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Memristor Modeling Using PSPICE

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ABSTRACT
Since conventional CMOS technology is facing the challenges in scaling down the devices beyond 22nm level, there is urgent need of new nanoscale devices. Memristor, known as the fourth basic two-terminal circuit element, has attracted many research interests since the first real device was developed by HP labs in 2008. The concept was originally put forward by Dr. Leon Chua in September 1971. The memristor has a unique capability of carrying a memory of its recent past. The memristor holds the value of previously applied voltage even when the power is switched off, in the form of its resistance level. That's an effect that cannot be duplicated by any circuit combination of resistor, capacitor and inductor, which is why the memristor qualifies as the fourth fundamental circuit element. The research is in progress on the concept of the memristor and its practical implementation. However it has not been commercially manufactured yet. However since memristor is at the experimental level only, the memristance characteristics and its effects in different circuits can only be observed using software simulations only. To study the effect of implementation of memristor in various electronic circuits, there is need of a standard memristor model which can be accepted universally and its results should be mathematically true and should resemble the theoretically proposed concepts. The manuscript describes a new memristor model simulated using PSPICE and its results.
Keywords – Charge—Flux relationship, I-V plot, Mathematical modeling, Memristance, Non volatile memory

I. Introduction

Memristor is the fourth fundamental component of basic electrical circuits. It was proposed by Dr. Leon Chua in 1971 [1]. But it was not manufactured in the form of a physical device at that time. However in 2008, a team led by R. Stanley William at HP Labs announced the discovery of memristor. Since then many scientists have been working on memristor and its applications in variety of fields. This manuscript gives a brief introduction of memristor and proposes a model. The proposed memristor model has been simulated using Pspice software. The manuscript concludes with advantages, limitations and future scope of memristors.

II. Literature review

The basic concept of memristor, its characteristics and a brief on modeling techniques is included in the literature review.

2.1 Introduction: Memristor, known as the fourth basic two-terminal circuit element, was originally proposed by Dr. Leon Chua in September 1971. Chua strongly believed that a fourth device existed to provide conceptual symmetry with resistor, capacitor and inductor. This symmetry follows from the description of passive elements as defined by a relation between two of the four fundamental variables. A device linking charge and flux (themselves defined as time integrals of current and voltage) which would be the memristor was still hypothetical at that time. However, on April 30, 2008, a team at Hewlett Packard Labs led by the scientist R. Stanley Williams announced the discovery of the memristor. The memristor based on a thin film of titanium oxide has been presented as an approximately ideal device. Since then a large deal of efforts has been spent in the research community to study the fabrication and characteristics of memristors.

The name 'Memristor' itself indicates its functioning as a resistor having memory of its previous condition. From the circuit-theoretic point of view, the three basic two-terminal circuit elements are defined in terms of a relationship between two of the four fundamental circuit variables, namely; the current i, the voltage v, the charge q, and the flux-linkage φ. Out of the six possible combinations of these four variables, five have led to well-known relationships. Three other relationships are given, respectively, by the axiomatic definition of the three classical circuit elements, namely, the resistor (defined by a relationship between v and i), the inductor (defined by a relationship between φ and i), and the capacitor (defined by a relationship between q and v) as stated in TABLE 1. Only one relationship remains undefined, the relationship between φ and q. It is nothing but the memristance.

Sr. No.	Definition	Equation
1.	Voltage(v)	dφ = vdt
2.	Current(i)	dq = idt
3.	Resistance(R)	dv = Rdi
4.	Capacitance(C)	dq = Cdv
5.	Inductance(L)	dφ = Ldi
6.	Memristance(M)	dφ=Mdq

Table 1. Fundamental variables of elctrical circuits

From the logical as well as axiomatic points of view, it is necessary for the sake of completeness to postulate the existence of a fourth basic two-terminal circuit element which is characterized by a φ -q curve. This element is called the memristor because, as will be shown later, it behaves somewhat like a nonlinear resistor with memory [1]. The symbolic representation of memristor is as shown in Figure 1. It was first suggested by Chua [1].

