ELECTRO-PHYSICAL PROPERTIES OF MIM STRUCTURES AFTER Xe HEAVY ION IRRADIATION

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1. Introduction

The Resistive Switching (RS) phenomenon in thin dielectric films is extensively investigated because of its enormous potential in the field of non-volatile memories (NVM) [1] - [4]. The Resistive Random Access Memory (RRAM), based on the RS effect in the Metal/Oxide/Metal (MIM) sandwich configuration, is especially of much importance and has attracted significant attention owing to its superior performance such as simple structure, fast operating speed, low power consumption, and a good compatibility with the Complementary MOS (CMOS) technology [5]. Generally, the RS effect, exhibiting reproducible switching between High Resistance State (HRS) and Low Resistance State (LRS), can be classified into two types, i.e., the electrical amplitude dependent unipolar RS and the electrical polarity dependent bipolar RS.

Recently, the RS effect has been widely investigated in numerous oxide-based materials including the binary transition oxides such as HfO_2, TiO_2, ZnO, and NiO, perovskite oxides such as $SrTiO_3$, $LaSrMnO_3$, $CoFe_2O_4$, [6] as well as the spinel oxides, and organic layers [7]. However, the underlying physical origin of the RS effect is still a controversial issue and the RS performance and reliability should be improved. Thus, it is of significant importance to explore new RS materials and elucidate the RS physical mechanism.

Properties of the semiconductor devices exposed to the harsh radiation have a negative influence on their functionality [8]. Formation of the radiation defects in the MIM structures irradiated by high energy heavy ions has particular influence on their electrical parameters including current. The high density of the oxygen vacancies in thin oxide layers as a result of irradiation can affect the formation of the conducting RS effect.

The contribution shows the results of the I-V measurement on the $Pt/HfO_2/TiN$ structures irradiated with the167 MeV Xe heavy ions.

2. Experiment

The MIM structures were fabricated on Si substrate with a thermal 100 nm thick SiO_2 layer. Bottom TiN electrode (70 nm) was reactively sputtered in the Ar/N_2 plasma at the temperature of 200°C. The insulated HfO_2 layer was prepared by the atomic layer deposition (ALD) in a flow-type reactor at the 300°C using the TEMAH precursor. The ALD cycle was repeated 70 times to obtain the 5 nm thick layer.

Subsequently, these samples were irradiated with the Xe heavy ions of 167 MeV in the Joint Institute for Nuclear Research, Dubna, Russia.

The sample irradiated with the irradiation dose of 1×10^{10} cm^{-2} is labeled as the **126-4**, with the dose of 1×10^{11} cm^{-2} as the **126-5** and with the dose of 1×10^{12} cm^{-2} as the **126-6** and non-irradiated control sample as the **126-3**. Owing to current measurement the top Pt (30 nm) contact was evaporated using the electron gun at the room temperature through the shadow mask.

After an initial electroforming (~ -1,5 V), different switching loops were obtained using the current compliances in the negative bias region. The structures exhibited the stable bipolar RS effect.

3. Results and discussion

The typical DC sweep responses of the Pt/HFO$_2$/TiN MIM structure are shown in Figure 1a). The samples are functional after - 1.5V forming process. Measurements were carried out at the ambient temperature.

The *I-V* measurement of the non irradiated sample 126-3 has indicated stable bipolar resistive RS switching effect. The cycle switching RS effect has reached the ratio of HRS/LRS in the range of approximately 10, in dependence on the measurement conditions (Fig. 1b)).

