P53

Conductive Atomic Force Microscopy study of local resistive switching by a complex signal in the yttria stabilized zirconia films

D.O. Filatov, M.N. Koryazhkina, D.A. Antonov, I.N. Antonov,
D.A. Liskin, M.A. Ryabova, O.N. Gorshkov

National Research Lobachevsky State University of Nizhny Novgorod, 603950, Russia
dmitry_filatov@inbox.ru

In recent years, the investigations of resistive switching (RS) have attracted much attention [1]. The effect of RS consists in the bistable (or multistable) switching of the resistance of a thin (from several nanometers to several tens nanometers in thickness) dielectric films sandwiched between two conductive electrodes under the external voltage applied between the electrodes [2]. The electronic devices, the functioning of which is based on the RS are called memristors [3]. Today's understanding of the RS mechanism in the metal oxides is based on the concept of forming the conductive filaments consisting of the oxygen vacancies between the conductive electrodes in the electric field between the electrodes [4]. The switching of a memristor from the low resistance state (LRS) to the high resistance one (HRS) is achieved by the rapture of the filament by a voltage pulse (the RESET process). The filament can be restored by a voltage pulse of the opposite polarity that results in the switching from the HRS back to LRS (the SET process). The memristors are considered to be promising for application in the next generation non-volatile computer memory (Resistive Random Access Memory, ReRAM) [5], in the neuromorphic computers [6], etc. However, at present the application of the memristors is limited by an insufficient stability of the memristor parameters, which is a fundamental property of the RS [7]. The origin of the RS instability is the stochastic nature of the rapture and restoring of the filaments in the functional dielectric layer: a very limited (countable) number of oxygen vacancies are involved into the RS [8]. Traditional approaches to the improvement of the RS stability include the appropriate choice of the insulator and electrode materials, the engineering of the grain boundaries in the functional insulator, the application of electric field concentrators inside the insulator, etc. [9-11]. The alternative approaches include the circuit solutions, the application of adaptive switching protocols, etc. [12].

In the present work, the local RS in the yttria stabilized zirconia (YSZ) films was investigated using Conductive Atomic Force Microscopy (CAFM) [13] using the triangular switching voltage pulses with superimposed sinusoidal high-frequency (HF) signal. The YSZ films (~12 mol.% Y_2O_3) of ≈4 nm in thickness were deposited onto the Si(001) substrates with pre-deposited SiO_2 (500 nm), Ti (25 nm), and TiN (25 nm) layers by magnetron sputtering at 300 °C using Torr International® 2G1-1G2-EB4-TH1 vacuum setup. The RS was investigated performed using Omicron® UHV AFM/STM LF1 in ultra high vacuum (~10^{-10} Torr) in the contact mode (Fig. 1). The NT-MDT® NSG-11 DCP™ probes were used.

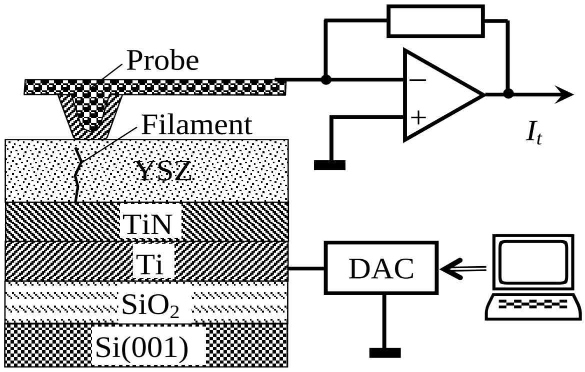

Figure 1. Scheme of the experimental setup.

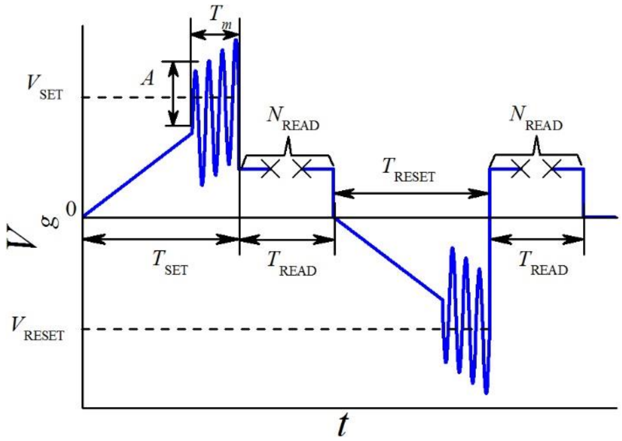

Figure 2. The RS protocol.