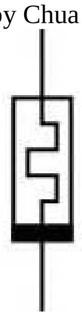

Figure 1. Symbolic representation of memristor

2.2 Characteristics of memristor: The characteristics of memristor are unique in nature. It shows a hysteresis curve on application of a sinusoidal signal. The I-V characteristics of the memristor obtained by theoretical calculations are as in Figure 2.

In the case of linear elements, in which M is a constant, memristance, is identical to resistance and, thus, is of no special interest. However, if M is itself a function of q, yielding a nonlinear circuit element, then the situation is more interesting. The i–v characteristic of such a nonlinear relation between q and Q for a sinusoidal input is generally a frequency-dependent Lissajous figure, and no combination of nonlinear resistive, capacitive and inductive components can duplicate the circuit properties of a nonlinear memristor.

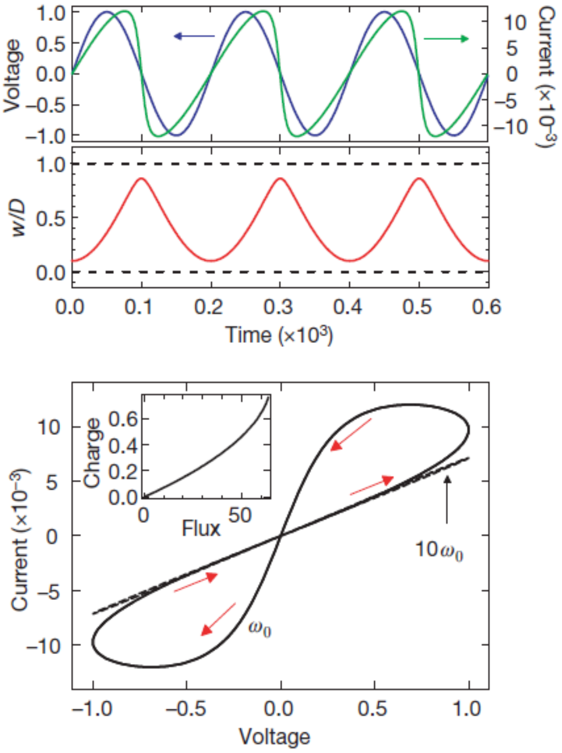

Figure 2. Input, Output, w/D and I-V Plots for Memristor [2]

2.3 Memristor modeling: There are three possible available types of memristor models ,viz., linear, nonlinear and exponential model. Linear model describes a memristor with linear drift. However, this mathematical form presents us with many difficulties such as the absence of physical boundary conditions. The Nonlinear model solves this problem by incorporating a window function that restricts the drift between the two physical limits (0<x<1). This Nonlinear model still doesn't satisfy the specifications of real devices because of its linear dependence on the current (electric field). The Exponential model adds nonlinear dependence on current in its drift equation. In addition, it uses an exponential I-V characteristic based on experimental data. The manuscript proposes a new model by referring an earlier model proposed by Biolek in [3].

III. Proposed memristor model

The memristor model by Biolek [3] has been taken as reference since it is considered to be one of the most efficient models in the research of memristor. The model proposed in[3] is as shown in Figure 3.

