World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:6, No:12, 2012

Memristor: The Missing Circuit Element and its Application

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Open Science Index, Electronics and Communication Engineering Vol:6, No:12, 2012 publications.waset.org/1519/pdf

***Abstract*—**Memristor is also known as the fourth fundamental passive circuit element. When current flows in one direction through the device, the electrical resistance increases and when current flows in the opposite direction, the resistance decreases. When the current is stopped, the component retains the last resistance that it had, and when the flow of charge starts again, the resistance of the circuit will be what it was when it was last active. It behaves as a nonlinear resistor with memory. Recently memristors have generated wide research interest and have found many applications. In this paper we survey the various applications of memristors which include non volatile memory, nanoelectronic memories, computer logic, neuromorphic computer architectures low power remote sensing applications, crossbar latches as transistor replacements, analog computations and switches.

***Keywords*—**Memristor, non-volatile memory, arithmatic operation, programmable resistor.

I. INTRODUCTION

MEMRISTOR or ‘memory resister’ is a passive two-terminal electrical component which functions as a fundamental non-linear circuit element relating charge and magnetic flux linkage. Memristor theory was formulated and named by Leon Chua in a 1971 paper [1]. Chua extrapolated the conceptual symmetry between the nonlinear resistor (voltage vs. current), nonlinear capacitor (voltage vs. charge), and nonlinear inductor (magnetic flux linkage vs. current). In 2008, a team at Hewlett Packard (HP) labs announced the development of a switching memristor based on a thin film of titanium dioxide [2].

This paper is organized as follows. Section II describes the basic principle of operation of memristor and its characteristic curve. Section III describes applications like non-volatile memory, low power and remote sensing and crossbar latches. Section IV describes basic arithmetic operations based on memristor and Section V concludes the paper.

II. BASIC OPERATION ON MEMRISTOR

A memristor is a nonlinear resistor whose resistance changes over time period based on the amount of current that flows through it [3]. A two terminal passive resistor is like a pipe whose diameter is constant and the flow of water is regulated as per the diameter. A memristor on the other hand is like a pipe with variable diameter, which has the property that if water flows through it in one direction, the diameter shrinks and if the direction of water flow reverses, the pipe diameter expands. Once the water flow stops, the pipe diameter remains the same size until water starts flowing again. Since the flux linkage (or integral of voltage) Φ_m between the terminals is a function of the amount of electric charge q that has passed through the device we can write:

$$M=d\varphi/dq \qquad (1)$$

where $d\varphi$ is the variation of magnetic flux and dq is the variation of charge and M is the memristance. M is not constant but is a function of charge flow and elapsed time. Substituting, that the flux is simply the time integral of the voltage, and charge is the time integral of current, equation 1 can be written as:

$$V(t)=M(q(t))I(t) \qquad (2)$$

Memristance is simply charge-dependent resistance. If $M(q(t))$ is a constant, then we obtain Ohm's Law

$$R(t) =V(t)/I(t). \qquad (3)$$

This equation reveals that memristance defines a linear relationship between current and voltage, as long as M does not vary with charge. Furthermore, the memristor is static if no current is applied. If $I(t) = 0$, we find $V(t) = 0$ and $M(t)$ is constant. This is the essence of the memory effect. The power consumption for a resistor is given by

$$P(t)= I^2R=I(t)V(t)=I^2(t)M(q(t)) \qquad (4)$$

III. OPERATION ON TITANIUM DIOXIDE MEMRISTOR

Memristor is an electrically switchable semiconductor thin film sandwiched between two metal contacts with a total length of L and consists of doped and un-doped regions as shown in Figure 1. The internal state variable determines the length of doped region with low resistance against un-doped region with high resistivity. This internal state variable and consequently the total resistivity of the device can be changed by applying external voltage bias. This means that passing current from memristor in one direction will increase the resistance while changing the direction of the applied current will decrease its memristance. The HP memristor device is composed of a thin (50nm) titanium dioxide film between two 5 nm thick electrodes, one Ti, the other Platinum (Pt). Initially, there are two layers to the titanium dioxide film, one of which has a slight depletion of oxygen atoms. The oxygen

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vacancies act as charge carriers, meaning that the depleted layer has a much lower resistance than the non-depleted layer.

