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Light and magnetic field double modulation on the resistive switching behavior in $BaTiO_3/FeMn/BaTiO_3$ trilayer films

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An obvious resistive switching (RS) was observed in $BaTiO_3/FeMn/BaTiO_3$ (BFB) trilayer films under different conditions. The RS effect was enhanced in light irradiation and restrained in magnetic field. The ratio of high resistance to low resistance of samples annealed at 500 °C is larger than 1500, and the samples showed a good stability. SET and RESET voltages decrease with increasing illumination intensity, but the ON/OFF ratio showed an inverse tendency. Conduction mechanisms in low resistance and high resistance were determined to be Ohmic and space charge limited conduction (SCLC) mechanism, respectively. A redistribution of oxygen vacancies and bound magnetic polaron (BMP) were used for explanation of the mechanism of RS behavior in this system under light irradiation and magnetic field, respectively.

1. Introduction

With an increase of amount of data that need to storage and decrease of size of electronic components, the most frequently used memory device, Flash Memory, is facing various challenges in technology and physics [1]. Therefore, to find out its replacement is a matter of great urgency. Among its potential replacements, Resistive Random Access Memory (RRAM) is considered to be the most promising candidate for the next generation nonvolatile memory due to its long retention time, high switching speed, small size, low power consumption, high density integration, simple metal–insulator–metal (MIM) structure, and most importantly, well compatible with the complementary metal–oxide–semiconductor (CMOS) technology [2–6]. RRAM is also known as memristor, the fourth fundamental circuit element in addition to resistor, capacitor and inductor [7]. It is based on RS effect in which the material resistance cloud be reversibly switched between two or more resistance states under the stimulus of electric pulse. RS effect could be classified into unipolar RS and bipolar RS according to whether its change of resistance depends on the polarity of applied voltage. Many materials, including perovskite oxides, transition metal oxides, organic compounds, superconducting materials and even eumelanin nanofilms have been reported to show RS effect [8–12]. In materials that exhibit RS phenomenon, perovskite-type materials were intensively studied after a report of RS in $La_{1-x}Sr_xMnO_3$ [13]. Though RS has been studied for years, the physical mechanism is still subject of heated debate and controversial. Nowadays, many models were proposed to explain the mechanism of RS, among them, filamentary model is the most accepted one and it is generally accepted that oxygen vacancies play a role in switching mechanism in many systems. In past few years, light as a new control parameter in RS has reported, an excess control parameter in RS could greatly expand its applications [14–16]. Magnetic field as another parameter in RS have also been reported in recent reports [17–19]. However, light and magnetic field double modulated RS effect has rarely been reported so far. In this work, we report the light and magnetic field double modulated RS behavior in BFB trilayer films. More excess control parameters means larger degree of freedom, and this could possibly bring about higher density integration and better multifunction.

2. Material and methods

Experimental methods is similar to our previous work [20]. The BFB trilayer thin films were deposited by RF sputtering. Purity of $BaTiO_3$ (BTO) and FeMn (FM) target is greater than 99.99% and a highly doped N-silicon (100) single crystal wafer is serve as substrate. The thickness of FM layer and both top ans bottom BTO layer is about 20 nm and 50 nm, the deposition rate is 0.042 nm/s and 0.044 nm/s, respectively. FM and BTO films were deposited under an Ar pressure of 1.0 Pa and the chamber base pressure was

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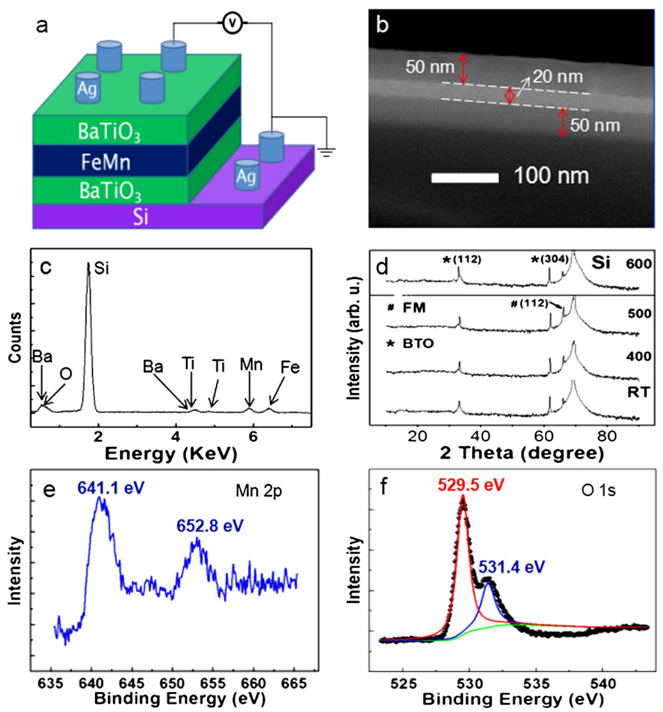

Fig. 1. (a) Configuration of samples and test circuit. (b) Cross profile of samples. (c) EDX pattern of 500 °C annealed sample. (d) XRD patterns of samples annealed at various temperature. (e) and (f) are the Mn 2p and O 1s core level XPS spectra of the films, respectively.

2.0×10^{-4} Pa. The BFB samples were annealed at various temperatures under vacuum of about 8.0×10^{-4} Pa for 1 hour. Then, the Ag top electrodes were deposited onto the BFB trilayer films with a metal mask. The bottom electrodes were made using colloidal silver liquid. In the measuring process, an ordinary filament lamp was used as the light source and the light is perpendicular to the sample surface. Magnetic field was produced by Vibrating Sample Magnetometer (VSM), and the direction of magnetic field is parallel to the film plane. The samples were characterized by X-ray Diffraction (XRD), Energy Dispersive X-Ray Spectroscopy (EDX) and X-ray Photoelectron Spectrocopy (XPS). The cross profile was measured by Scouldning Electron Microscope (SEM). Hysteresis loops of current-voltage characteristics were tested by and 4200 SourceMeter at room temperature.

