The memristive characteristics of $Ba_{0.77}Sr_{0.23}TiO_3$ film device

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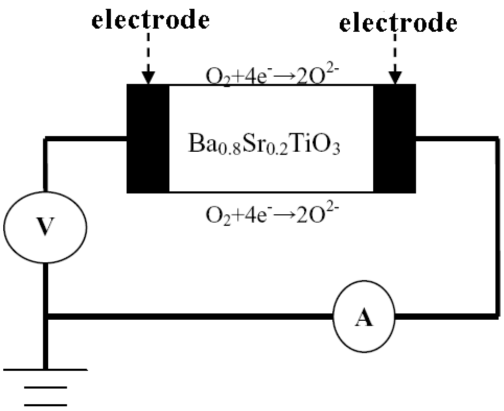
The memristor was postulated in 1971 as the fourth basic circuit element, alongside the resistor, capacitor, and inductor[1]. After that, this device has remained purely theoretical research for many decades. Until 2008, the first physical memristor has been invented[2], which rekindled the attention in the memristor system because of its potential memory applications in electronic circuits[3]. And it has been followed by some researchers[4–14]. However, the memristor models are relatively single, and there is no universal model to describe the behavior of memristors. For example, the TiO_2-based thin layer devices based on Pt/TiO_2-TiO_{2-x}/Pt double membrane structure are characterized by voltage-dependent resistances[15], and their behavior changes of resistance are bipolar resistive swich behavior, related to the applied voltage polarity, with rectification effect. In recent years, the research of memristors made significant progress, but the study of memristors as a basic circuit element is just beginning: the memristor is mainly for certain application or function, similar to TiO_2-memristor with bipolar resistive swich behavior. At present, unipolarity memristor models with generality and universality are rarely reported.

Recently, we have found an apparently related effect of a voltage-dependent resistance in a Sr-doped $BaTiO_3$ (BST) ceramic (~1 mm thickness) riched in oxygen vacancy. Under the condition of bias voltage, the production of the hole and the ionized oxygen ion (O^-) is related to the electric current and the power-on hours[15-17]. BST showed a nonlinear resistive changes associated with applied voltage time, and recorded the transiting quantity of charge, that is, it had the characteristics of the memristor. However, according to memristance theoretical formula[2], it was obtained that memristance becomes more important for understanding the electronic characteristics of any device as the critical dimensions shrink to the nanometre scale. Consequently, in the paper, the memristance behavior of BST nanometre film was studied, alongside BST ceramic.

The mathematical model and working mechanism of $Ba_{0.77}Sr_{0.23}TiO_3$ memristor is: under the condition of bias voltage, the hole and the ionized oxygen ion (O^-) are used as the carrier, and the resistance variation depended on the production of the hole and the ionized oxygen ion (O^-). The working mechanism of $Ba_{0.77}Sr_{0.23}TiO_3$ memristor is obviously different from HP TiO_2 memristors based on ON/OFF switch model. The variation on resistance of $Ba_{0.77}Sr_{0.23}TiO_3$ memristor is related to number of mobile carriers, not related to voltage direction, which was named unipolarity resistive switch behavior memristors. Fig.1 shows the mathematical model and working mechanism M(q) of $Ba_{0.77}Sr_{0.23}TiO_3$ memristor. It consisted of $Ba_{0.77}Sr_{0.23}TiO_3$ monolayer nanometer film. When a voltage or current applied to the device, it will generate huge electric field due to the film thickness as nanoscale. The surface of $Ba_{0.77}Sr_{0.23}TiO_3$film may react with the oxygen in air ($O_2+4e^- \rightarrow 2O^{2-}$), and the hole may occur inside the $Ba_{0.77}Sr_{0.23}TiO_3$ film. At the same time, as the reaction($O^{2-} \rightarrow e^- + O^-$) occurred within the film affected by bias effect, hole and ionized oxygen ion (O^-) as the main carrier moved directionally in the electric field. The quantity change of hole and ionized oxygen ion (O^-) will cause the change of the resistance between the two electrodes, resulting in the corresponding resistance minimum (Rmin) or maximum (Rmax) for the film. O(t) is used to signify the hole quantity of $Ba_{0.77}Sr_{0.23}TiO_3$ with bias at a certain moment, M is used to signify the maximum of the hole quantity, and v is used to signify the rate of generating hole. Since the quantity in hole and ionized oxygen ion (O^-) is related with its current and charge accumulation: $\frac{dO(t)}{dt} = v\frac{R_{\min}}{M}i(t)$, namely, $O(t) = v\frac{R_{\min}}{M}q(t)$; the film resistance is function of charge through the film: $M(q) \approx R_{\max}[1 - v\frac{R_{\min}}{M^2}q(t)]$ (Rmin<<Rmax). There is no driving electric field in the film after interruption of bias (current), and the movement of ions and electrons (hole) at room temperature are not active, so the hole and ionized oxygen ion (O^-) in the film can not be returned to their

original state. Therefore, it has memory function and keeps the resistance of bias (current) interrupting . This behavior may be driven by defect structure. And in this letter, we intends to realize a class unipolarity resistive switch behavior memristor with a monolayer structure of generality and universality, which has important theoretical significance and great application prospect for memristors and circuit theory.



$$M(q) = R_{\min}\frac{O(t)}{M} + R_{\max}[1-\frac{O(t)}{M}]$$
$$\approx R_{\max}[1-v\frac{R_{\min}}{M^2}q(t)]$$

Fig.1 The mathematical model and working mechanism M(q) of $Ba_{0.77}Sr_{0.23}TiO_3$ memristor. O(t) signify the hole quantity of $Ba_{0.77}Sr_{0.23}TiO_3$ with bias at a certain moment, M signify the maximum of the hole quantity, v signify the rate of generating hole with bias.

In the work, we prepared $Ba_{0.77}Sr_{0.23}TiO_3$ film device by sol-gel technique using spin-coating method. And the experimental result illustrates non-Ohmic behavior, the *I-V* curves are hysteretic. They are both indicative of a memristive system. Moreover, it was observed that memristance in $Ba_{0.77}Sr_{0.23}TiO_3$ is an even function of the current. Therefore, our BST device should be unipolarity memristor.

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