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MEMRISTOR: THE 4TH CIRCUIT ELEMENT

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ABSTRACT

Everyone who have study the circuit theory are familiar with the fundamental passive circuit element: resistor, inductor and capacitor. In 1971 leon chua have discovered the fourth fundamental circuit element, which he named memristor (memory + resistor). This element has many interesting and valuable circuit properties. This paper introduces compact models for memristors. A memristor is a passive element, but there are some condition when, it will acts as an active element has been discussed in this paper. The models are developed based on the fundamental constitutive relationships between charge and flux of memristors. Current-voltage behavior, hysteresis, resistance of memristor shows a wide range application of nanoscale electronic device.

Keywords— Memristor, Circuit Variable, Active and Passive element

I. INTRODUCTION

We are familiar with the three fundamental circuit elements the resistor, the capacitor and the inductor. These three elements are defined by the relation between two of the four fundamental circuit variables current, voltage, charge and flux. In 1971, Leon Chua reasoned on the grounds of symmetry that there should be a fourth fundamental circuit element which gives the relationship between flux and charge. He named this circuit element the memristor, which is short for “memory resistor”.

In circuit theory there are three basic two-terminal devices namely the resistor, the capacitor and the inductor. These elements are defined in terms of the relation between two of the four fundamental circuit variables namely current, voltage, charge and flux. The current is defined as the time derivative of the charge. According to Faraday‘s law, the voltage is defined as the time derivative of the flux. A resistor is defined by the relationship between voltage and current, the capacitor is defined by the relationship between charge and voltage and the inductor is defined by the relationship between flux and current. Out of the six possible combinations of the four fundamental circuit variables five are defined. In 1971 Prof. Leon Chua proposed that there should be a fourth fundamental circuit element to set up the relation between charge and magnetic flux and complete the symmetry as shown in Fig [1].

The rest of the paper is organized as follows: Section II describes the theory and technology of the memristor. Section III describes the properties of memristors. Summary and conclusions are reported in the final Section.

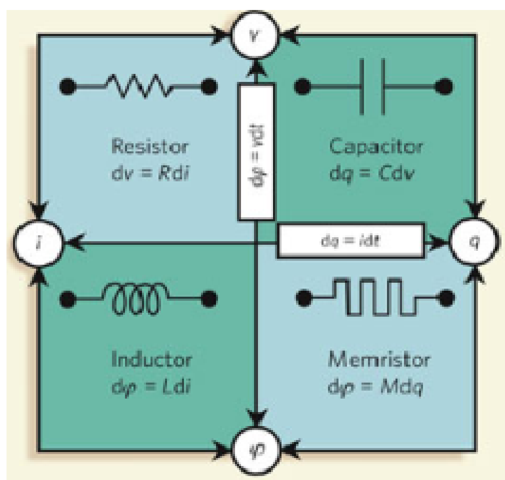

Fig1. Relation between four circuit variables

II Definition of memristor

Memristor is the contraction of **Memory + Resistor**. It is a passive device that provides a functional relation between charge and flux. It is defined as a two-terminal circuit element in which the flux between the two terminals is a function of the amount of electric charge that has passed through the device. Memristor is not an energy- storage element. Fig. 2 shows the symbol for a memristor.

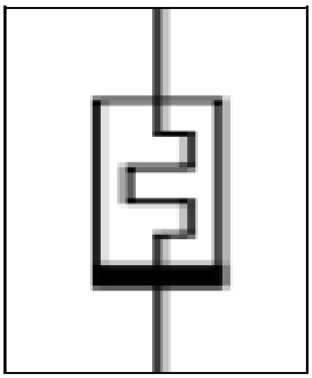

Fig.2 Symbol of memristor[1]

A memristor is said to be charge-controlled if the relation between flux and charge is expressed as a function of electric charge q and it is said to be flux-controlled if the relation between flux and charge is expressed as a function of the flux linkage φ. Ketaki Kerur has shown the charge controlled and voltage controlled memristor[1].

For a charge-controlled memristor

$$\varphi = f(q) ----(1)$$

Differentiating equation (1) yields

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

We know that $v(t) = \frac{d\varphi}{qt}$ and $i(t) = \frac{dq}{dt}$

$$v(t) = M(q).i(t) ----(3)$$

Where $M(q) = \frac{df(q)}{dq}$, M(q) is called as memristance, and it has the units of resistance. Thus memristor is a charge controlled device. Memristance defines a linear relationship between current and voltage as long as the charge does not vary. Thus if M is constant a memristor behaves as a resistor.

