Circuit Element with Memory- Memristor

Jaipreet Kaur[1*], Manjit Sandhu[2], Sukhdeep Kaur[3]

[1, 2, 3]Assistant Professor, Department of ECE, GNDU Regional Campus, Sathiala, Amritsar, India

Abstract: This paper presents a review about the emerging technology of the fourth basic circuit element named memristor. A memristor is two terminal element postulated by Leon Chua in 1971 as the fourth fundamental circuit element, along with the three classic circuit elements known as resistor, inductor and capacitor. A memristor is the resistor with memory whose resistance be governed by the magnitude, direction and duration of the voltage applied. A physical memristor was built at HP Laboratories led by Stanley Williams by nano-scale titanium dioxide thin film, consists of two doped and undoped regions, sandwiched between two platinum contacts in 2008. A memristor is a non-volatile memory device which has the capacity to replace flash memories and DRAMs in the coming years. A huge amount of research is carried out for the better modelling of the device and realising more practical applications of the memristor.

Keywords: Memristor; Modelling; Memristor applications; Memeristance

I. INTRODUCTION

From the circuit-theoretic point of view, the three basic two-terminal circuit elements are defined in terms of a relationship between the four fundamental circuit variables namely, current i, voltage v, charge q, and flux-linkage ϕ. The current i is defined as the time derivative of charge q. According to faraday's law, the voltage v is defined as the time derivative of flux ϕ. A resistor is defined by the relationship between voltage and current $(dv = Rdi)$, the capacitor is defined by the relationship between charge and voltage $(dq = Cdv)$ and the inductor is defined by the relationship between flux and current $(d\Phi = Ldi)$. 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). Only one relationship remains undefined, the relationship between ϕ and q [1].

The basic passive circuit elements were restricted to the capacitor (1745), the resistor (1827), and the inductor (1831) for about 150 years. All the electronics were centred on three fundamental circuit elements namely resistor, capacitor and inductor, until Berkeley in 1971 proposed that there should be a fourth fundamental circuit element to complete the symmetry, memristor, to set up the relation between charge and magnetic flux as shown in Figure 1 and Table 1[1].

Table 1. The equations of four basic circuit elements.

Device	Differential equation	Characteristic property (units)
Resistor (R)	$R = dV / dI$	Resistance $(V / A$, ohm)
Capacitor (C)	$C = dq / dV$	Capacitance $(C / V$, farad)
Inductor (L)	$L = d\Phi / dI$	Inductance $(Wb / A$, henry)
Memristor (M)	$M = d\Phi / dq$	Memristance $(Wb / C$, ohm)

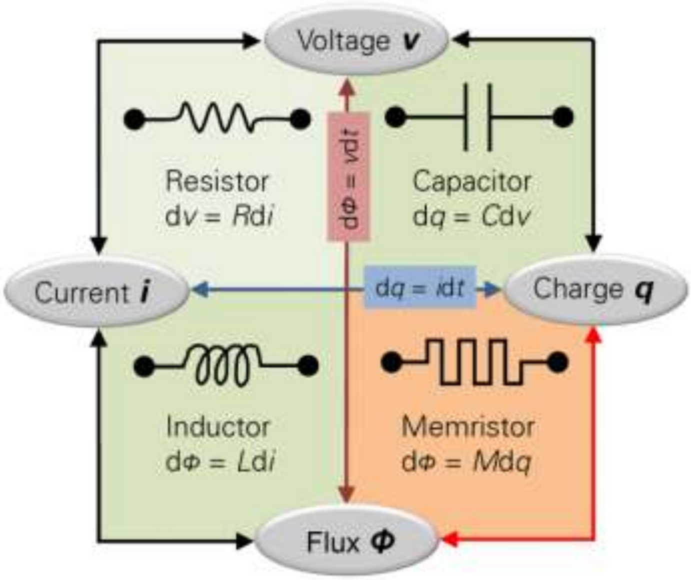

Figure 1: Conceptual symmetry between resistor, capacitor, inductor and memristor [2].

II. MEMRISTOR

Memristor is the compression of memory and resistor. The transistor works by using flow of electrons. The new memristor electronic component use flow coupled with ions, which are electrically charged atoms. All information is lost in the transistor when the power is cut, results the flow of electrons is interrupted. The resistance of memristor (memristance) governed by the amount of current passing through the memristor. Memristor is a two terminal passive device that has relationship between the time integrals of current and voltage. This relation is defined by the term memristance, which is similar to variable resistance. Memristance is the electrical property of a device to maintain its resistance level even after the power is switched off. A device linking charge and flux, memristor, was hypothetical before 2008, when in the issue of the journal named Nature; a team of Hewlett-Packard Labs mentored by scientist R. Stanley Williams had declared the invention of a switching memristor [2, 9]. The property that makes memristor remarkable is that at any point of time, the resistance is a function of the current being passed through it. Also, another reason for its uniqueness is that it is thoroughly different from other basic circuit elements because it retains memory of its past. The memristor is defined as a nonlinear functional relationship between magnetic flux linkage $\Phi\ (t)$ and the electric charge possessed, $q\ (t)$ in equation 1-5 [2].