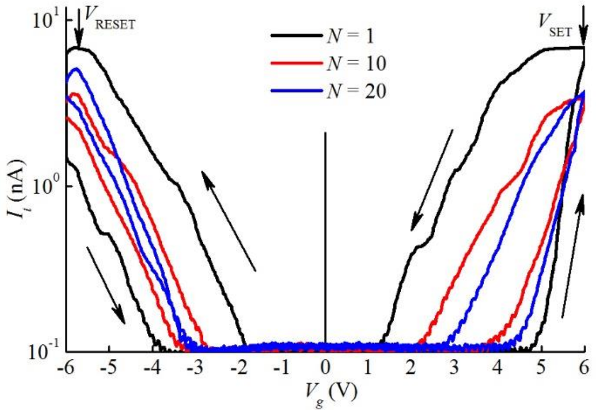

Figure 3. Cyclic I–V curves of the virtual memristor. N is the number of switching cycles.

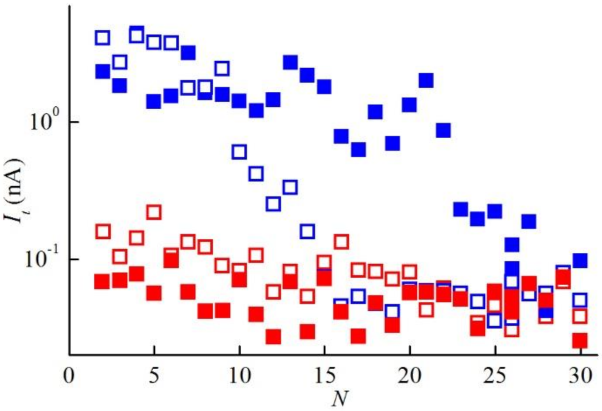

Figure 4. Endurance diagram for a virtual memristor (■,□ – I_{ON}, ■,□ – I_{OFF}) with (■,■) and without (□,□) HF sinusoidal signal (A = 0.2 V, f = 6.5 kHz).

The bias voltage V_g applied between the CAFM probe and the TiN sublayer was supplied by the digital-to-analog converter (DAC) of NT-MDT® Solver Pro™ AFM controller. The endurance of the probe currents in the LRS and HRS I_{ON} and I_{OFF}, respectively to the multiple cyclic write/erase operations was investigated. The switching/measurement protocol is shown in Figure 2. After the triangular switching voltage pulses with an amplitudes $V_{SET} = 5$ V and $V_{RESET} = –6$ V, the values of I_{ON} and I_{OFF} were recorded at read voltage $V_{READ} = 3$ V. The HF sinusoidal signal with the amplitude $A = 0.2$ V and frequency $f = 6.5$ kHz (matching the frequency of the O^{2-} ion jumps to the nearest neighboring oxygen vacancies in YSZ at 300 K [14]) was superimposed onto the triangle V_g pulses.

A pronounced hysteresis typical for the bipolar RS was observed in the cyclic current-voltage (I–V) curves of the CAFM probe contact to the YSZ film composing a virtual memristor (Fig. 3). The hysteresis magnitude decreased with increasing number of switching cycles N that was the manifestation of the virtual memristor degradation. Accordingly, the I_{ON} values approached I_{OFF} with increasing N (Fig. 4). The adding of the HF sinusoidal signal to the triangular switching pulses led to an increase in the local RS stability: the decrease in I_{ON} began at larger N values than in the case of switching by triangular pulses without the HF sinusoidal signal. The observed effect was attributed to the resonant activation of the O^{2-} ion migration via the oxygen vacancies under the external alternating electric field.

This work was supported by RFBR (18-42-520059p_a).

1. D. Ielmini, R. Waser, *Resistive Switching: From Fundamentals of Nanoionic Redox Processes to Memristive Device Applications* (Wiley-VCH), (2016).
2. R. Waser, M. Aono, *Nature Materials* **6**, 133 (2007).
3. D.B. Strukov, G.S. Snider, D.R. Stewart, R.S. Williams, *Nature* **453**, 80 (2008).
4. I. Riess, *J. Electroceram*. **39**, 61 (2017).
5. J. Ouyang, *Emerging Resistive Switching Memories* (Springer), (2016).
6. A. James, *Memristor and Memristive Neural Networks* (IntechOpen), 314 (2018).
7. W. Yi, S.E. Savel'ev, G. Medeiros-Ribeiro, et al, *Nature Commun.* **7**, 11142 (2016).
8. P. Parreira, G.W. Paterson, S. McVitie, D.A. MacLaren, *J. Phys. D: Appl. Phys.* **49**, 095111 (2016).
9. Y. Sun, C. Song, J. Yin, et al, *ACS Appl. Mater. Interf.* **9**, 34064 (2017).
10. M. Trapatseli, S. Cortese, A. Serb, et al, *J. Appl. Phys.* **121**, 184505 (2017).
11. W. Wu, H. Wu, B. Gao, N. Deng, H. Qian, *J. Appl. Phys.* **124**, 152108 (2018).
12. F. Alibart, L. Gao, B.D. Hoskins, D.B. Strukov, *Nanotechnology* **23**, 075201 (2012).
13. M. Lanza, *Materials* **7**, 2155 (2014).
14. S. Tikhov, O. Gorshkov, I. Antonov, A. Morozov, M. Koryazhkina, D. Filatov, *Adv. Cond. Mat. Phys*. **2018**, 2028491 (2018).