For a flux-controlled memristor.

$$q = f(\varphi) ----(4)$$

$$\frac{dq}{dt} = \frac{df(\varphi)}{d\varphi}.\frac{d\varphi}{dt} ----(5)$$

We know that $i(t) = \frac{dq}{qt}$ and $v(t) = \frac{d\varphi}{dt}$

$$i(t) = w(\varphi).v(t) ----(6)$$

Where $w(\varphi) = \frac{df(\varphi)}{d\varphi}$, W (φ) is called memconductance and it has the units of conductance.

Memristance is a property of the memristor. When the charge flows in one direction through a circuit the resistance of the memristor increases and its resistance decreases when the charge flows in the opposite direction in the circuit. If the applied voltage is turned off the memristor remembers the last resistance that it had. When the flow of charge is started again the resistance of the circuit will be what it was when it was last active.

Fig 3 shows the behaviour of a memristor for input voltage signal. The value of Ron and Roff is kept 10Ω and 10000Ω respectively, the magnitude of input voltage is 1V. The magnitude of output current varies from -10µA to +10µA. This shows the resistive nature of memristor. When resistance on positive increases the resistance on negative side decreases vice versa.

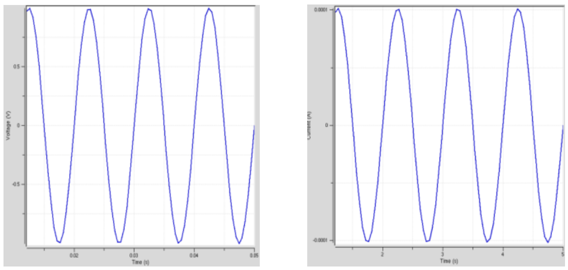

Fig3. Input voltage and output Current memristor

III. PROPERTIES OF A MEMRISTOR

The memristor devices we are primarily concerned with are based on metal-oxides the device models considered here are based on the theoretical underpinnings proposed by Hewlett-Packard Labs[2]. The basic premise is that charge transport in metal-oxide memristors is based on a form of atomic rearrangement which adjusts the overall resistance of the device as a function of electric current. For modeling purposes, a thin film metal-oxide material of thickness D sandwiched between two conductors is modeled as two variable resistors connected in series, as shown in fig4. Each resistor in the model represents two distinct regions of the metal-oxide, one with a high ionic dopant concentration, Ron, and the other with a low concentration, Roff

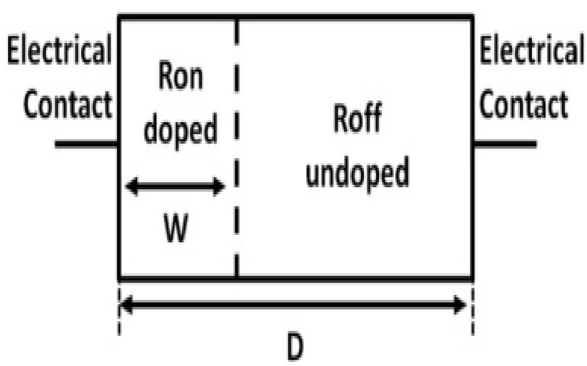

Fig4. Structure of memristor[2]

The most basic mathematical definition of a memristor is that of a current-controlled device for circuit analysis in the generalized class of nonlinear dynamical systems called memristive systems described by the equations.

V=R(w,i)i----------------------(7)

dw/dt=f(w,i)------------------(8)

where w can be a set of state variables and R and f can in general be explicit functions of time. For simplicity and ease of simulation the memristor's resistance or memristance definition has been reduced to that of a current-controlled time-invariant one-port device given by.

$$M(w) = \frac{w}{D} Ron + (1 - \frac{w}{D}) Roff \; ------(9)$$

Where w represents the doped region of the memristor, D the total device length and Ron/Roff are the lowest and highest resistance states graphically described in Figure. Thus, there can be different values for the memristance M as changes in the electric current cause atomic rearrangement and x is varied between 0 and D.

Flux –Charge Curve of a Memristor

The φ-q curve of a memristor is shown in fig5, is monotonically increasing. The memristance M (q) is the slope of the φ–q curve. According to the memristor passivity condition a memristor is passive if and only if memristance is non-negative. If $M(q) \geq 0$, then the instantaneous power dissipated by the memristor, is always positive and so the memristor is a passive device. The memristor is purely dissipative like a resistor. Thus the φ–q curve of a memristor is always a monotonically increasing function. Fig. shows some examples of typical φ–q curves of memristors.