$$\mathrm{f}\ (\emptyset_m(t), q(t)) = 0 \qquad (1)$$

$$\frac{d\emptyset}{dt} = \frac{d\emptyset}{dq} \cdot \frac{dq}{dt} \qquad (2)$$

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

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

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

$M\ (q)$ in the equation 5 is known as the memristance of the memristor, and it has the same units as that of resistance, therefore the units of memristance is ohms (Ω). As long as the charge does not change, memristance maintains a linear relationship between current and voltage. Thus when it is constant, a memristor behaves as a resistor. The memristor is an electrical component that confines or controls the flow of current in a circuit and remembers the amount of charge that was flowing in the past. Due to their non-volatile nature of memristor, they play significant role in the memories.

To understand the functioning of memristor, it can be compared to an imaginary pipe in which water is flowing. The pipe diameter expands continuously, when the water flows in one direction. So, allowing the water to flow faster but when the water flows in the opposite direction of the previous direction, the pipe diameter contracts continuously and slow the water flow. When the water is not passed, the pipe maintains its diameter until the water is passed. To make similarity with the analogy, when the memristor power is gone, it retains its resistance value. This would mean that if power to a so when the computer was done with hard shut down, all the going applications that were working before the shutdown would be saved and can be restored when the computer was restarted [4].

III. CONDITIONS FOR MEMRISTOR

Chua had done various experimental tests to determine the essential conditions of a device to be worked properly as memristor which are listed below [3].

1. The Lissajous curve is the pinched hysteresis loop in the voltage current plane when driven by any bipolar periodic voltage or current independent from the initial conditions.

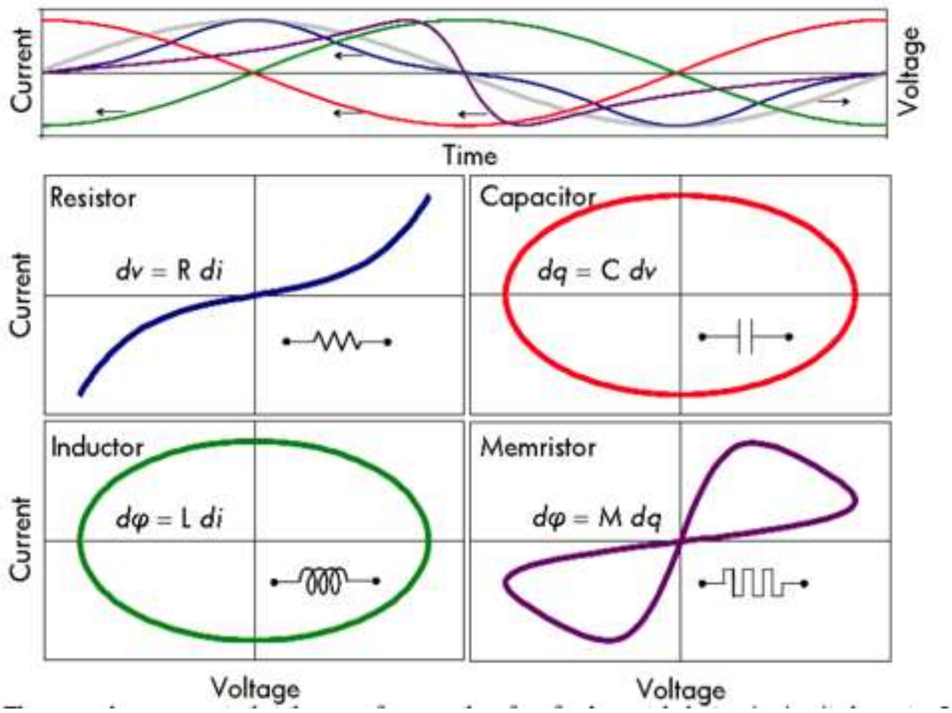

Figure 2: The characteristics of current-voltage of the four basic circuit elements [4].

2. By the increase of the frequency of the input signal, the area of each lobe of the pinched hysteresis loop shrinks simultaneously.

3. When the frequency approaches to infinity, the hysteresis loop degenerates to a straight line passing through the origin and the slope of line depends on the amplitude and shape of the input signal.

IV. CONSTRUCTION OF MEMRISTOR

The research team at HP Labs succeeded to build an actual physical memristor in 2008. The memristor consisted of a nanometer scale titanium dioxide thin film, having doped and undoped regions which are sandwiched between two platinum contacts as shown in the figure 3. After this invention, major research is continuing with the purpose of better modelling of the device and discovering more potential applications of the memristor. The simple mathematical model of HP memristor is given in figure 3.

