Abstract:
For past 180 years, circuit theory is studied with three fundamental circuit elements, the resistor, the capacitor and the inductor. The memristor (short for memory resistor) is a yet quite unknown circuit element. It was predicted from the theory arguments nearly 40 years ago, but not realized as a physical component until recently. Memristors are labelled as a significant candidates for building a better storage, higher capacity and more efficient performance. The device, memristor has great potential to replace conventional flash memories in near future. In this paper a brief survey on memristor models is done and a PSpice model of the equivalent circuit of the titanium-dioxide memristor is presented based on the current-voltage relationship. This paper will discuss the fundamental properties, basic device model and prominent applications of memristor as an advancement in fundamental circuit element.

Keywords: Memristor, Non-volatile memory, Resistance- switching, titanium-dioxide memristor, PSpice model; memristor Wien oscillator, Hysteresis, V-I characteristics.

I. Introduction
The memristor as a fourth basic nonlinear circuit element was predicted in 1971 by Professor Leon Chua. The first physical sample of the memristor was invented in 2008 by Stanley Williams of Hewlett-Packard laboratory, that the memristor consisting of two sub-layers of titanium dioxide, sandwiched between two platinum rims. The main unique property of this element is to memorize the full amount of charge which has passed through it. The definition of memristor has no requirement or restriction that memristor must involve in a direct interaction of charge within a magnetic flux. Many research results and simulations on the memristors have been made in the last few years. The main properties and the principle of operation of titanium-dioxide memristor have been described. An image of this memristor is given in Fig.1.
Fig: 1 The first realized memristor, produced in hp lab. Seventeen nanometres are shown in parallel (The image was produced by R. Stanley Williams of the HP labs.)

All these three basic elements in circuits are related by four fundamental variable quantities in circuits i.e., the voltage [v], the current [i], the charge [q] and the flux linkage [ø]. With these four variable quantities, we can define six possible relationships. They are:-

\[ q(t) = \int i(t) \, dt \] \hspace{1cm} (1)

\[ \phi(t) = \int v(t) \, dt \] \hspace{1cm} (2)

\[ v = R \cdot i \] \hspace{1cm} (3)

\[ \phi = L \cdot i \] \hspace{1cm} (4)

\[ q = C \cdot v \] \hspace{1cm} (5)

But the last relation between \( \phi \) and \( q \) remained undefined. Hence from the theoretical and the logical point of view, it became necessary to postulate the new fourth basic two terminal element which can be characterized by \( \phi \) and \( q \) curve. This new basic element was named as MEMRISTOR since it behaves like a non-linear resistor with memory.

\[ M = \frac{d\phi}{dq} \]

Fig: 2 Symbol representing a memristor in an electric circuit.

The relationship between flux and charge defines memristance as

Fig: 3 Symmetry diagram showing the 6 distinct possible Realizations based on the four circuit variables.
D is the device channel length and w is the length of the doped region. The size of the doped region is a function of applied charge and is responsible for the memristive effect as it changes the effective resistance of the memristor. Usually, w is shown by its normalized counterpart, x=w/D. (Adapted from Strukov et al. (2008). Since Hewlett Packard Laboratories announced the fabrication of a working memristor by electrical conduction in titanium oxide (TiO2) in 2008, it has become popular to link different physical phenomena of resistive switching with the term named Memristor. These devices include a large variety of oxides, also named Resistive RAM (RRAM). Additional emerging memory devices such as, (Phase Change Memory and STT-MRAM) may also be considered as memristors since these devices are basically non-volatile two-terminal devices with varying resistance.

II. Surveyed Memristor Models

Leon O. Chua (1971) has hypothesized that this new device could have several applications in digital memory, analog electronics, neural networks and he proposed a possible realization of memristor using passive and active circuit elements, as shown in Fig. 4. While the three circuit elements (R, C and L) can be easily constructed, up to 2008 nobody has proposed a material or physical structure that shows the characteristics of a memristor.

Valeri Mladenov and Stoyan Kirilov (2013) analysed that the electrical circuit of the memristor Wien generator constructed is presented in Fig. 6. It is obtained by modifying the classical scheme of the oscillator with Wien Bridge by substituting some of the resistors with memristors. The operational amplifier used here works as a master nonlinear unit. The resistance of the memristor cells used in the circuit could be managed by external current or...
voltage sources. The variation of the resistance in memristors M1 and M2 is used for regulating the frequency of the output signal of the oscillator. With changing the equivalent resistance in memristors M3 and M4 we can regulate the magnitude of the output signal in a determined interval.

