Study of Forming Process in Memristive Devices using Rectangular Waves

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Abstract

- The behavior of memristors during the process of forming is studied (setting the resistance of the element and testing the stability of the resistance).
- Two types of BS-AF memristive elements are selected for laboratory experiments.
- The investigation of the conditions under which the resistance of the element is changed when voltages of different levels, duration and polarization are applied.
- Finding the threshold voltage value which is needed to modify the state of the element.
- Such a value defines the voltage level below which one can safely measure instantaneous value of memristor's resistance (data read operation) without changing this value.

Introduction

In Theory

- Theoretical definition of memristor was formulated by Leon Chua in 1971.
- The memristor is defined as an element in which the resistance depends on the history of flux or charge of the element.
- Memristors are capable of changing the resistance after application of an appropriate voltage or current signal.
- The value of the resistance can be measured by applying a relatively much smaller sensing signal.

In Practice

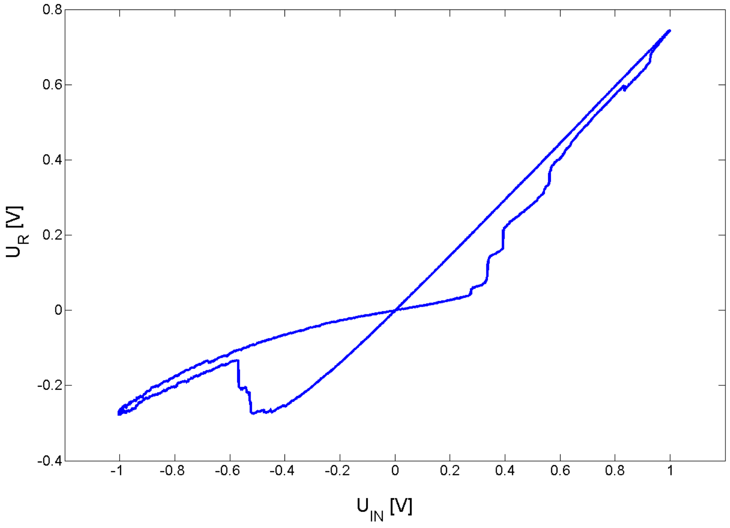
- The discovery of the element, which exhibits electrically controllable state-dependent resistance was reported by the HP scientists in 2008.
- The most crucial property of memristor is the fact, that it can take two significantly different values of resistance in a stable way.

Pinched Hysteresis Loop

- When a sinusoidal voltage is applied to the element a characteristic pinched hysteresis loop (also called the bow-tie curve) in $v - i$ relation is observed.
- This $v - i$ hysteresis loop always passes through the origin for any bipolar periodic input voltage.
- The pinched hysteresis loop narrows down when the frequency f is increased and the area of the loop converges to zero when f grows to infinity.

Pinched Hysteresis Loop

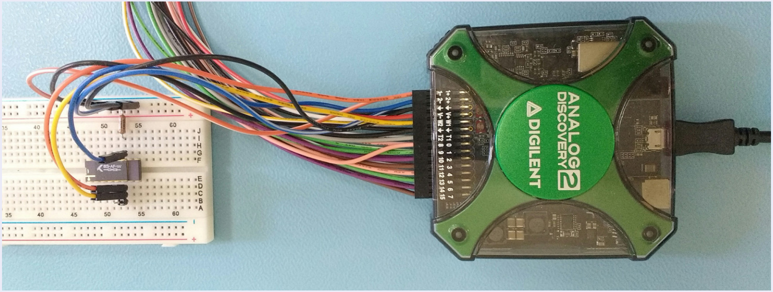
Hysteresis loop observed for a BS-AF-W memristor, input signal frequency is $f = 100$ Hz



Measurements

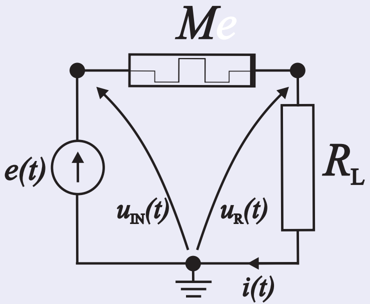
- Tests are carried out with 16-pin chips each containing 8 memristors.
- Two types of memristors are considered: BS-AF-W and DM8-16DIP-BS-AF.
- Measurement circuit based on Analog Discovery 2.0 device - portable oscilloscope set with two-channel periodic signals generator integrated.