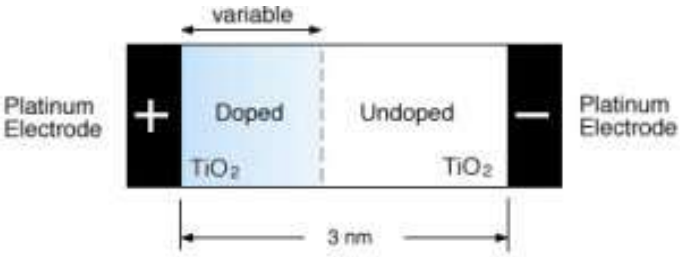

Figure 3: The physical composition of memristor.

The memristance function of the device can be generalized by given equation 6.

$$M(q(t)) = R_{OFF}\left(1 - \frac{\mu_v R_{ON}}{D^2} q(t)\right) \quad (6)$$

R_{OFF} represents the high resistance state, R_{ON} represents the low resistance state, μ_V represents the mobility of dopants in the thin film, and D represents the film thickness.

In October 2011, the HP team announced the commercial availability of memristor technology within 18 months, as a replacement for Flash, SSD, DRAM and SRAM. In March 2012, a team of researchers from HRL Laboratories and the University of Michigan announced the first functioning memristor array built on a CMOS chip [3].

V. TYPES OF MEMRISTOR

Memristors can be classified into different types, depending on construction. Broadly memristors are classified into two types explained below [5, 6].

A. *Molecular and Ionic Thin Film Memristive Systems*

These types of memristors depend on material properties of thin film different atomic lattices and in the presence of charge shows hysteresis behaviour.

1) *Titanium dioxide Memristors:* The Titanium dioxide memristor is a two-layer thin sandwich of titanium dioxide films device, consists of symmetrical lattices of titanium and oxygen atoms. In the presence of oxygen the resistance of titanium oxide is changed. The bottom layer acts as an insulator, and the top film layer acts as a conductor via oxygen vacancies in the titanium dioxide. The oxygen vacancies in the top layer are moved to the bottom layer, changing the resistance of the device. To pass the charge to the device, crossbars of nanowires are placed above and below the top and bottom layers and memristive properties are observed [7].
2) *Polymeric (ionic) Memristors:* In solid-state ionic material structure the ions are free to move in the structure as a charge carrier. Polymeric memristors use doping of polymer to show hysterisis type behaviours. A single passive layer between an electrode and an active thin film helps in the extraction of ions from the electrode.
3) *Manganite Memristors:* These types of memristors use a substrate of manganite bilayer oxide film as opposite to titanium dioxide memristors.
4) *Resonant-tunneling diode Memristors:* The memristive properties are also exhibited by the quantum-well diodes with doping of the spaced layers between the source and drain regions.

B. Spin Based and Magnetic memristive systems

Spin- based memristive systems depaends on the characteristic of degree of freedom of electron spin. The electron spin polarization is altered through the movement of a magnetic domain wall which leads to separating polarities.

1) *Spintronic Memristors:* In these types of memristors, the resistance is changed when the magnetization state of the device is changed due to the route of spin of electrons.

2) *Spin Torque Transfer Memristors:* In these types of memristors, the resistance is changed when the magnetic state is affected by the comparative magnetization position of the two electrodes [7].

VI. CONCLUSION

Memristors circuits leads to revolutionary small PCs. These memristors can be used both for digital switches and of analog devices. Memristors can have wide applications in signal processing, arithmetic processing, pattern recognitions, robotics, artificial intelligence, fuzzy systems, communication hardware and virtual reality etc. Memristors have been predicted to replace flash memory and find the best place of memories. The storage hierarchy can be replaced from DRAM and hard drives with memristors. By use of memristors the analog computers can be created which are capable of carrying out calculations on the same chips that store data.

VII. REFERENCES

[1] L. O. Chua. (1971) Memristor - the missing circuit element. IEEE Trans. Circuit Theory, pp. 507-519.

[2] D. B. Strukov, G. S. Snider, D. R. Stewart, R. S. Williams (2008). The missing memristor found. Nature, pp. 80-83.

[3] N. Gergel Hackelt et al. (2009). A Flexible Solution-Processed Memristor. Electronic Device Letters IEEE, pp. 706-708.

[4] D. B. Strukov et al. (2009). Switching dynamics in titanium dioxide memristive devices. Journal of Applied Physics, pp. 106.

[5] Y. V. Pershin et al. (2010) Practical approach to programmable analog circuits with memristors. IEEE Transactions on Circuits and Systems I, pp. 1857-1864.

[6] C. Yakopcic et al. (2011) A Memristor Device Model. Electron Device Letters IEEE. pp 1436-1438.

[7] P. Mazumber et al. (2012) Memristors: Devices, models, and applications. IEEE Proceedings, pp. 1911-1919.

[8] Zhen Yu Yin et al. (2015) What are Memristor, Memcapacitor, and Meminductor? IEEE Transactions on Circuits and Systems II, pp. 402-406.

[9] R. Williams. (2008) How We Found the Missing Memristor. Spectrum, IEEE, pp. 28–35.

Conflict of Interest: NIL

