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Modeling and Simulation of Memristor using SPICE Model

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ABSTRACT

In evolution of memory technology the invention of memristor has colossal impact. It is the memory with resistor as its name indicates its function. The development of memristor as the non-volatile memory device replaces the flash memory and for this reason it is compared to flash memory for the better understanding of the memristor. The demand for high scalability, speed and endurance, the CMOS technology has limitation for the current lithography technology. As the result it is hard to supply the increasing demand for the non-volatile memory with high density. The only hope for the semiconductor industry is memristor by easier way to increase storage density. These larger storage density The increasing demand for high capacity ,high speed and lower priced acts as the force for the research in this field. The performance and the proposing innovation towards the development of the memristor is simulated using the LTspice for new technology.

Keywords: Memristor and LTspice.

1. INTRODUCTION

In circuit theory there are three basic two-terminal devices namely-resistor, capacitor, and inductor. These elements are defined by the relation between two of the four fundamental circuit variables- current i, voltage v, charge q and fluxφ, where the time derivative of charge q is current i and according to Faradays laws voltage v is the time derivative of fluxφ. The resistor is defined with the relation between the voltage v and current i as dv = Rdi. The capacitor is defined with the relation between the charge q and voltage v is expressed as dq=Cdv. The inductor is defined with the relation between the flux φ and current i as dφ = Ldi. The discovery of the existence of the fourth fundamental circuit element came to light in 1971 when Prof. Leon Chua proposed the missing relation between charge q and the flux φ through symmetry in figure 1 [1].

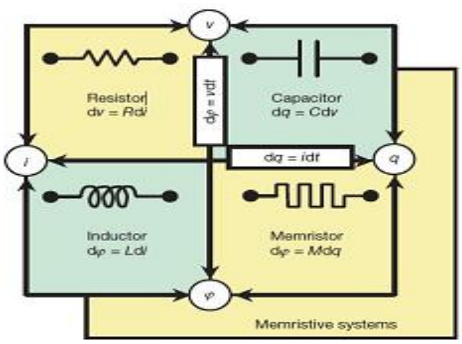


Fig.1. The four fundamental two-terminal circuit elements

Leon Chua named the element as memristor, which is the short for memory resistor. The memristor has a memristance M and the functional relation between flux φ and charge q is given by dφ=Mdq. The already known passive two-terminal devices are the basic building blocks of modern electronics and are therefore ubiquitous in circuits. But we know that though some elements store information they eventually decay out. Even if the state of one element changes, the information about the new state would be lost once the power is turned on and wait sometime. This basic point may seem irrelevant but fundamentally this is very crucial. The capacity to store information without the need of a power source would represent a paradigm change.

2. BASIC MEMRISTOR PROPERTIES

The memristor based on a lean 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 manufacture and characteristics of memristors. The name Memristor itself indicates its functioning as a resistor having memory of its previous condition. From the circuit-theoretic top of view, the three basic two-terminal circuit elements are defined in terms of a relationship between two of the four fundamental circuit variables. Out of the six possible combinations of these our 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, the inductor and the capacitor as stated in Table 1. Only one relationship remains undefined, the relationship between φ and q. It is nothing but the memristance.

Table 1. Fundamental Variables of Electrical Circuits

Sl. 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

3. ORIGIN OF MEMRISTORS

Leon Chua noted that there are six different mathematical relations connecting pairs of the four fundamental circuit variables current i, voltage v, charge q and flux φ. The relation between these variable is deduced from Faradays law of Induction. A resistor is defined by the relationship between voltage v and current I (do = Rid), the capacitor is defined by the relationship between charge q and voltage v (dq = Cdv) and the inductor is defined by the relationship between flux φ and current i dφ = Ldi. In addition, the current i is defined as the time derivative of the charge q and according to Faradays law, the voltage v is defined as the time derivative of the flux φ. This relation is shown in the figure 2 [2].