Test circuit: a series connection of the on chip memristor and a linear resistor



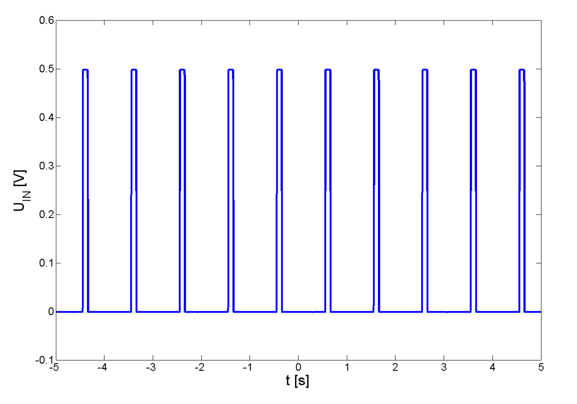
- The memristor element is connected in series with a resistor to measure the current flowing through the element.
- The value of the resistance $5\ \mathrm{k}\Omega$ is selected to protect the element under study by limiting the current.
- The WaveForms software package is used to define the input signal and save the results.

The simplified diagram of the circuit considered in tests



Input Signal

Rectangular wave with the amplitude 0.5 V, the period 1 s and the duty cycle 10%



The duration of the signal is limited to 10 s.

Calculation of Memristor's Resistance

- The experimental setup permits to apply the input signal U_{IN}, measure and record the input voltage U_{IN} and resistor voltage U_{R}.
- Using these measurements and the value of resistance R_{L} one can calculate the resistance R_{M} of the memristor using the following formula:

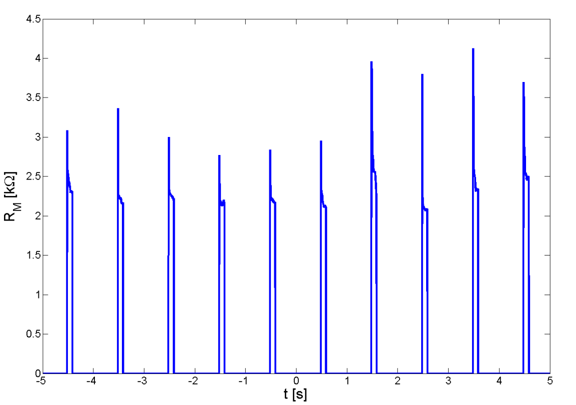
$$R_{\mathrm{M}} = \frac{U_{\mathrm{IN}} - U_{\mathrm{R}}}{U_{\mathrm{R}}} \cdot R_{\mathrm{L}}$$

Results

- At the beginning of each experiment it is verified whether a device under study operates as a memristor.
- To this end the sinusoidal voltage signal of amplitude 1V and frequency 100Hz is applied to the element and the $v - i$ characteristics is recorded.
- If the observed characteristics forms a pinched hysteresis loop then we assume that a selected element works as a memristor and can be used for testing.
- Two types of memristive elements were tested: BS-AF-W and DM8-16DIP-BS-AF.

BS-AF-W Memristors

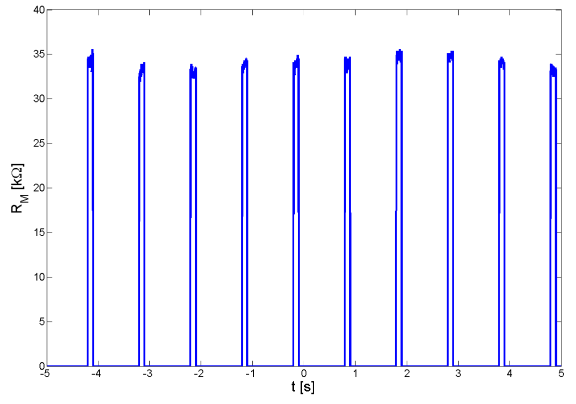
The resistance of a BS-AF-W memristor;
input signal: 10 pulses $U_{\text{IN}} = 0.5$ V of length $t = 0.1$ s.



