The total resistance of the device is determined by two layers as a two-resistance connected in series. The minimum resistance can be named by \( R_{ON} \) otherwise maximum resistance is \( R_{OFF} \).

Figure 2b. Different layers resistances of memristor
The time dependent boundary between two layers is a time varying depend on the applied voltage and current on the device see figure 2a. Then, the applied voltage $v(t)$ across the device will move the boundary between two layers causing the different doping concentration of the layers which in turn different layers’ resistances, this can be mathematical modeled as [5],

$$v(t) = \left(\frac{R_{ON}}{D} + R_{OFF}\left(1 - \frac{w(t)}{D}\right)\right)i(t) \quad (4)$$

$$\frac{dw(t)}{dt} = \frac{\mu_i}{D} R_{ON} i(t) \quad (5)$$

Where, $\mu_i$ is the average ion mobilities of the semiconductor which introduce to $w(t)$

$$w(t) = \frac{\mu_i}{D} R_{ON} q(t) \quad (6)$$

Substituting 6 into 4 we obtained the total resistance $M(q)$ as follow

$$M(q) = R_{OFF} \left(1 - \frac{\mu_i R_{ON}}{D^2} q(t)\right) \quad (7)$$

3. Modelling of the memristor

The physical model as in figure 2a as listed in HP laboratories which is consists with in two-layer thin film of size $D$ that is taken in this paper in 10nm of TiO$_2$ semiconductor material and sandwiched between platinum metal contact as a study case. The doped and undoped regions have a total series resistance of,

$$R_{mem}(x) = R_{on}x + R_{off}(1 - x) = R_{off} - \left(R_{off} - R_{on}\right)x \quad (8)$$

Where $x$ is the width of the doped region with respect to the total length $D$ of the total memristor thickness

$$x = \frac{w}{D} \in (0,1) \quad (9)$$

and $R_{off}$ and $R_{on}$ are the limit values of the memristor resistance for $w=0$ and $w=D$. The ratio of the two resistances $R_{off}/R_{on}$ is usually given as 102 to 103 as typical value. This mathematical model is implemented in emulator circuit shown in figure 3

![Memristor Emulator](Figure 3)
Using HP script spice model [6] listed in table 1, with the initial parameters shown in table.

Table 1. Spice Model in HP memristor implementation following results using this parameter $R_{on}$=1 k, $R_{off}$=100 k, $R_{init}$=80 k

```
* HP Memristor SPICE Model  
* For Transient Analysis only  
******************************
* Ron, Roff - Resistance in ON / OFF States  
* Rinit - Resistance at T=0  
* D - Width of the thin film  
* uv - Migration coefficient  
* p - Parameter of the WINDOW-function  
* for modeling nonlinear boundary conditions  
* x - W/D Ratio, W is the actual width  
* of the doped area (from 0 to D)  
*.SUBCKT memristor Plus Minus PARAMS:
+ Ron=1K Roff=100K Rinit=80K D=10N uv=10F p=1
******************************
* DIFFERENTIAL EQUATION MODELING *
**********************************************
Gx 0 x value={ I(Emem)*uv*Ron/D^2*f(V(x),p)}
Cx x 0 1 IC={(Roff-Rinit)/(Roff-Ron)}
Raux x 0 1T
* RESISTIVE PORT OF THE MEMRISTOR *
*******************************
Emem plus aux value={-I(Emem)*V(x)*(Roff-Ron)}
Roff aux minus {Roff}
**********************************************
*Flux computation*
**********************************************
Eflux flux 0 value={SDT(V(plus,minus))}
***********
```

Here are some results in different voltages and frequencies
Case.1: 0.1v 0.3Hz In this case, at the low or before applying the voltage across the device the resistance value of memristor is high as can be seen in figure 5, and so when the voltages is increased
to about 300mV the current become of about 100µ in which that value reaches 3kohm. that means the memristor changed its resistance value from high or infinity to minimum value.

Table 2. Memristor form in case of 0.1V, 0.3Hz.

| $I$ ($\mu A$) | $V$ (mV) | $\frac{\Delta V}{\Delta I} = M\Omega$ |
|--------------|----------|---------------------------------|
| 0            | 0        | 0                               |
| 100          | 75       | 750                             |
| 250          | 250      | 1k                              |
| 180          | 270      | 1.5k                            |
| 100          | 300      | 3k                              |
| 0            | 400      | $\infty$                        |

Case 2: 2V, 0.3Hz in this case we increase the input voltage with the same frequency noticing the figure characteristics being more sharpener and the memristance value become larger in the same applying voltage.

Figure 5a. result of memristor in case.1

Figure 5b. result of memristor in case.2
Table 4. Memristor form in case of 0.5V,0.5Hz.

| $I$ ($\mu A$) | $V$ (mV) | $\Delta V/\Delta I = M \Omega$ |
|---------------|-----------|-------------------------------|
| 0             | 0         | 0                             |
| 4             | 100       | 25K                           |
| 7             | 250       | 35.714K                       |
| 9             | 400       | 44.44K                        |
| 9.6           | 450       | 46.875K                       |
| 8             | 500       | 62K                           |

Case 4: 2V,0.5Hz in this case the two state value resistances, at low voltage the resistance is very high; when the voltage increased to 920 mV the resistance become in low state with linear value ($\infty$).

Table 5. Memristor form in case of 2V,0.5Hz.

| $I$ ($\mu A$) | $V$ (mV) | $\Delta V/\Delta I = M \Omega$ |
|---------------|-----------|-------------------------------|
| 0             | 0         | 0                             |
| 200           | 100       | 500                           |
| 400           | 500       | 1.25K                         |
| 600           | 600       | 1K                            |
| 300           | 700       | 2.333K                        |
| 8             | 1V        | $\infty$                      |
Case 5: 2V, 50Hz increasing the applying voltage and the frequency to more than 10 Hz and so on we notice that the memristor is acting like traditional resistor in linearity characteristic.

Table 6. Memristor form in case of 2V,50Hz.

| $I$ (\( \mu A \)) | $V$ (\( v \)) | $\Delta V/\Delta I = M\Omega$ |
|------------------|----------------|--------------------------|
| 0                | 0              | 0                        |
| 5.8              | 0.5            | 86.2 K                   |
| 11.6             | 1              | 86.2 K                   |
| 17.4             | 1.5            | 86.2 K                   |
| 23.2             | 2              | 86.2 K                   |

5. Conclusions
In this paper, the memristor were realized, simulated and evaluated according to HB laboratories Pspice. The result of memristor model were implemented in spice script and with drowning symbol. The simulation obtained in this work is 5 cases tested for resistances of the device, in case 1 as two resistances values the first is infinity where the minimum is 700, in case 5 also two resistances values the first is 86.2 K\( \Omega \) where the minimum is 23\( \Omega \), the result obtained was compatible with the model and implementation of the memristor. The memristor mentioned in this paper is a resistance whose value and nature change according to the voltage and frequency highlighted, and its characteristics to be the value of its resistance high when not highlighting the voltage on it, and when the voltage is highlighted on it for a certain period of time the value of resistance differs from its predecessor, which makes it possess the property of remembering and hence came to be named by this name ((Memristor)). Pspice was used in this work to simulate memristor design and the required properties for memristor work were obtained.

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