Identification circuit based on memristor

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Abstract. Aiming at the characteristics of the memristor with memory function in the circuit, the establishment of the memristor model and the simulation of the recognition circuit based on the memristor were carried out through the PSPICE simulation software. The NiO memristor was successfully fabricated on Si substrate by magnetron sputtering method, and the typical V-I hysteresis characteristic curve was obtained. Connecting the NiO memristor to the identification hardware circuit, the physical test results show that it is the same as the simulation diagram of the recognition circuit based on the memristor, which further confirms that the identification circuit based on the memristor has the learning function.

1. Introduction
The concept of memristor was proposed by Professor Cai Shaotang in 1971[1] to define the relationship between charge (q) and magnetic flux (φ), and M is used to represent the resistance of the memristor. Memristor is the fourth passive component after resistance (R), capacitance (C), and inductance (L). They collectively describe the relationship between voltage (V), current (I), charge (q), and magnetic flux (φ). For many years after that, they were only theoretical concepts without physical support, until the HP laboratory produced a TiO₂ memristor model in 2008[2]. It is a charge-controlled memristor, which depends on the accumulation of charge to change the resistance of the memristor, which is defined as:

\[ dq = M(q(t))dq \]  \hspace{1cm} (1)

With people's constant exploration of memristors, scientists have developed many kinds of memristor models, using many different materials to prepare the memristor objects. Memristors have nanometer size, non-volatility, memory characteristics, etc., and can be applied to memory, chaotic circuits, information encryption, associative memory neural network circuits and other fields [3-8]. The more famous is the Pavlovian dog experiment [9-10], which imitates the memory function of the human brain and lays a good foundation for imitating more complex human behaviors.

Lin Mi et al. of Hangzhou Dianzi University have designed a relay-based TiO₂ memristor simulator circuit[11], which uses a single-chip microcomputer to control the resistance change. T. ZHENG et al. proposed an adversarial synaptic spike neural network, which can learn different features between different tags[12]. This article first simulates the memristor and the identification circuit based on the memristor in the PSPICE software, and then uses the NiO memristor to connect the hardware circuit according to the simulation circuit and test and verify it.

2. Linear boundary migration model
The memristor boundary migration model was proposed by Hewlett-Packard Laboratories [13], the electrodes at both ends are made of platinum Pt, the middle layer is an oxygen-deficient titanium
dioxide layer TiO$_{2x}$, and the other layer is an oxygen-free titanium dioxide layer TiO$_2$. When V is applied, the movement of oxygen ions will cause the boundary line of the two films to change, which will change the resistance of the memristor. $w$ represents the width of the TiO$_{2x}$ layer, and $D$ represents the total width of the two titanium dioxide films. The resistance value $M(t)$ of the memristor is expressed as:

$$M(t) = \frac{w(t)}{D} + R_{OFF} \left(1 - \frac{w(t)}{D}\right)$$  \hspace{1cm} (2)

The width $w$ of the oxygen-deficient titanium dioxide layer is between 0 and D. When $w=0$, the memristor is TiO$_2$ and the resistance value is $R_{OFF}$; when $w=D$, the memristor is TiO$_{2x}$ and the resistance value is $R_{ON}$. The voltage across the memristor can be expressed as:

$$v(t) = \left(\frac{w(t)}{D} + R_{OFF} \left(1 - \frac{w(t)}{D}\right)\right) \cdot i(t)$$  \hspace{1cm} (3)

This article builds the memristor model in PSPICE according to the above formula, puts the memristor into a small test circuit, and applies sinusoidal signal input to it, the voltage is 6v, the frequency is 400Hz, and the loop characteristic curve of voltage and current is obtained as shown in Figure 1(a), the changing trend of resistance is determined by the applied voltage.

### 3. Preparation of NiO Memristor

In the laboratory, we used magnetron sputtering to prepare NiO memristor films on Si substrates. The sputtering power is 150W, the working pressure is 2Pa, the deposition time is 1h, and annealed at 400°C for 30min, the NiO memristor is obtained. It is found that under the change of the applied voltage, the resistance of the memristor changes accordingly, and a typical hysteresis curve is obtained. The electrical characteristic curve of NiO thin film is shown in Figure 1(b). Like the simulation results, it shows that the resistance of the memristor changes with the applied voltage. Process 1 and 3 in the figure indicate that the resistance of the memristor changes with the voltage. The absolute value increases and decreases; Process 2 and 4 show that the resistance of the memristor increases with the decrease of the absolute value of the voltage. During the debugging and testing phase of the memristor, attention must be paid to the film breakdown problem, and the voltage across the memristor must not be too large, otherwise there will be problems such as unstable local memristor resistance or the memristor not connected to the circuit.

[Figure 1 Voltage and current relationship diagram]

### 4. Identification circuit based on memristor

#### 4.1 Identification circuit design

The structure of the identification network is shown in Figure 2. When it see an apple, it will immediately recognize that it is an apple, but if it only know apple’s size, color, shape, and whether the surface is smooth, circuit can’t identify whether it is an apple. If the unconditional stimulus in1 is
activated, that is, a certain fruit is directly seen, the connection weight w1 is very large, and the output terminal has output; if the other 4 conditioned stimuli are activated, the connection weights between them will change. The interaction between the US and CS causes the weight of the connection to change, which leads to a process of learning and forgetting.

