# Memristor Theory

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***Abstract:*** Based on the problem that Moore's law of integrated circuit technology is about to fail, this paper studies the characteristics of memristor and its model. In today's information age, integrated circuit technology is the core of the whole information technology and information society. Memristor is considered as the fourth basic circuit element besides resistor, capacitor and inductor, and it has high speed and low power consumption Easy integration and compatibility with CMOS technology can meet the performance requirements of next-generation high-density information storage and high-performance computing for general-purpose electronic memory, which is regarded as the next generation of non-volatile memory technology.

***Keywords:*** Moore's Law; CMOS Technology; Electronic Memory; Memristor; Integrated Circuit Technique

## 1. The origin of memristors

Characteristics of the circuit can be described by the quantity of the circuit circuit basic variables involved in the physical by current I voltage v, charge q and magnetic flux phi, respectively corresponding to the electromagnetic field of the magnetic field intensity H electric field intensity E electric displacement and magnetic induction intensity B D circuit element is by different algebraic relation between the above four basic variables defined.

There are six combinations of the four variables:

i=dq/dt    v=dφ/dt    R=V/I    C=q/v    L=φ/i

In 1971, Professor Leon O. Chua of the University of California, Berkeley, from the perspective of the completeness of circuit theory, predicted that there was a fourth kind of missing passive basic circuit element besides resistance, capacitance and inductance, which represented the relationship between charge and magnetic flux, and named it memristor. He proved that memristor is a kind of nonlinear resistor, and the resistance value of the device can change with the history of input current or voltage, that is to say, it can remember the electric charge and magnetic flux through the change of resistance value.

## 2. Memristor theory

In recent years, researchers have found the characteristic phenomenon of pinch hysteresis loop in various materials and devices such as binary oxides, complex perovskite oxides, solid electrolyte materials, amorphous carbon materials, organic polymer materials, etc., and devices can reversibly change between high impedance state and low resistance state. Researchers call these devices memristors or devices with memristor characteristics, and propose different physical mechanisms for different materials to explain their memristor characteristics.

At present, most researchers in the world mainly study the quasi-static electrical characteristics of devices, but have not strictly proved that the devices they studied conform to the theory or model of memory group mathematics. On the one hand, the memrist theory itself is constantly improving and perfecting; on the other hand, researchers have not fully accepted the mathematical model of memrist theory. In 2015, Professor Leon O. Chua wrote a long article to classify memristors into four categories: ideal memristors, ideal universal memristors, universal memristors and extended memristors, and expounded in detail the most important concepts, namely, the definition of memristors, the mathematical principle of memristors classification, and its experimental discrimination method; Memristor can be non-volatile or volatile; Memristors can be passive or active.

## 2.1 Experimental definition of memristor

The simplest and most common definition of memristor is that its volt-ampere characteristic curve crosses the origin when it is excited by the current source i(t) or the voltage source v(t) with arbitrary amplitude and arbitrary frequency sine (or the periodic current or voltage signal with arbitrary zero DC component). Such a multivalued volt-ampere characteristic is called pinch hysteresis loop. The shape and size of the hysteresis loop are determined by the amplitude and frequency of the periodic input signal.

## 2.2 Classification of memristors

According to the definition from narrow to wide, a class of memristors defined by Professor Leon O. Chua in 1971 is called Is an ideal memristor. An ideal memristor can get a class of memristors with different mathematical forms but equivalent through transformation, which is called an ideal universal memristor. Because they are driven by the same input signal of current or voltage, they have exactly the same odd-symmetric hysteresis loops, and they are actually derivatives of ideal memristors. A broader class of memristors, called universal memristors, whose memristors are determined by one or more state variables, so their hysteresis loops do not need to be odd symmetric. The most generalized memristors are called extended memristors, whose memristors are determined by input current (or voltage) and one or more state variables at the same time. Most reported memristors should belong to this generalized memristors, such as spin memristors, phase change memories, thermistors, ion channels in neurons and so on.