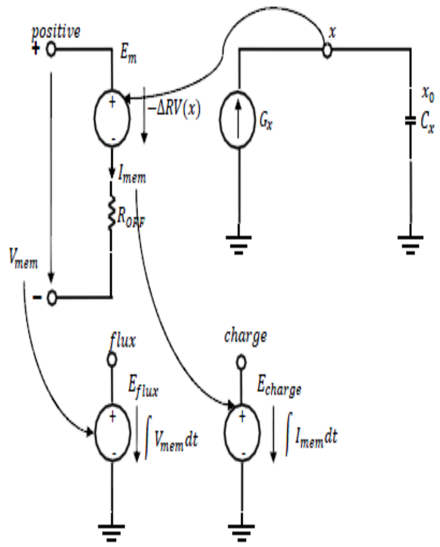

Figure 3. Reference model

The memristor library function for this model is as follows:

```
.SUBCKT memristor Plus Minus PARAMS:
+ Ron=10 Roff=16K Rinit=11K D=10N uv=10F
p=10
****************************************
* 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))}
****************************************
*Charge computation*
***************************************
Echarge charge 0 value={SDT(I(Emem))}
****************************************
* WINDOW FUNCTIONS
* FOR NONLINEAR DRIFT MODELING *
****************************************
*window function, according to Joglekar
.func f(x,p)={1-(2*x-1)^(2*p)}
*proposed window function
;.func f(x,i,p)={1-(x-stp(-i))^(2*p)}
.ENDS
```

The new model has been simulated in PSPICE software in the form of a library function. The component saved as a memristor in the library can be used in any circuits using PSPICE.

The proposed model can be represented as shown in Figure 4.

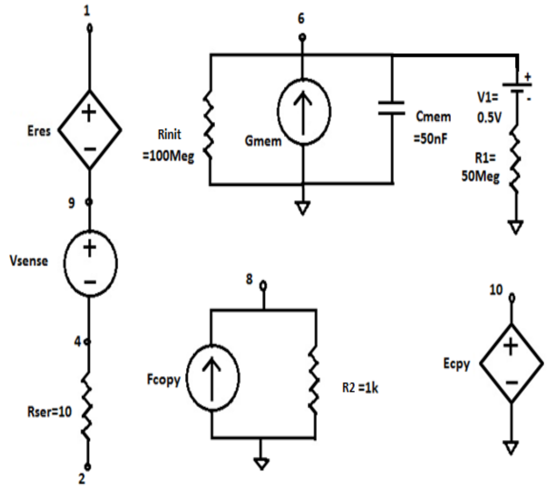

Figure 4. Proposed memristor model

The model is developed by referring the model proposed by Biolek. The memristance is observed between terminals 1 and 2. This circuit is transformed in the form of a sub circuit, which can be saved as a library function in PSPICE software. This software is mostly used for the simulation of electrical circuits and also lets the user use variety of functions. Here, the new subckt named 'newmem' is simulated. In reference model, integration equations are used for the calculation of flux and charge. But here in this model, instead of using integration function, POLY() function is used, which gives direct integration value. A serial resistance Rser of small value for the purpose of sensing the current through nodes 1 and 2. A clamping circuit is used to initiate the working of memristor. Both the charge and flux depend on state of the memristor, which is sensed at node no.6.

The PSPICE library of memristor is as follows:

```
.SUBCKT newmem 1 2
****************************
**Squared quantity of voltage**
Eres 1 9 POLY(2) (8, 0) (10, 0) 0 0 0 0 1
****************************
Vsense 9 4 DC 0V
****************************
**Current sensing**
Fcopy 0 8 Vsense 1
****************************
R2 8 0 1k
Rser 2 4 10
****************************
**Differential equation**
Gmem 6 0 VALUE={I(Vsense)*max(v(6,0)*(1-v(6,
0)), 0)}
****************************
```

```
Cmem 6 0 50nF
*****************************
**Limiting the window of 0 and 1**
Ecpy 10 0 VALUE={min(max(v(6,0), 0), 1)}
*****************************
Rinit 6 0 100Meg
V1 6 7 DC 0.5V
R1 7 0 50Meg
.ENDS
```

The memristor model implemented by using the software Orcad Pspice is simulated as follows. The current through the memristor is plotted versus input sine voltage of the amplitude 10V and frequency 5kHz. The I-V plot obtained by simulating the proposed model resembles the I-V plot obtained from simulation of HP model [2]. Thus the model can be assumed to be verified and working properly. Figure 5 shows the simulation of model using PSPICE.