According to this theory all matter consists of earth, water, air and fire. Each of these elements exhibits two of the four fundamental properties moistness, dryness, coldness and hotness. So depending on the above theory he saw a striking resemblance and predicted the existence of the fourth kind of element and called it memristor. The physical memristor device is essentially an a.c device, or else the d.c electromagnetic fields would give rise to non-negligible zero-order fields.

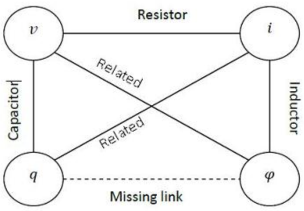


Fig.2.The Relation between the Circuit Elements

4. DEFINITION OF MEMRISTOR

Memristor is a contraction of memory resistor because its main function is to remember its history. The memristor is a two-terminal device whose resistance depends on the magnitude and polarity of the voltage applied to it and the length of the time that voltage has been applied. When this voltage is turned off the memristor remembers its most recent resistance until the next time you turn it on. The simple model of this is as shown in figure3 [3].

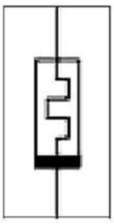


Fig.3. Simple Model of Memristor

Memristor is either said to be a charge controlled or a flux controlled depending upon the relation between the flux φ and the charge q as a function of the other. For a charge controlled memristor the relation between flux and charge is expressed as a function of electric charge q [2],

$$\varphi = f\,(q) \qquad (1)$$

By differentiating (1) we get,

$$\frac{d\varphi}{dt} = \frac{df(q)}{dq}\frac{dq}{dt} \qquad (2)$$

$$\frac{d\varphi}{dt} = v(t) \qquad (3)$$

$$v(t) = M(q).i(t) \qquad (4)$$

$$M(q) = \frac{df(q)}{dq} \qquad (5)$$

For a flux controlled memristor the relation between flux and charge is expressed as a function of flux linkage φ [2],

$$q = f(\varphi) \qquad (6)$$

$$\frac{dq}{dt} = \frac{df(\varphi)}{d\varphi}\frac{d\varphi}{dt} \qquad (7)$$

$$i(t) = W(\varphi).v(t) \qquad (8)$$

5. CHARACTERISTICS OF MEMRISTORS

5.1 I-V characteristics

An important characteristic of a memristor is the pinched hysteresis loop current- voltage characteristics [2]. For a memristor excited by a periodic signal, when the voltage v(t) is 0, the current i(t) is zero and vice versa. If any device has the above characteristics, then the device is either a memristor or a memristive device. The characteristics are as shown in figure 4[7].

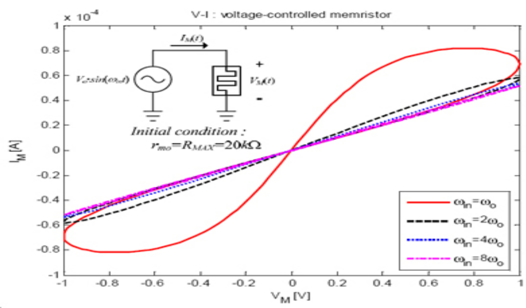


Fig.4. The Pinched Hysteresis Loop

5.2 φ-q Characteristics of Memristor

One of the main characteristics of φ-q of a memristor is it is monotonically increasing. The memristance M(q) is the slope of the φ-q curve. Prof. Leon Chua postulated a passivity criterion, according to which a memristor is passive if and only if the memristance M (q) is non-negative [5]. If M(q) 0, then the instantaneous power dissipated by the memristor, p(i) = M(q):[i(t)] 2, is always positive and so the memristor is a passive device [6].The typical curves are as shown in figure 5.