Figure 2 Identification network structure diagram

Figure 3 is the identification circuit diagram. W1 is generated by directly seeing the apple, the connection weight is large and hardly changes in the circuit, so the resistance R1 is used instead, and the four weights of w2, w3, w4, and w5 are respectively determined by M2, M3, M4, and M5 are replaced. The function of amplifiers U1 and U2 is to sum the input signals in1 and in2. The function of amplifier U7 is to perform a weighted summation of the signals after they pass through the memristor. U8 is a comparator, power supply V1 is -0.37v. The signals after the weighted summation are compared, and finally a signal is output at the out terminal to determine whether the fruit is an apple.

Figure 3 Identification circuit diagram

4.2 Identification circuit simulation results

Figure 4(a) is the input signal of the identification circuit, there is no input between 0s-0.1s; 0.1s-0.2s means that only the characteristics of the apple are known, but the apple is not seen; 0.2s-0.3s means that the apple itself is seen; 0.3s to 0.5s It means that you can see the apple itself and can receive the various characteristics of the apple. This is a learning process; 0.5s-0.8s means that you can only know the various characteristics of the apple if you can't see the apple itself. This is a process of forgetting.
Figure 4 Identification circuit input and output signals

Figure 4 (b) is the output signal of the identification circuit, there is no output because there is no input between 0s and 0.1s; there is only the characteristic input of apple between 0.1s and 0.2s, the circuit has not been performed Learning, so the circuit cannot be identified, there is no output; between 0.2s and 0.3s, it means that you can see the apple, the weight $w1$ is very large, and there is output at the out terminal; the circuit between 0.3s and 0.5s I can see the apples and receive the various characteristics of the apples, this is the learning process of the circuit. The corresponding weight increases, and the output terminal has output; after 0.5s, the out terminal lasts for a period of time, which means that the circuit can remember the characteristics of the apple for a period of time without seeing the apple. Because the learning is carried out between 0.3s-0.5s, the conditional stimulus CS and the out terminal have been connected, and the corresponding weight has been increased. When only conditional stimulus CS appears, the input of 0.5V voltage makes the memristor voltage lower than its threshold voltage, so that the corresponding connection weight is reduced. After a period of time, the connection weight is reduced to a certain level and the out terminal has no output, then it shows complete forgetting, which is the forgetting process of the circuit.

The simulation results show that the memristor can be used in the recognition network to realize the learning and forgetting process. It can be recognized by the characteristics of the fruit, or it can create a more complex recognition network and learn the characteristics of a variety of fruits.

4.3 Hardware realization of recognition circuit

Combining the simulation circuit and the actual NiO memristor prepared in the laboratory, the layout, wiring and welding of the identification hardware circuit are carried out, and the actual diagram is shown in Figure 5(a). The amplifiers involved in the circuit all use LM324, the comparator Using LM339, nmos transistor using IRF540N, VCC is set to 5v, V1 is -0.37v, V2 is 1v, in1 is set to voltage 5v, period is 1.25s, duty cycle is 50%; in2, in3, in4, and in5 are set to voltage 5v, Cycle 2.5s, duty cycle 50%; the square chip in the upper right corner is the NiO memristor made in the laboratory, M1, M2, M3, M4 are connected to 4 memristors.

Connect the circuit to the oscilloscope and the test result displayed on the oscilloscope is shown in Figure 5(b). Vin1 represents unconditioned stimulus, that is, see an apple; Vin2 represents conditioned stimulus, that is, know a certain characteristic of the apple; Vout represents output. The output result shows that Vout only has output when Vin1 has input, that is, it can be recognized by the circuit only under unconditioned stimuli. When Vin1 and Vin2 are both 0, that is, when there is no input, the output Vout is also 0; when Vin1 and Vin2 are 5v, Vout has output, indicating the learning process of the recognition network; according to the circuit principle of the previous section, the learning is completed After that, there will be a short period of output. Relying on the memory function of the memristor, the output will continue for a period of time after Vin1 stops the input, and there is no such short period of output after the circuit is tested. It may be that the memristor appeared during
production. The problem caused no memory function, or the memristor was broken down and lost its function due to excessive voltage applied during the test.

![Figure 5 The physical object of the identification circuit and the test result diagram](image)

5. Conclusion
According to the characteristics of the memristor memory function, an associative memory circuit based on the memristor was constructed. This article first constructs and simulates the memristor model in the PSPICE software, constructs and simulates the identification circuit, and uses the NiO memristor prepared in this laboratory to weld and test the hardware of the identification circuit. The result is the same as the simulation result, which proves that the memristor has a learning function. With the research of memristors by scientists in recent years, there have been many results. It is believed that memristors can be better used in various fields in the near future to improve circuit integration, reduce power consumption, promote technological development, and even produce technological change.

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