When the input signal is positive then the resistance of the element decreases. This behavior corresponds to the OFF-ON switching in which the memristor's resistance changes from a high value to a low value.

BS-AF-W Memristors

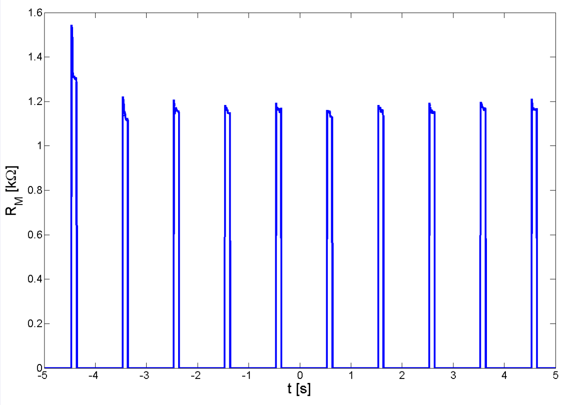
The resistance of a BS-AF-W memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = -0.5$ V of length $t = 0.1$ s.



Applying the negative voltage $U_{\mathrm{IN}} = -0.5$ V causes an almost immediate switching to high resistance state. The ON-OFF and OFF-ON switchings take place at different levels of the absolute value of the input signal.

BS-AF-W Memristors

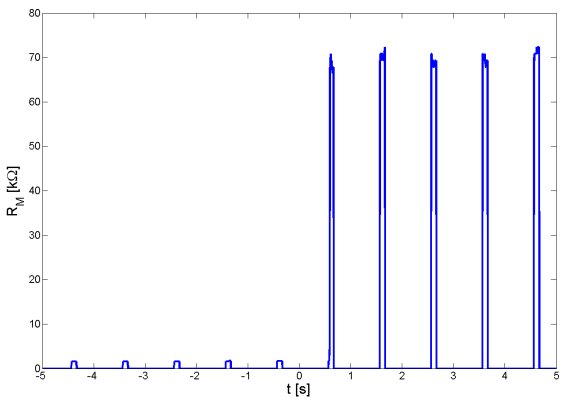
The resistance of a BS-AF-W memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = 1.0\ \mathrm{V}$ of length $t = 0.1\ \mathrm{s}$.



The switching takes place during the first two pulses and then the resistance stabilizes. The final value of the resistance $R_{\mathrm{M}} \approx 1.2\ \mathrm{k}\Omega$ is approximately two times smaller than in the first experiment ($R_{\mathrm{M}} \approx 2.5\ \mathrm{k}\Omega$ for $U_{\mathrm{IN}} = 0.5\ \mathrm{V}$).

BS-AF-W Memristors

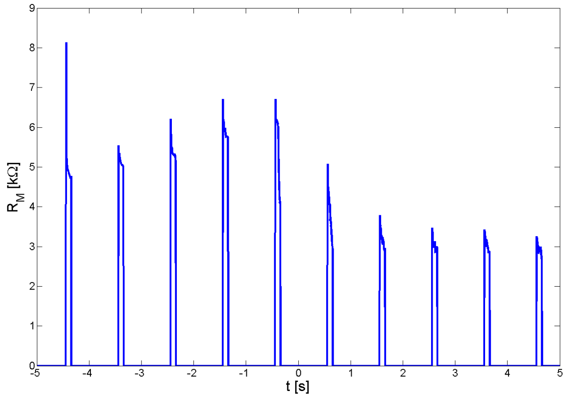
The resistance of a BS-AF-W memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = -0.25$ V of length $t = 0.1$ s.



The switching occurs during the sixteenth voltage pulse. The memristor resistance changes to a much higher level $R_{\mathrm{M}} \approx 70\ \mathrm{k\Omega}$ than in the case $U_{\mathrm{IN}} = -0.5$ V.

DM8-16DIP-BS-AF Memristors

The resistance of an DM8-16DIP-BS-AF memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = 0.5\ \mathrm{V}$, duration time $t = 0.1\ \mathrm{s}$.