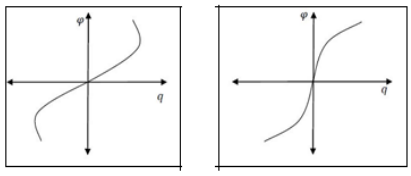


Fig.5. The φ-q curve of Memristor

6. LTSPICE MODEL OF MEMRISTOR

Biolek provided the Spice model of the memristor. Though PSpice and LTSpice are similar in the nature of their analysis, but even though there wasn't any analysis done in LTSpice. So I tried using LTSpice to be the basis of my simulation. The listing for the LTSpice model is included in the appendix. The model generated by me in LTSpice is as shown in figure 6. The passing current from memristor in one way will increase the resistance while changing the direction of the applied current will decrease its memristance.

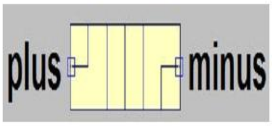


Fig.6. Symbol of the Memristor Model in LTSpice

The total resistance of the doped and undoped regions of a HP memrister is given by,

$$R_{mem}(x) = R_{on}^{x} + \Box_{\Box\Box\Box}(1 - \Box) \qquad (9)$$

$$= R_{off}\,x - (R_{off} - R_{on})x \qquad (10)$$

Where x = w/D ε(0,1) is the thickness of the doped region, referenced to the total length D of the TiO2 layer, and Roff and Ron are the limit values of the memristor resistance for w=0 and w=D. The ratio of the two resistances is given. The speed of the movement of the boundary between the doped and undoped regions depend on the resistance of the doped area, on the passing current, and on other factors according to the equation given by,

$$\frac{dx}{dt} = k.\,i(t).\,f(x) \qquad \ldots (11)$$

$$k = \frac{\mu_v R_{on}}{D^2} \qquad \ldots (12)$$

Where $\mu_v \approx 10^{-14} m^2 s^{-1} V^{-1}$ is the dopant mobility. As mentioned in [9], in nanoscale devices, small voltages can yield enormous electric fields, which can secondarily produce significant nonlinearities in ionic transport. These non linearities manifest themselves particularly at the thin film edges, where the speed of boundary between the doped and undoped regions gradually reduces to zero. This phenomenon, called nonlinear dopant drift, can be modeled by the so-called window function f(x).

6.1 Different Types of Window Function

1) Jogelkar window
2) Biolek window
3) Strukov window
4) Prodromakis window
5) Kvatinsky window

7. SIMULATION RESULTS-USING LTSPICE MODEL

For the simulation of the memristor for its desired characteristics, the width D of the TiO2 film is considered to be 10nm and the dopant mobility. The values assumed for Ron = 100Ω, Roff = 16k Ω and the initial resistance Rinit = 11k ΩD=10N, uv=10F, p=10. The circuit symmetry is shown in figure. The simulation results are shown in figure 10 and figure 11 Parameter details for Transient Non-Linear Domain Analysis Ron=100Ω, Roff=16KΩ, Rinit=11KΩ, D=10N, uv=10F, p=10, Stop time = 3 seconds, Maximum time step = 3m.

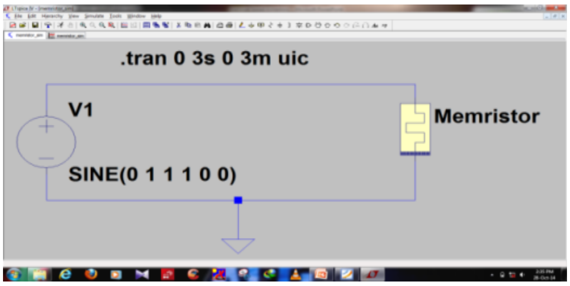


Fig.7. Memristor Model Circuit

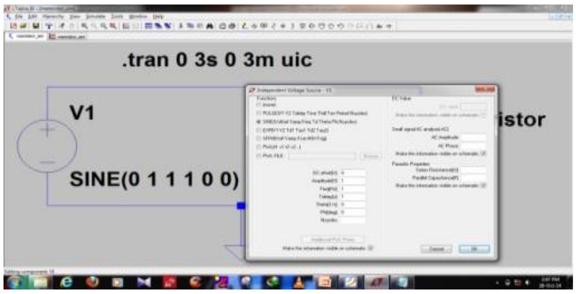
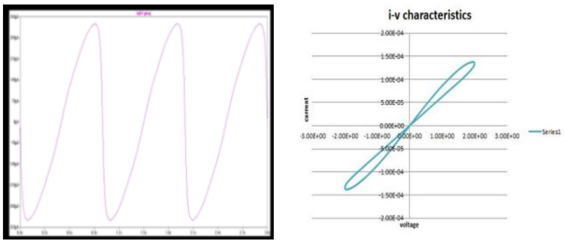