In actual physical devices, the above four types of memristors are often distinguished by the following simple tests:

Apply a sinusoidal voltage signal with the waveform of v(t)=Asinwt to a memristor physical device, fix the amplitude and adjust the frequency, and observe the hysteresis loop corresponding to the volt-ampere plane. When the frequency increases, the area of each lobe will gradually decrease. When the frequency approaches the limit, the hysteresis loop will eventually become a "single value" trajectory. If this limit trajectory is a curve instead of a straight line, this memristor is an extended memristor. On the contrary, if the limit trajectory is a straight line that crosses zero, and its slope changes with the increase of amplitude A, then this memristor is a universal memristor. Under special circumstances, if the limit trajectory is a straight line that crosses zero and its slope does not change with the increase of amplitude, then this memristor is an ideal universal memristor. Under the condition of satisfying the ideal universal memristor, the relationship between charge and magnetic flux is a continuous monotone function, so this memristor is an ideal memristor.

## 2.3 Nonvolatile memristor and volatile memristor

If there are at least two obvious memristor resistances corresponding to the on-state and off-state of the memristor, and the memristor can keep the original on-state or off-state memristor resistance without power excitation, we call it nonvolatile. All ideal memristors and their derivatives are nonvolatile, but many general memristors and extended memristors are volatile.

## 2.4 Passive, active, local passive and local active characteristics

If a memristor is subjected to any periodic signal with zero DC component, the hysteresis loop is only distributed in the first and third quadrants, we call it passive; Otherwise, it is called active. The hysteresis loop of active memristor can not exceed zero point. Because when the hysteresis loop falls on the second or fourth image limit of the volt-ampere plane, v(t)*i(t)<0, the active memristor behaves like an energy source.

# 3. Memory Capacitance

After the concept of memory group system is gradually accepted by people, two other concepts of memory resistance elements, memory ease and memory sense, have been put forward one after another. Memory capacity system literally means a capacitance system with memory system, whose capacitance can record the history of the excitation signal passing through the capacitance. The definition of memory container establishes the state dependence between charge Q and voltage V, and the hysteresis loop of q-v domain is also considered as the judging mark of memory container. In the q-v characteristic curve of the memory container, when the voltage V is equal to 0, the charge Q must be equal to 0, but the current is not necessarily 0, which indicates that the memory container must be an energy storage device. In addition, the left half and right half of the q-v characteristic curve of memory capacity are completely symmetrical about the origin, which means that the output energy is exactly equal to that of the input device, that is, the memory container must be a passive device. Like the system characteristics of memristor, the characteristic curve of memristor system is also frequency-dependent, and its enclosed area will decrease with the increase of input excitation frequency until it shows a straight line at infinite high frequency. Memory container is a device that can store energy and charge. Such a device usually has two metal flat plates with almost negligible resistance at the outer ends, and a dielectric between the plates. Memory effects can come from changes in geometry and/or dielectric constant.

# 4. Memory inductance

Magnetic flux is involved in the definition of memory sense, but it doesn't mean that there really exists a magnetic field in the memory sense system. The definition of magnetic flux means the integration of voltage across the memory sense system with time. Like memristive system, the characteristic curve of memristive system is also a hysteresis line. The difference is that the definition of memristive system establishes the state dependence between charge Q and voltage V, while the memristive system establishes the state dependence between magnetic flux φ and current I parameters, that is, the characteristic curve of memristive system is the hysteresis loop of φ-i domain. In the characteristic curve, when the current I is 0, φ must be 0, but the voltage at this time is not necessarily 0, so it can be judged that the memristor is also a passive two-port circuit device with energy storage. The characteristic curve of recall system is also frequency-dependent, that is, the area surrounded by the curve decreases with the increase of external excitation frequency, until it shows a straight line at infinite high frequency.

# 5. Conclusion

Although encouraging research progress has been made in the physical mechanism, performance optimization, scale integration, nonlinear circuit and brain morphology calculation of memristor material system in China, researchers and engineers still need to continue to work together in many aspects. For example, the reliability of memristors, the control circuit design of arrays, and CMOS integration technology restrict the commercialization of memristors as non-volatile memory products. As a potential application field in the future, memrist-based neuromorphological computation and logical computation are in the early stage of development, lacking mature system theory, algorithm and perfect architecture of integration of storage and computation, and more subversive innovative ideas are urgently needed to promote the research in this field.

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