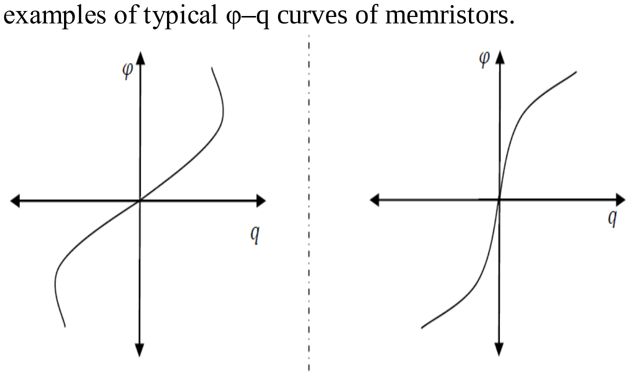

Fig5. Charge-flux characterices of memristor[1]

Current–Voltage Curve of a Memristor

An important fingerprint of a memristor is the pinched hysteresis loop current-voltage characteristic. For a memristor excited by a periodic signal when the voltage v (t) is zero the current i(t) is also zero and vice versa. Thus both voltage v(t) and current i(t) have identical zero-crossing. If any device has a current–voltage hysteresis curve then it is either a memristor or a memristive device. Fig5 shows the V I characterices of memristor at frequency 1Hz.

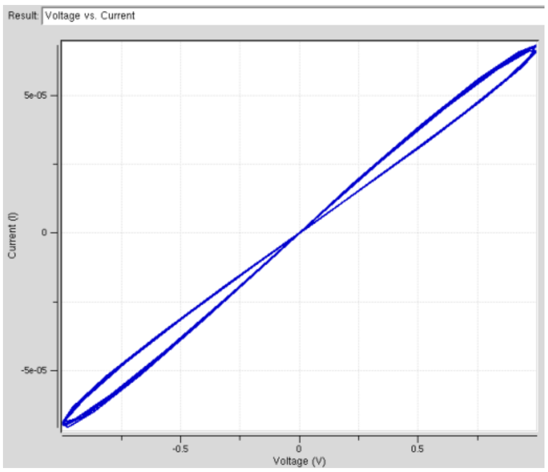

Fig5. Current –voltage characterices of memristor

From the figure5 we can clearly observe that the memristor device toggles between two states of high and low conductivity. As the device transitions between low to high conductivity states it goes through high nonlinear diode-like processes at two dofferent threshold voltages. The threshold voltage analogy is used here to describe the biasing regions where nonlinear behavior occurs.

Another property of the memristor is the pinched hysteresis loop shrinks with the increase in the excitation frequency. Figure6 shows the pinched hysteresis loop and an example of the loop shrinking with the increase in frequency. In fact, when the excitation frequency increases towards infinity the memristor behaves as a normal resistor. Fig 5 shows the VI curve at 1Hz and fig. 6a and 6b shows the memristor behavior at frequency 2Hz and 5Hz respectively. It is clearly observed from the diagram that the loop shrinks and it will behave as a conventional resistor (a passive element).

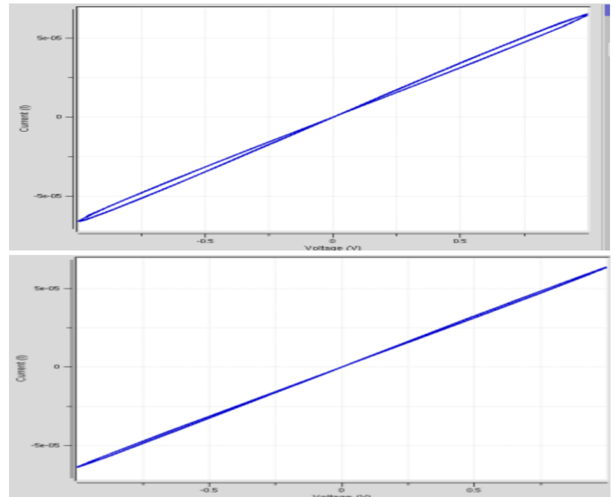

Fig6a V I curve at 2HZ   fig6b V I curve at 5Hz

The memristor act differently with decreasing value of frequency, as shown in fig. 7a and fig.7b at frequency 0.02 hz and 0.01 Hz respectively. The V I curve rotates left and lies in the II and IV quadrant. and it will no longer a passive element (an active element).