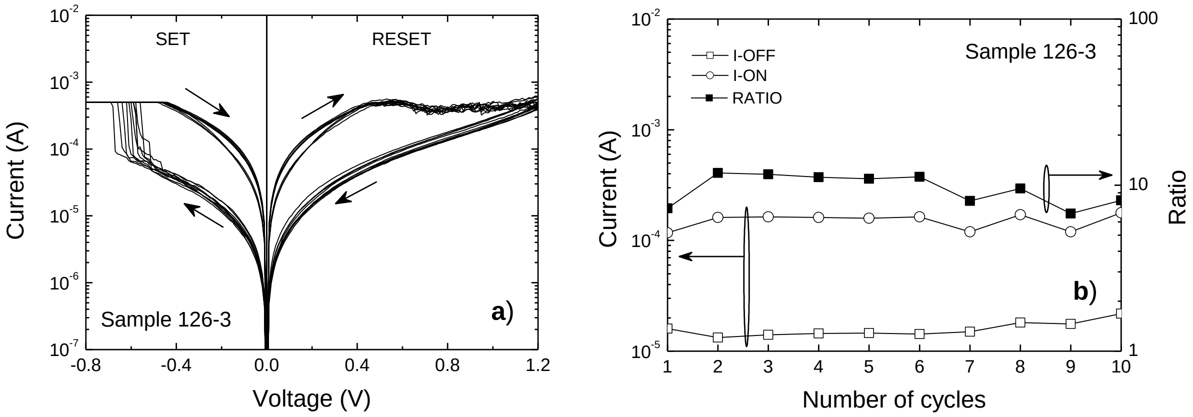

Fig.1 *a) Typical I-V curves of the resistive switching behaviors of the Pt/HFO$_2$/TiN MIM structure 126-3 and b) pulse cycling with an area of 100x100 μm^2, (reading 0,2 V).*

The irradiated structures showed increase in the current about approximately one order as the result of increasing in the radiation defects in the oxide layer and its interfaces. The resistive switching effect was measured at the lower fluencies. Transition between the HRS to the LRS effect was not continuous. In the RESET state was evidently seen jump change in a current which has changed with the increase in the radiation defects up to elimination of the RS effect. In figure 2a) and figure 3a) are shown the measured *I-V* curves after irradiation with the Xe heavy ions with the increase fluencies. At the cycle switching failure of the RS effect was occasionally observed (see figure 2b), and figure 3b)). However, the current ratio between HRS and LRS was observed in the range of 10. The samples irradiated with the highest fluence of 1×10^{12} cm^{-2} have not indicated the resistive switching RS.

The current results confirmed the existence of the resistive switching effect as a result of the conducting filament formation containing the oxygen vacancies. This phenomenon was confirmed by a measurement of the irradiated samples as well.

Indeed, the oxygen vacancies play an important role on the resistive switching. It is well established that the radiation creates oxygen vacancies that induce electron trapping in the HfO_2 [9]. Model for the conduction mechanism during the forming process is based on the trap-assisted tunneling (TAT) [10]. The traps form percolation paths for the electron tunneling and result in the TAT current. As the TAT current increases a Hf-rich ohmic conducting filament (CF) is formed with an electrical resistance corresponding to the *on* state. During the reset process the high ohmic current flowing in the metallic CF generates sufficient Joule-heating at the narrowest tip of the CF-presumably adjacent to the electrode-to induce oxidation of the Hf and create a tunneling barrier. Upon establishment of this barrier the system is in the *off* state characterized by TAT.

The voltage-induced formation/rupture of this CF comprises the on/off switching of the RRAM device.