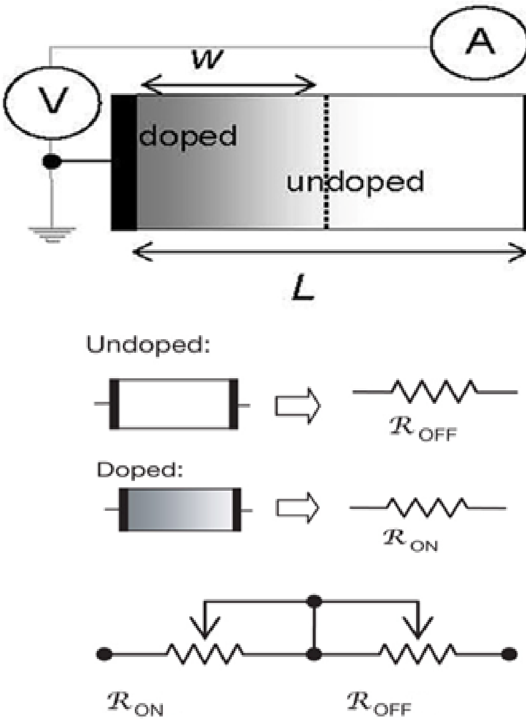


Fig. 1 Memristor diagram and its equivalent circuit representation

When an electric field is applied, the oxygen vacancies drift, changing the boundary between the high-resistance and low-resistance layers. Thus the resistance of the film as a whole is dependent on how much charge has been passed through it in a particular direction, which is reversible by changing the direction of current. Since the HP device displays fast ion conduction at nanoscale, it is considered as a nanoionic device. Memristance is displayed only when both the doped layer and depleted layer contribute to resistance. When enough charge has passed through the memristor that the ions can no longer move, the device enters hysteresis. It ceases to integrate $q=\int I dt$, but rather keeps q at an upper bound and M fixed, thus acting as a constant resistor until current is reversed.

The most common VI characteristics is a ‘figure of 8’ or a ‘pinched loop’. For this current i=0, when voltage v=0. On the application of electric field, oxygen vacancies drift changing boundary between high and low resistance layers. Memristance is only displayed when the doped layer and the depleted layer both contribute to resistance. The device enters hysteresis when enough charge has passed through memristor and ions can no longer move.

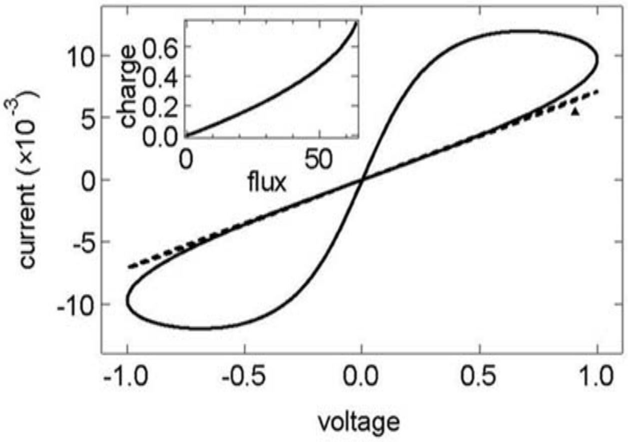


Fig. 2 Memristor characteristics

IV. APPLICATION OF MEMRISTORS

A. Non-volatile Memory Applications

Memristors can retain memory states and data, in power-off modes [4]. Non-volatile random access memory (NVRAM) is an important commercial application of the memristor. 3 nm memristror fabrication technologies already exist. The HP developed cross bar latch memory has a speed of one-tenth the speed of DRAM. These memories are expected to be available in the market in next two years.

