On the resistive switching and current conduction mechanisms of amorphous $LaGdO_3$ films

P. Misra, S.P. Pavunny and R. S. Katiyar
Department of Physics and Institute for Functional Nanomaterials,University of Puerto Rico
San Juan, PR 00936-8377, USA

The conventional memory technologies are facing the scaling issues as the semiconductor devices are rapidly approaching the miniaturization limits. Recently the memory concept based on resistive switching (RS) i.e. RRAM has emerged to construct the next-generation miniaturized nonvolatile memories. The memory effect in RRAM devices is realized through switching of the resistance of the device between the two states (high and low) of resistances. Amongst other materials currently being explored for the development of RRAM, lanthanum based amorphous high-k oxides have emerged as potential candidates. In this paper we report, for the first time (to the best of our knowledge), the growth of RRAM devices based on amorphous thin films of $LaGdO_3$ (LGO), their RS characteristics, underlying switching mechanisms and associated conduction behaviors in both the low resistance state (LRS) and high resistance states (HRS).

About 50 nm thick amorphous LGO films were grown on commercial $Pt/TiO_2/SiO_2/Si$ substrates using pulsed laser deposition at a substrate temperature of ~ 300 ºC and oxygen partial pressure of ~ 2×10^{-3} Torr. Top electrodes of ~ 70 nm thick Pt film with a typical diameter of ~ 80 µm were used to construct MIM capacitors. The RS characteristics and conduction mechanisms of these devices were studied through current-voltage (I-V) measurements in the top-bottom configuration.

The fresh devices were in HRS with resistance of ~ 40 MΩ. By sweeping the voltage from zero with a current compliance of 10mA, an abrupt increase in the current took place above a threshold voltage of ~ 7V known as forming voltage as shown in Fig.1 rendering the device in LRS with resistance of ~10 Ω (reset process). Afterward, by re-sweeping the voltage the resistance of the device was recovered to the original HRS value (set process) as shown in Fig.1. The reproducible unipolar switching between LRS and HRS was observed with nearly constant resistance ratio of ~ 10^6 and non overlapping switching voltages in the range of ~ 0.6-0.75 V and 2.2-3.2 V respectively for up to 25 cycles and over a temperature span from 300 to 500 K. To understand the RS mechanism we studied the resistance in LRS and HRS as a function of temperature. As shown in Fig. 2(a) the R_{LRS} increased linearly with temperature following the equation $R_T=R_0[1+\alpha(T-T_0)]$ with the temperature coefficient (α) ~ 8×10^{-4} K^{-1} which is typical for electronic transport in metallic nanowires. In HRS the device exhibited semiconducting behavior as shown in Fig. 2(b) with a dependence of HRS current on temperature in the form of $I=I_0 \exp(-\Phi/kT)$ where Φ is the thermal activation energy with value of ~ 165 meV. Based on the above analysis, we can derive that the conduction behavior of the Pt/LGO/Pt device follows the conductive filament (CF) model. According to this model during LRS switching the tiny CFs are formed out of point defects such as oxygen vacancies and metallic Gd (confirmed by XPS measurement) under initial high external electric field which provide low conducting path between top and bottom electrodes through LGO film and structure transforms in to LRS. In the reset process, most of the CFs are disrupted via the Joule heating effect due to high current flowing through the CFs. For the set process, the ruptured CFs in the LGO films regroup under an electric field resulting stable RS behavior. Thus, the RS process can be elucidated by the rupture and formation of CFs on application of suitable bias voltage.

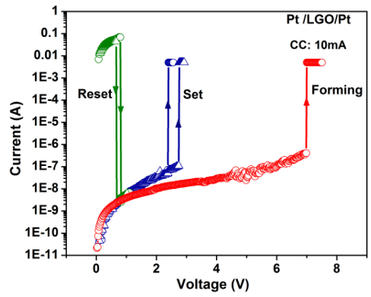

Fig.1 Current–voltage (I–V) plot of LGO film showing forming process and resistive switching for two cycles.

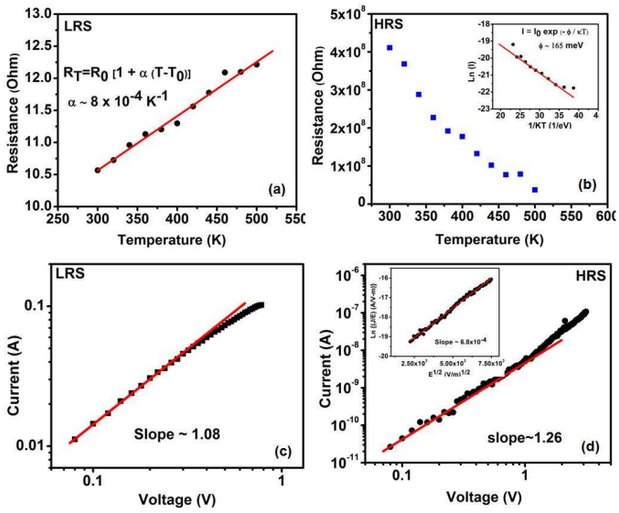

Fig.2 Temperature dependence of resistance in (a) LRS and (b) HRS. Log–log I-V plot of LGO film in (c) LRS & (d) HRS. Inset shows the plot of ln(J/E) vs $(E)^{1/2}$ in HRS.

To understand the current conduction mechanisms in LRS an HRS the corresponding I-V graphs were plotted in log-log scale as shown in Fig.2 (c) and (d). It can be seen that the I-V characteristics in LRS in the low voltage regime (< 0.5 V) is linear with a slope of ~ 1 indicating metal like Ohmic conduction while slight deviation for the initial linearity in high voltage regime (> 0.5 V) was perhaps due to the heating induced increase in the resistance of the metal like CFs before the onset of the rupture process. The I-V characteristics in HRS was also linear in low voltage regime like that in LRS perhaps due to the presence of small concentration of leftover CFs even after the rupture process. However, at higher bias voltages the I-V characteristics showed non-linear behavior which could be explained by the Poole-Frankel (P-F) emission mechanism. From the slope of the linear ln(J/E) vs $E^{1/2}$ relation in high voltage regime in HRS, the refractive index of ~ 2.1 was obtained for LGO film, which is in close agreement with the experimentally obtained value using optical measurements. In summary, the observed reproducible resistive switching, large HRS/LRS ratio, good endurance, nonvolatility, amorphous structure and high dielectric constant make LGO as a promising material for the future nonvolatile RRAM devices.

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