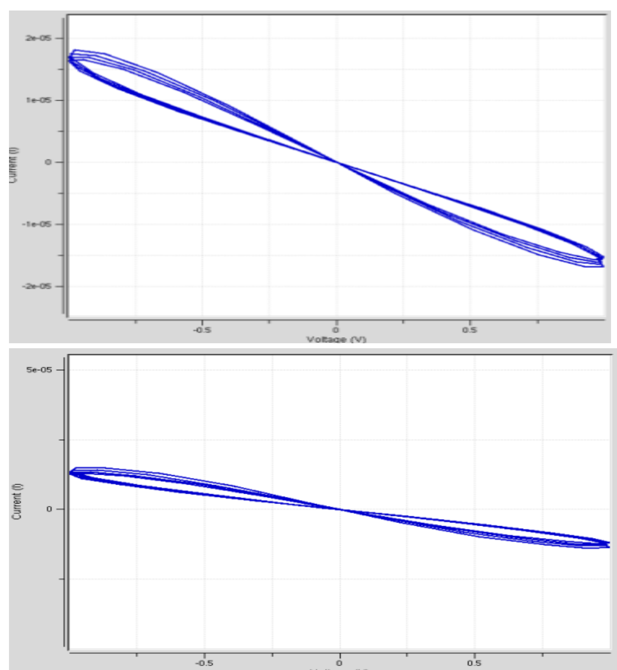

fig7a VI curve at 0.02 Hz   fig7b VI curve at 0.01 Hz

At constant frequency if the value of applied input voltage increases the curve rotates left and lies in II and IV quadrant, as shown in fig8. The curve rotates more as the input voltage increases 1v, 2v, 3v and 4v.

An element whose VI characterises lies on II and IV quadrant will be an active element and value memristance (M) < 0.

An element will be active only if having storage capacity; so a memristor is a memory element,

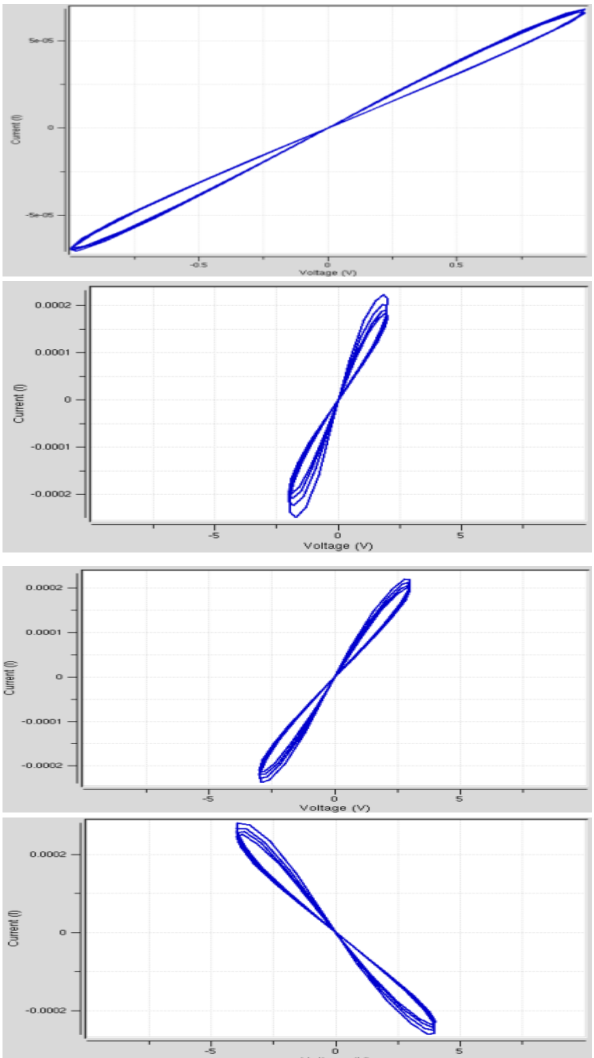

Fig8 VI curve at Input voltage 1v,2v,3v,4v at frequency 1Hz

Application of memristor

Memristor find it potential application in switching device, non volatile memory design because a memristor can remember its last state. Memristors can possibly allow for nano-scale low power memory and distributed state storage coupled with memcapacitors and meminductors. The hungry power consumption of transistors has been a barrier to both miniaturization and microprocessor controller development. Solid-state memristors can be combined into devices called crossbar latches which could replace transistors in future computers taking up a much smaller area.

IV. CONCLUSIONS

A compact model of memristor based on the constitutive relationship between charge and flux has been introduced. A current-controlled and voltage-controlled memristors has been demonstrated. The passivity condition of memristor and its dependency on frequency and amplitude of input signal have been shown. A memristor will behave as passive element or active element all possible condition have been demonstrated.

V. REFERENCES

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