B. Low-power and Remote Sensing Applications

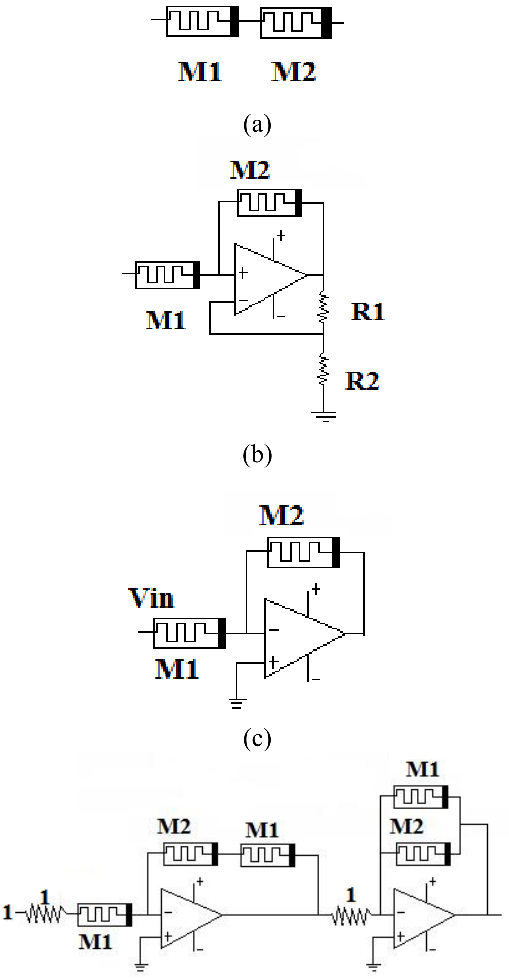
Coupled with memcapacitors and meminductors, the complementary circuits to the memristor which allow for the storage of charge, memristors can possibly allow for nano-scale low power memory and distributed state storage, as a further extension of NVRAM capabilities [6].

C. Crossbar Latches as Transistor Replacements or Augmentors

The high power consumption of transistors restricts its use to 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 s very small area.

D. Analog Computation and Circuit Applications

Using memristors for processing brings other potential changes. Memristors can represent many states instead of just two states, ‘on’ or ‘off’, as with transistors. This means new types of computing models and analog computers can be created. For performing any arithmetic operation such as addition, subtraction, multiplication or division, at first, two operands should be represented by some ways. In almost all of currently working circuits, signal values are represented by voltage or current. Basic arithmetic operations are addition, subtraction, multiplication and division. The total memristance of two memristors connected in series is the addition operation (M1+M2). Any subtraction operation i.e. M1− M2, can be written as M1+ (−M2). This means that for doing subtraction, memristor should be connected in series with another memristor, which has memristance as – M2. A simple opamp-based inverting amplifier, which intrinsically is a memristance divider (M2/M1)V_{in} is in Figure 3(c). Setting $V_{in} = -1$ will cause the output to be equal to M2 ⁄ M1. In this case, this circuits acts as a simple divider. Finally, the circuit, which can be used as a multiplier, is shown in Figure 3(d). By applying standard opamp circuit analysis techniques, output voltage of the circuit is M1×M2. Note that in all of the described circuits, input voltage or current maybe used for scaling the output voltage for avoiding opamps from being saturated [7].



(d)

Fig. 3 (a) Addition (b) Substaction (c) Division (d) Multiplication

V. Operation as a Switch

For some memristors, applied current or voltage will cause a great change in resistance. Such devices may be characterized as switches by investigating the time and energy that must be spent in order to achieve a desired change in resistance.

VI. Conclusion

In this paper we surveyed application aspects of memristor as a promising nano device. The memristor motivates future work in nano electronics and nano computing. The memristor can be used to design biological cognitive systems or complex material assemblies which can learn to make decisions and analyse information in a highly parallel way.

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