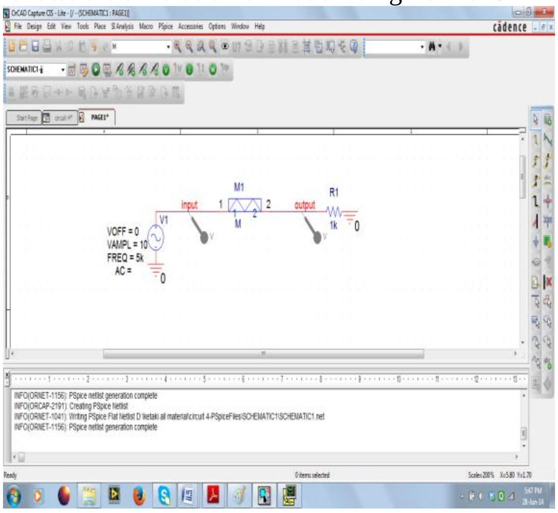

Figure 5. Simulation of memristor model for sinusoidal input

The output observed in the form of I-V plot is as shown in Figure 6.

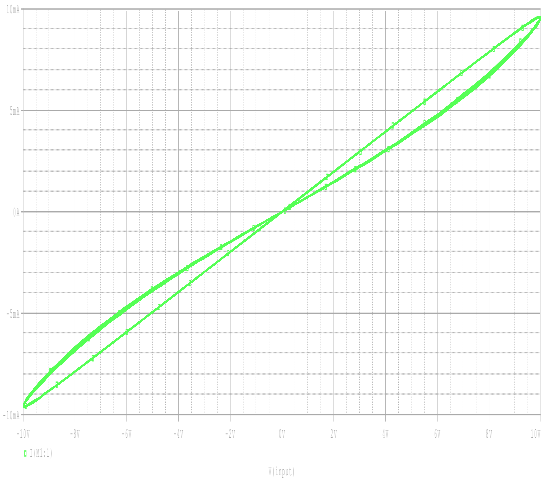

Figure 6. I-V plot obtained by the simulation

IV. Comparison of Reference model and proposed model

Sr. No.	Feature	Reference Model	Proposed Model
1.	Working range	Input Voltage Amplitude: 1.2-20V; Input frequency range: 1-5Hz	Input Voltage Amplitude: 1.2-30V; Input frequency range: 1kHz-10kHz
2.	Advantages	Accurate results under specified input ranges	Better Amplitude and frequency range
3.	Disadvantages	Works only at 1Hz frequency	Poor results at very low frequency
4.	Application	Very low frequency circuits	High frequency circuits

V. Advantages and limitations of memristor

Memristor can hold the value between ‘0’ and ‘1’, i.e., values other than digital levels. This is a great advantage as this property can be used to hold analog values, which are available at physical level. The need of memory space required to hold the analog value in the form of memristor level may provide advantage as the bit storage system certainly needs more space. This feature can also be utilized in the field of neural networks, as neural network deals with analog values only.

The major challenges in the application of the memristor are its relatively low speed, major changes in the characteristics at high frequency and the need for designers to learn how to build circuits with this new element. Since the memristor is not yet manufactured commercially, the research remains at the laboratory level only. Also there is urgent need for a standard memristor model which can be acceptable for fabrication and simulation purpose.

VI. Future scope

As stated earlier, memristor is proposed to be manufactured at nano scale. Hence the device density reduction is main goal in the manufacturing process. Since it is at nano scale, the issues arising at nano level need to be studied and tackled. The research is in progress on how to model the memristor as a solid state device. The memory holding capacity of the memristor needs to be improved in terms of longevity and accuracy. Speed increase will add major advantage to memristor technology regarding its use in Crossbar devices. The use of memristor in non-volatile Random Access Memory (NVRAM) will bring about ultimate change in the memory storage systems. Also use of memristor in the neural network systems may unfold important information about the working of human brain.

VII. Conclusion

The simulation of memristor model implemented in the software Orcad Pspice shows results relevant to the ones obtained theoretically. The ideal model works under specific conditions of input voltage and frequency levels, whereas the one with modifications shows significantly better results as the cost of certain assumptaions. It has been proposed that by redesigning certain types of circuits to include memristors, it is possible to obtain the same function with fewer components, making the circuit itself less expensive and significantly decreasing its power consumption. The power consumption by using memristors will be compared with the one using traditional components and results will show the efficiency of memristors.

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