International Conference on Applied Science, Technology & Management
Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India) ASTM 2018
10th February 2018, www.conferenceworld.in ISBN: 978-93-86171-99-3

MEMRISTORS: THE FUTURE OF TECHNOLOGY

Akshita Abrol[1], Meghal Nargotra[2]

[1]*Department of Electronics & Communication, GCET, Jammu, J&K, (India)*

[2]*Department of Technology, SSPU, Pune, Maharashtra, (India)*

ABSTRACT

Fourth fundamental circuit variable which relates charge and flux linkage was first introduce by Prof. Leon Chua in his Research Proposal at IEEE Transaction on "memristor the missing circuit element". Using this relation he predicted fourth fundamental element which is known as memristor. The first nanoscale TiO2 based physical model of memristor was proposed by Hewlett-Packard Laboratories which gave rise to a new research field called by researchers as 'ionics'. In this paper, we review a memristor, properties of memristor, the physics behind fourth fundamental circuit element, first physical model of memristor introduced by Hewlett Packard as well as the future scope of these devices. Comparison with existing technologies is also discussed. Some potential applications and major challenges for memristor development are also mentioned for which future work can be carried out.

Keywords: Memristor, Nanoscale

I. INTRODUCTION

Moore's law is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years. The invention of the 4th fundamental element has the capability to shift the electronics design which are not only increasingly very small but increasingly capable also. There are only three fundamental circuit elements which are known as a resistor, an inductor, and a capacitor. The relations are also established as follows Voltage-current relation defined by the resistor, charge-voltage relation defined by the capacitor and flux linkage-current relation defined by the inductor. But amongst these variables there was a missing link between charge-flux. From symmetry arguments, Leon Chua proposed there should be an element which gives a relation between charge and flux linkage. A functional relation between charge and magnetic flux linkage, $M = d\Phi/ dq$.

So, in 1971 he predicted the existence of a fourth fundamental circuit element, which he called a Memristor. He proved that Memristor behaviour could not be represented by any circuit built using only the other three elements, based on this he said the Memristor is truly a fundamental circuit element. Memristor is a resistor with memory. After about 37 years in 2008, one of the scientist at the Hewlett–Packard (HP) laboratories proposed nanoscale TiO_2 based physical model of memristor which followed the relation predicted by Leon Chua. This invention has opened door to many research fields and applications such as analog and digital logic design, soft Computing, Synapses design using Memristor. The Memristor is the first element which can remember its resistance itself depends upon how much, charge flowed through it. The Memristor behaves like a linear resistor with memory but also exhibits many interesting nonlinear characteristics. Emulating the behaviour of a single memristor, Chua showed, requires a circuit with at least 15 transistors and other passive elements. Hence circuits can be supercharged by replacing a handful of transistors with one single memristor.

It was observed that the graph described the current-voltage (I-V) characteristics that Chua had plotted for his memristor as in figure 1. Chua had called them “pinched-hysteresis loops”. The researchers at Hp labs called their I-V characteristics “bow ties.” A pinched hysteresis loop looks like a diagonal infinity symbol with the center at the zero axis, when plotted on a graph of current against voltage. The voltage is first increased from zero to a positive maximum value, then decreased to a minimum negative value and finally returned to zero. The bow ties were identical to the pinched graphs proposed by Leo Chua.

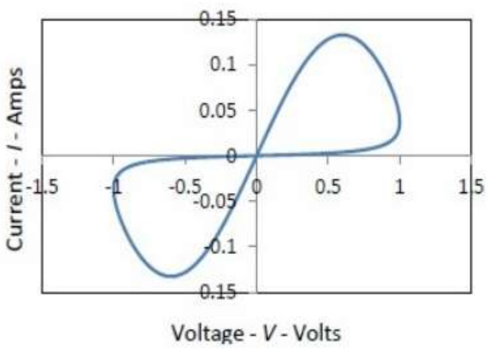

Fig. 1. V-I Characteristics of Memristors

The total change in the resistance measured in the devices also depended on how long the voltage was applied, the longer we applied a positive voltage, the lower the resistance until it reached a minimum value. And the longer we applied a negative voltage, the higher the resistance became until it reached a maximum limiting value. When the applied voltage was zero, whatever resistance characterized the device was frozen in place, until reset it by once again applying a voltage. The loop in the I-V curve is called hysteresis, and this behaviour is startlingly similar to how synapses operate: synaptic connections between neurons can be made stronger or weaker depending on the polarity, strength, and length of a chemical or electrical signal.

II. CONSTRUCTION OF MEMRISTORS

The very first memristor was conducted while creating a crossbar memory. The researchers tried to build a crossbar memory where the interconnects behaved as switches. The switches were required to have an on resistance to off resistance of the ratio 1:1000. They realised such a high resistance could be establish at nanoscale. The arranged platinum wires in criss-cross fashion and oxidised on of the wires. They field the interconnect space with switching molecules and titanium at on side. Hence a sandwich structure was obtained. It was observed at nanoscale how the memristors changed resistance as current passed. Under the molecular layer, instead of platinum dioxide, there was only pure platinum. Above the molecular layer, instead of titanium, there was an unexpected and unusual layer of titanium dioxide. The titanium had sucked the oxygen right out of the platinum dioxide. The oxygen atoms had somehow migrated through the molecules and been consumed by the titanium.

The titanium dioxide had split itself up into two chemically different layers. Adjacent to the molecules, the oxide was stoichiometric TiO2, meaning the ratio of oxygen to titanium was perfect, exactly 2 to 1. But closer to the top platinum electrode, the titanium dioxide was missing a tiny amount of its oxygen, between 2 and 3 percent. This is called oxygen-deficient titanium dioxide TiO2-x, where x is about 0.05. It was found that a positive voltage would switch the device on and a negative voltage would switch the device off.