Fig.8. Input Voltage Applied to the Memristor

Input source voltage parameter details:

Ron=100Ω, Roff=16KΩ , Rinit=11KΩ, D=10N, uv=10F, p=10, Sine wave with Amplitude = 1V, Frequency = 1Hz, Time delay = 1 sec.



(a) (b)

Fig.9.(a) The Current through Memristor and (b) Current-Verses-Voltage

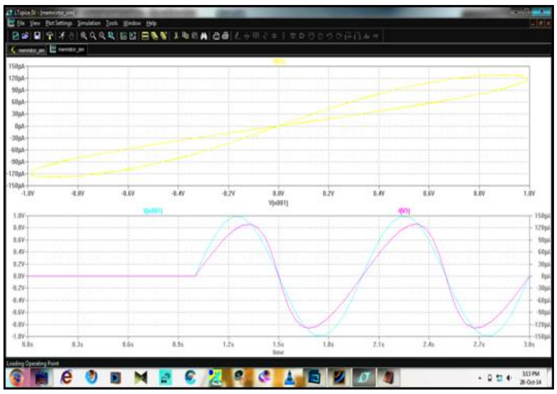


Fig.10.Transient Non-Liner Time Domain Analysis Result of a Memrister Model Using LT Spice

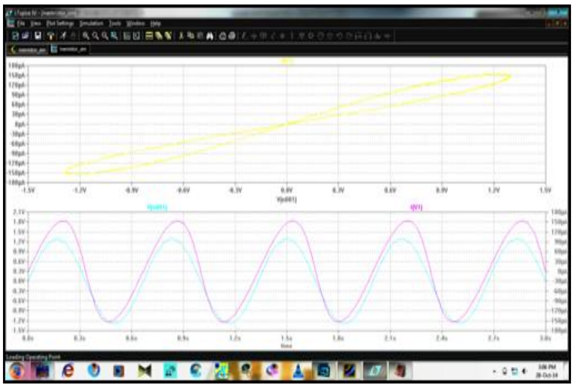


Fig.11.Transient Non-Liner Analysis Result(a): F(1 Hz), Td(0), A(1V)

Ron=100Ω, Roff=16KΩ , Rinit=11KΩ, D=10N, uv=10F, p=10, Stop time = 3 seconds, maximum time step = 3m, Sine wave with Amplitude = 1V, Frequency = 1Hz, with out any time delay.

8. CONCLUSION

The impact that the memristor can have on the existing technology is vast. This report presents the detail study of memristors and also shows some worked out applications. The memristor is modeled in LTSpice using the existing model is proposed and plotted by the use of LTSpice. Memristors has certainly showed a lot of promise and also has the potential to be another milestone in the lane of evolution of technology for superior. It was rightly said by Prof. Leon Chua that all the engineering text books have to be re-written. The future design of NV RAM design is implemented and analyzed using LTSpice software.

Spice Model of a Non Linear Memristor Using LTspice
.SUBCKT memristor plus minus PARAMS
+ Ron=100 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))}

For Non-Linear Drift Modeling
.func f(x,p)={1-(2*x-1)**(2*p)}

Proposed Jogelkar Window Function
.func f(x,i,p)={x(1-(2*x/(D-1))**(2*p))}
.ENDS memristor

//Another Reference Spice Model of a Mon Linear Memrister with Various values of Ron, Roff and Window Function codes using LTSpice
*Modified HP Memristor SPICE Model
****
* 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

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