3. Results and discussion

In experiment, the effect of annealing temperature on the electrical properties was found to be very weak, but the stability of sample annealed at 500 °C is slightly better than others. So, a detail analysis was made only on the samples annealed at 500 °C. Fig. 1(a) shows the configuration of samples and test circuit. Fig. 1(b) shows the SEM cross profile of the sample. The thickness of both top and bottom BTO layer is approximately 50 nm, and the thickness of FM layer is about 20 nm. Fig. 1(c) is the EDX pattern of the sample. It conforms that the element compositions of the sample are Ba, Ti, Fe, Mn, and O, and there are no other impurities. Fig. 1(d) shows the XRD patterns of samples with various annealing temperatures ranging from room temperature to 600 °C. The BTO (112) peaks as well as the FM (420) peaks become stronger with the increase of annealing temperature before 500 °C, indicating better crystallinity of the samples, but after that, FM (420) peaks decrease dramatically with the increase of annealing temperature. Indicating that crystallization of FM layer has been completed before 600 °C. Moreover, the $BaTiO_3$ (304) peak has no obvious changes. Fig. 1(e) and 1(f) are the Mn 2p and O 1s

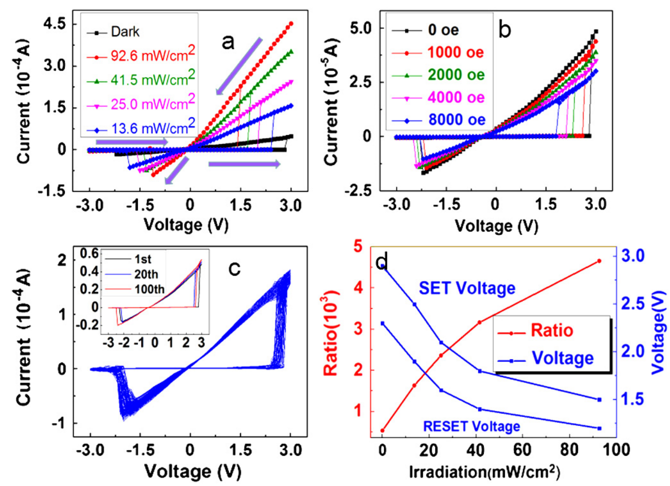

Fig. 2. (a) and (b) are the I–V curves of the 500 °C annealed sample under different irradiation intensity and different magnetic field, respectively. (c) I–V curves over 100 consecutive cycles under the irradiation of 13.6 mW/cm. The inset shows 1st, 20th and 100th I–V curves of the samples in dark and the unit is the same as the Fig. 3(c). (d) The OFF/ON ratio, SET and RESET voltage as a function of irradiation intensity, the ratio is measured at 0.5 V.

core level XPS spectra for the sample, respectively. In Fig. 1(e), the Mn $2P_{3/2}$ peak located at 641.1 eV, indicating the contribution of Mn^{2+} ions. For oxygen XPS spectra, the main peak (i.e., 529.5 eV) and the minor one (i.e., 531.4 eV) should be attributed to the lattice oxygen ions and the extrinsic contamination, respectively.

In the measuring process of the electrical properties of the sample, a compliance current of 1 mA was set to protect the sample from irreversible hard broken, the sweeping sequence as fellow: $0 \rightarrow V_{max} \rightarrow 0 \rightarrow -V_{max} \rightarrow 0$, as shown in Fig. 2(a). When the sample was placed in dark condition, an apparent bipolar RS behavior was detected, but the current-voltage hysteresis loop is relatively small. However, when a light was added, it is quite different. At low voltage region, the current is extremely small, it means the sample is at the high resistance state (HRS). But when the voltage exceeds a critical voltage called SET voltage, the current suddenly soared to a high level and much higher than that in darkness, it means the sample was set to low resistance state (LRS). Then, the sample will maintain in LRS until another critical voltage called RESET voltage reset it back to HRS again. Fig. 2(a) demonstrates that the RS effect of the films is enhanced by light irradiation. In contrast, Fig. 2(b) shows that the RS effect of the samples is suppressed by the magnetic field. To check the stability of our samples, we successively measured I–V curves for over 100 holonomic circles (i.e., $0 \rightarrow V_{max} \rightarrow 0 \rightarrow -V_{max} \rightarrow 0$) under light irradiation of 13.6 mW/cm^2, the results shown in Fig. 2(c). One could see that the I–V curves have no obvious changes in the whole process. The inset of Fig. 2(c) shows the 1st, 20th and 100th I–V curves of the samples in dark. The I–V characteristics in both dark and light show no significant decay, this indicating good stability of the samples. Fig. 2(d) shows the OFF/ON ratio, SET and RESET voltage as a function of irradiation intensity, where the OFF/ON ratio is defined as R_{HRS}/R_{LRS}. This result indicating that with growing intensity of light irradiation, the OFF/ON ratio becomes larger and larger while the SET and RESET voltage exhibit entirely reverse trend.

Fig. 3(a) shows the evolution of resistance in 100 cycles under irradiation of 13.6 mW/cm^2, the data were read out at 0.5 V. The resistance exhibits good stability in both HRS and LRS with a little fluctuation. The OFF/ON ratio always keeps about 1500, and this is large enough for information storage. Fig. 3(b) is the I–T curve measured at 0.1 V. From 25 s to 50 s, 85 s to 130 s and 170 s to 215 s, the sample was placed in light irradiation, in other time, it was placed in darkness. The result indicates a good