The exotic molecule monolayer in the middle of our sandwich had nothing to do with the actual switching. Instead, what it did was control the flow of oxygen from the platinum dioxide into the titanium to produce the fairly uniform layers of TiO2 and TiO2-x. The key to the switching was this bilayer of the two different titanium dioxide species. TheTiO2 is electrically insulating (actually a semiconductor), but the TiO2-x is conductive, because its oxygen vacancies are donors of electrons, which makes the vacancies themselves positively charged. The vacancies can be thought of like bubbles in a glass of beer, except that they don't pop, they can be pushed up and down at will in the titanium dioxide material because they are electrically charged. If a positive voltage is applied to the top electrode of the device, it will repel the (also positive) oxygen vacancies in the TiO2-x layer down into the pure TiO2 layer. That turns the TiO2 layer into TiO2-x and makes it conductive, thus turning the device on. A negative voltage has the opposite effect: the vacancies are attracted upward and back out of the TiO2, and thus the thickness of the TiO2 layer increases and the device turns off.

Memristance arises in a semiconductor when both electrons and charged dopants are forced to move simultaneously by applying a voltage to the system. The memristance did not actually involve magnetism in this case; the integral over the voltage reflected how far the dopants had moved and thus how much the resistance of the device had changed.

III. ADVANTAGES AND POTENTIAL APPLICATIONS

The most obvious benefit is to memories. In its initial state, a crossbar memory has only open switches, and no information is stored. But once we start closing switches, we can store vast amounts of information compactly and efficiently. Since memristors remember their state, they can store data indefinitely, using energy only when you toggle or read the state of a switch, unlike the capacitors in conventional DRAM, which will lose their stored charge if the power to the chip is turned off.

The wires and switches can be made very small and then multiple crossbars could be stacked on top of each other to create a ridiculously high density of stored bits. Non-volatile memory applications: Memristors can retain memory states, and data, in power-off modes. There are already 3nm Memristors in fabrication now. Crossbar latch memory developed by Hewlett Packard is reportedly currently about one-tenth the speed of DRAM. Soon non volatile RAM will be in use. Some other applications include:

• 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. These are currently all hypothetical in terms of time to market.

• Crossbar Latches as Transistor Replacements or Augmentors: 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. There are difficulties in this area though, although the benefits these could bring are focusing a lot of money in their development.

• Circuits which mimic Neuromorphic and biological systems (Learning Circuits): This is a very large area of research, in part because a large part of the analog science has to do with advances in cognitive psychology, artificial intelligence modelling, machine learning and recent neurology advances. The ability to map people's brain activities under MRI, CAT, and EEG scans is leading to a treasure of information about how our brains work. But modelling a brain using ratiocinated mathematics is like using linear algebra to model calculus. Simple electronic circuits based on an LC network and memristors have been built, and used recently to model experiments on adaptive behaviour of unicellular organisms. The experiments show that the electronic circuit, subjected to a train of periodic pulses, learns and anticipates the next pulse to come, similar to the behaviour of the slime mold Physarum polycephalum periodic timing as it is subjected to periodic changes of environment. These types of learning circuits find applications anywhere from pattern recognition to Neural Networks. Memristors hold the key to develop artificial brain.

IV. CONCLUSION AND FUTURE SCOPE

Memristors have a great deal of scope for research. Though they will reduce the size of machines and make computations faster than done by transisotrs but it would not be right to say that transistors would be replaced completely by memristors beacause most of the circuits require an external transistor based power supply. Memristors predicted to be developed would depend on magneto resistive memory effect, electrostatic effect, valency change effect, thermo chemical effect, phase change memory, nano mechanical memory. So intensive research needs to be taken in these fields in order to develop memristors as a technology for future applications.

REFERENCES

[1] Z. Bolek, D Biolek, Javra V. Biolokova and Z Kolka. The simplest memristor in the world. In 2016 IEEE International Symposium on Circuits and Systems(ISCAS), pages 1854-1857, May 2016

[2] L. Chya , Memristor,- the missing circuit element. IEEE Transactions on circuit theory. 18(5):507-519, September 1971.

[3] V Erokhin. Oraganic memristors: Basic principles. In Proceedings of 2010 IEEE International Symposium on circuits and systems, pages 5-8, MAay 2010.

[4] S. Hamdioui, S. Kvantinsky, G. Cauwenberghs, L. Xie, N. Wald, S. Joshi. H.M. Elsayed, H. Corporaal, and K. Bertels. Mmemrisotr for computing: Myth or reality? In Design, Automation Test in Europe Conference Exhibition(DATE), 2017, pages 722-731, March 2017.

[5] T. Prodromakis, K Michelakis, and C Toumazou. Fabrication and electrical characteristics of memrisotrs with Tio2/TiO2+X active layers. In Proceedings of 2010 IEEE International Symposium on Circuits and Systems, pages 1520-1522, May 2010

[6] S.N. Truong , K Van Pham, W. Yan , and K.S.Min. Memristor circuits and systems for future computing and bio-inspired information processing. In 2016 IEEEBiomedical Circuits and systems Conference(BioCAS), Pages 456-459, Oct 2016

[7] L. Zheng, S Shin, and S.M.S Kang . Memristor- based synapses and neurons for neuromorphic computing. In 2015 IEEE International Symposium on Circuits and Systems(ISCAS), pages 1150-1153, May 2015.