![Fig: Memristor Wien Generator.](image)

**Fig: 6: Memristor Wien Generator.**

Gennaro Gelao and Anna Gina Perri (2014) analysed that the memristor can possibly allow for nano-scale low power memory and distributed state storage, as a further extensions of NVRAM capabilities. While memristor can be used at its high (or) extreme resistance values in order to provide digital memory, it can be made to behave in an analog manner also. One potential application of this behaviour is a dynamically adjustable electric load. Thus, existing electronic circuit topologies with their characteristics that depend on a resistance can be made with memristors that behave as variable programmable resistances. This design approach has the potential to create electronically adjustable filters and amplifiers as shown in Fig.7

![Fig.7: Programmable Gain Differential Amplifier.](image)

**Fig.7: Programmable Gain Differential Amplifier.**

Saraju P. Mohanty (2013) analysed the memristors in Analog Nano electronics that the inductor-capacitor tank based voltage-controlled oscillator (LC-VCO) presented In Fig.8 is typically used as an electronic oscillator to control the frequency of the phase-locked loop (PLL). A PLL is the heart of every synchronous circuit or system needing a global clock. The LC-VCO circuit is typically controlled by applying a DC input voltage through a loop filter. The LC-VCO produces cleaner output; however it occupies a significant area of the chip and size able portion of the power budget. An alternative of LC-VCO, the ring oscillator has high phase noise, is highly sensitive to disturbance, and has
poor stability at high oscillation frequencies. As a mitigation of the issues of the existing oscillators, a memristor-based VCO are explored. The schematic diagram of the memristor-VCO is presented in Fig 8. In this design the memristor works with LC-tank for sustained oscillations. The memristor can be used for oscillator design as it provides negative resistance. In the negative resistance region, the memristor in essence behaves as an active device (like transistor) and hence can maintain sustainable oscillations. Thus, by replacing the transistors from the traditional LC-VCO circuit designs in Fig.8 memristor-based VCO circuit design are explored by the designers.

Fig.8 Memristor-based VCO circuit designs.

Saraju P. Mohanty (2013) analysed the Memristors in Digital Nano electronics. In principle, a memristor can be used as a switch if an applied voltage will make severe change in the memristance. In such a memristor switch the time and energy that must be spent to achieve a targeted change in memristance are key quality factors. For a memristor to switch from RON to ROFF in time TON to TOFF the change in charge is quantified as \( Q = Q_{ON} - Q_{OFF} \). The energy consumed for such a switching is quantified as \( E_{switch} = VQ \), where \( v(t) = V \) is a constant supply voltage. Thus, there will be switching energy dissipation as in the case of CMOS. Most of the existing research on memristor is focused on cross-bar based memory design. Memristive Programmable Logic Arrays (PLAs) are also being explored for efficient reconfiguration in field-programmable gate-array (FPGA) implementation.

For any technology to be useful in the design of main stream digital circuits and systems it needs to be functionally complete. In terms of Boolean logic, the basic gates like AND, OR, NOT needs to be designed for AND-OR-NOT implementations of digital functions. At the same time design of universal gates NAND/NOR can enable NAND-based or NOR-based digital design. It is observed that memristors can realize “implication logic” instead of Boolean logic. Consequently, the implication logic which is functionally complete can be used to realize any Boolean functions.

Fig 9: A memristor-based n-bit adder.
Peng Li, Garng M. Huang and YenpoHo (2009) proposed Memristor Memory Circuitry with read and write schemes for memristor memories and discussed the associated circuit design issues associated with read, write stabilities and data integrity.

![Fig. 10: Circuit structure for one memristor cell.](image)

The sense amplifier stage as shown in Fig. 10 fully converts the sensed memristor state to a full-swing digital output. The voltage Vx will be compared with the reference voltage Vref which is half of Vin. If the memristor stores logic zero, Vx is less than Vref and output Vo is VL. If memristor stores logic one, Vx is greater than Vref and output Vo would be VH. Fig. 11 illustrates a memristor-based memory array with peripheral circuits. Just like a typical memory array such as that of DRAM, it still has row decoder, sense amplifier and column selector/decoder. In addition, there is a pulse generator unit and a selector unit. Pulse generator generates read/writes pattern signals. In Fig. 11, when Pselect signal is high, NMOSs are short and PMOSs are open, signal directly goes through. If Pselect signal is low, NMOSs are open and PMOSs are short so signal gets negative in sign. Furthermore, the purpose of the selector unit is to switch the memristor to ground for a write operation and Rx for a read operation. Read Enable (RE) signal controls the MUX to switch properly depending on whether it is a read or a write operation.

![Fig. 11: Overall design structure.](image)

**III. Pinched Hysteresis Curve:**

As Memristor is not an energy storage device like the capacitor and inductor, the voltage must equal to zero whenever the current goes to zero. This causes the I-V curve of the device to produce a pinched hysteresis loop revealing the memory effect associated with it as shown in Figure 12. The reason to call Memristor as a fundamental circuit element is that no combination of non linear resistor, capacitor or inductor can reproduce the hysteresis loop or lissajous behaviour of Memristor.
It is interesting to observe that a Memristor under AC conditions can switch reversibly between a less conductive OFF state and a more conductive ON state as the voltage polarity of the device changes. For this resistive reversible switching, Memristor is considered as a possible breakthrough in non-volatile memory technology with its resistive switching characteristic.

IV. Conclusion:
An extensive survey has been done for various designs of memristors. In summary, memristors provide an inspiring variety of opportunities for electronics. Memristor technology is still immature and the device characteristics can vary a great deal. Memristor is proving a promising advancement in fundamental circuit elements at nano scale. According to the recent report, density of memristor can go beyond 100Gbits/cm2. Compared to the latest flash memories which typically have a density of 32Gbits/cm2, the memristor-based memories can be much more dense and compact. The switching power consumption for memristor can be 20 times smaller than flash. Still, there remains much work to be done to implement these memory elements properly in our field.

References:


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