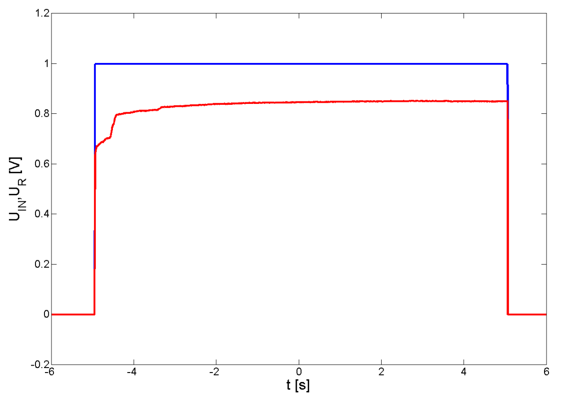
During the first four pulses the value of R_{M} increases. For the remaining pulses the resistance decreases, as expected.

DM8-16DIP-BS-AF Memristors

- The experiment carried out for the negative input voltage $U_{\mathrm{IN}} = -0.3$ V leads to similar results as for BS-AF-W memristor. The element switches to a high resistance state during the first two pulses and than the resistance of the element stabilizes.
- An interesting observation is made for the input signal with the amplitude $U_{\mathrm{IN}} = 1.0$ V. In this case R_{M} does not stabilize after 10 impulses.
- To further investigate this phenomenon we study the behavior of the element under a DC signal.

DM8-16DIP-BS-AF Memristors

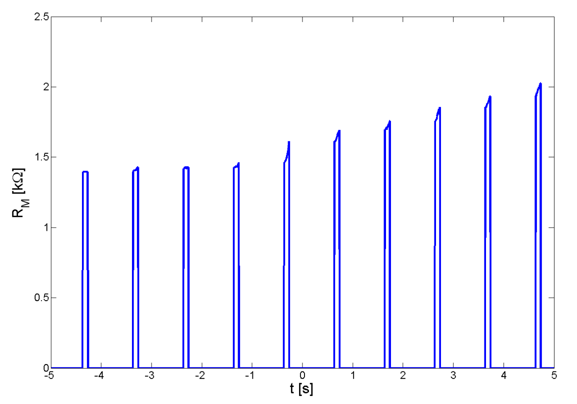
Forming an DM8-16DIP-BS-AF memristor with the DC signal.



Input and output voltages versus time. Red line indicates output voltage U_R. This experiment was repeated three more times, after which the resistance stabilizes.

DM8-16DIP-BS-AF Memristors

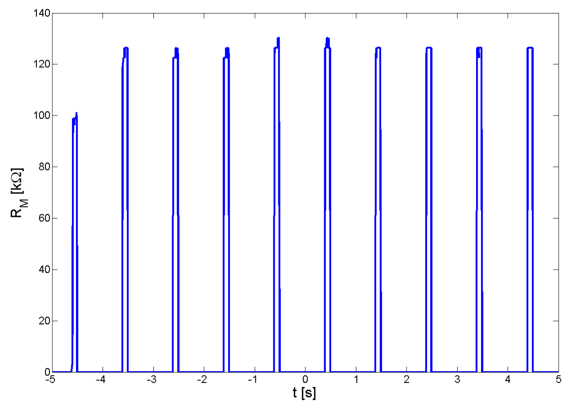
The resistance of an DM8-16DIP-BS-AF memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = -0.25\ \mathrm{V}$, duration time $t = 0.1\ \mathrm{s}$.



The resistance is slowly increasing in time during the whole experiment.

DM8-16DIP-BS-AF Memristors

The resistance of an DM8-16DIP-BS-AF memristor;
input signal: 10 pulses $U_{\mathrm{IN}} = -0.3$ V, duration time $t = 0.1$ s



The ON-OFF switching takes place much faster—already during the first pulse the resistance reaches $100\ \mathrm{k}\Omega$ and after the second pulse the resistance stabilizes around $125\ \mathrm{k}\Omega$.

Conclusions

1. Both the amplitude of the signal and number of pulses influence the final state of memristors.
2. The elements under study are much more sensitive to negative input voltages.
3. Slight change of the amplitude of the input signal can cause an immediate ON-OFF switching of the device.
4. By a proper selection of the amplitude of the input signal one can easily obtain a required value of the resistance
5. Memristive elements can take more than two resistance values in a stable way.

Thank You For Your Attention