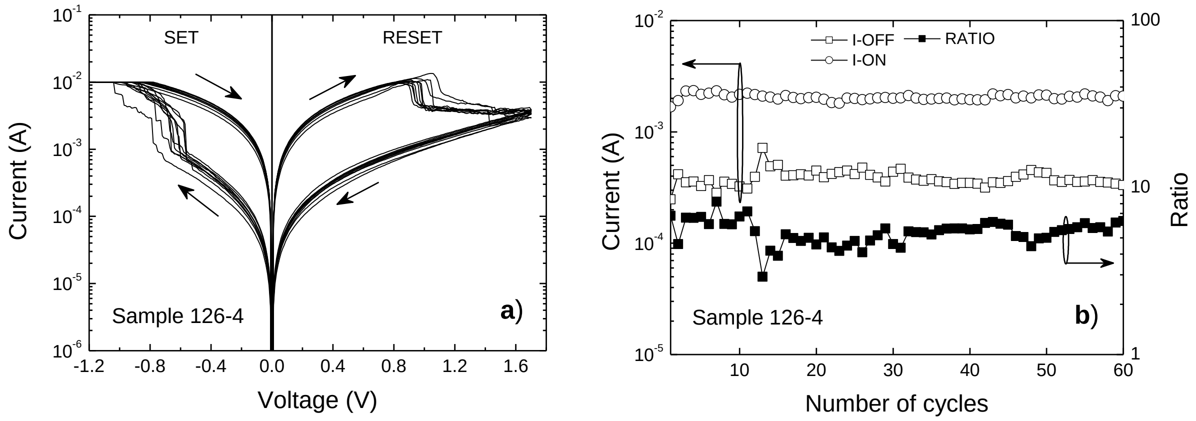

Fig.2 *a) Typical I-V curves of the resistive switching behaviors of the Pt/HFO$_2$/TiN MIM structure 126-4, irradiated with the 167 MeV Xe ions with the fluence of 1×10^{10} cm^{-2} and b) pulse cycling with an area of 100x100 µm^2, (reading 0,2 V).*

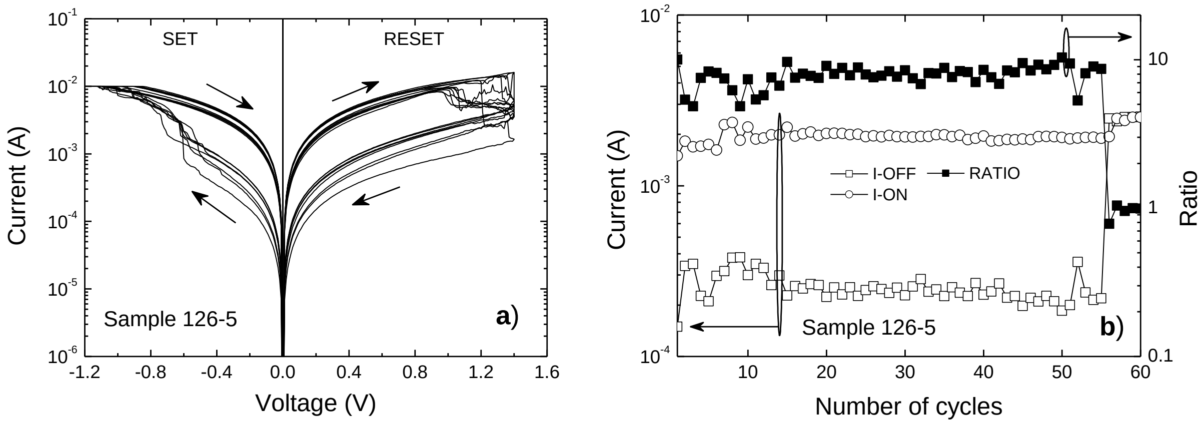

Fig.3 a) *Typical I-V curves of the resistive switching behaviors of the Pt/HFO$_2$/TiN MIM structure 126-5, irradiated with the 167 MeV Xe ions with fluence of 1×10^{11} cm^{-2} and b) pulse cycling with an area of 100x100 µm^2, (reading 0,2 V).*

4. Conclusion

The results of the current measurement on the Pt/HFO_2/TiN MIM structure based on HfO_2 oxide confirmed the stable bipolar resistive switching. The irradiated samples with the Xe heavy ions showed some increasing in current. The radiation defects which bring about increase in the density of the oxygen vacancies into the oxide layer confirmed existence of the particular physical phenomenon of the conducting filament forming owing to the Hf - O_x. bonds breaking.

Partial destruction of the MIM structure was seen at the fluence of over 1×10^{12} cm^{-2} The resistive switching phenomenon was not registered on the I-V curves with the higher current densities.

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