Resistivity Switching in Binary and Complex Transition-Metal Oxides

E. Zhitlukhina[1,2], M. Belogolovskii[1]

[1]Vasyl' Stus Donetsk National University, 021021 Vinnytsia, Ukraine
[2]O.O. Galkin Donetsk Institute for Physics and Engineering, 03028 Kyiv, Ukraine

Oxygen vacancies which are intrinsic to transition-metal oxides play a major role in electronic and magnetic properties of the strongly correlated systems and just now are the subject of intensive research due to the increasing complexity from the fundamental point of view and ever growing activities for practical applications [1]. In this work, we discuss the role of oxygen vacancies for modulating the physical states of correlated oxides at the mesoscale level. We focus on nanoscale resistance-switching cells that operate via the formation and disruption of conducting filaments that bridge metallic electrodes and are among the most promising devices for post-CMOS electronics. Despite their importance, the key mechanisms governing the change-over properties are not well identified and at present we have a limited understanding of how device size and operating frequency affect the processes, especially for nanoscale devices operating at ultrafast rates.

Our theoretical analysis of the switching events under the application of ac electric fields to oxide-based heterostructures is focused on yttrium-barium cuprate $YBa_2Cu_3O_{7-x}$ (YBCO) famous for displaying high-temperature superconductivity and therefore studied and characterized in detail for different oxygen deficiencies by various physical and chemical techniques. In particular, it relates the compound conductivity which dependence on the vacancies content x has been well known [2]. Experimentally, [3,4] it was found that double-valued current-voltage curves typical for memristive trilayers with metallic electrodes and a binary-oxide nanometer-thick interlayer can be realized in direct contacts formed by a metallic counter-electrode, a film or an STM tip, with a YBCO film. We show that this observation can be understood in terms of a minimalist one-dimensional model, whose major ingredient is the drift of doubly positive oxygen vacancies across regions of high electric field. The key relation describing the oxygen subsystem is the conventional mass balance equation, a consequence of the conservation of the number of vacancies. We have reproduced pinched hysteretic ***I-V*** curves for YBCO-based planar junctions and point contacts measured at Comenius University, Bratislava [3,4]. Our results suggest that the electric field produced by the current bias modifies the vacancies profile shape and thus can radically reconfigure the physical properties of conducting filaments through the near-interface region of the YBCO film. The data obtained for complex transition-metal oxides are attracted for the analysis of experimental characteristics for related binary compounds.

Our numerical simulations predict the ultrafast switching in such memristive devices. At higher frequencies, the theory predicts the degeneracy of the hysteresis effect, resulting in a straight line typical for a linear resistor. We show also that the very substantial changes in dielectric properties of a nanometer-thick binary-oxide layer should be enough to create and destroy self-aligned conductive filaments in superconducting Josephson junctions and point contacts providing a means for controlling the McCumber-Stewart parameter in the first case and measuring the energy gap values in superconducting electrodes in the second case.

The work was supported by the Ministry of Education and Science of Ukraine.

[1] Z.-t. Xu et al., *Small* **8** (2012) 1279.
[2] K. Yamamoto et al., *J. Appl. Phys.* **69** (1991) 7189.
[3] T. Plecenik et al., *J. Appl. Phys.* **111** (2012) 056106.
[4] M. Truchly et al., *J. Appl. Phys.* **120** (2016) 185302.