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Frequency dependence of the resistive switching effect in $Bi_2Sr_2CaCu_2O_{8+y}$/Ag film heterocontacts

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Abstract

In this work we have performed the relaxation studies "*in situ*" of the electron instability effect (EIE) in the heterostructures based on BSCCO single crystals. The new effect of suppression of EIE or colossal electroresistance via application of an alternating low frequency electric field to the heterojunctions in the BSCCO-based single crystals has been found. It has been shown that the top possible frequencies for observation of the effect are of the order of 10^3 Hz. This fact is interpreted as accumulation of the oxygen ions driven by the electric field to the interface. On the other hand, it has been shown that the switching events are limited by two time processes: $t \approx 1$ ms and about ten seconds. The first ones are caused by rearrangement of a charge net in the degraded surface at the electric field switching. The latter are caused by oxygen diffusion to vacancies under electric field above some threshold value. The considered experimental data confirm the correlation character of the HTSC properties as Mott systems, which appears in extreme sensitivity to the doping level, in the tendency to phase separation under external actions, in the hysteresis character of the metal–insulator transition.
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Strongly correlated electron systems (SCES) such as perovskite compounds based on the oxides of transition metals including high-temperature superconductors (HTSC), doped manganites (DM) are studied intensely in contemporary physics [1–8]. The effects of electron instability (EIE) and colossal electric resistance (CER) are observed in the heterostructures based on a number of compounds having the perovskite structure. The term colossal electric resistance CER was introduced in [17], probably, as analogue of the term "colossal magnetoresistance" CMR in the studied doped manganites, it determines variation in resistance in magnetic field. After the magnetic field is removed, CMR does not persist, the circumstance that confirms that CMR does not have the memory effect. In contrast to this term CER is applied to determine variation in resistance in the electron instability effects [9–21], which demonstrate variation in the phase state and resistive properties of the SCES structures and remain after switching off of the electric field:

$$CER = \Delta R/R = \big(R_{off}(V=0) - R_{on}(V=0)\big)/R_{on}(V=0), \quad (1)$$

where $R_{off}(V=0)$ is resistance in the switched-off state, $R_{on}(V=0)$ is resistance of the metastable SCES phases in the switched-on state.

EIE are caused by the processes on a normal metal/SCES interface [9–21] and appear as reversible resistive switching of the heterostructures. The effects of electron instability are polar which means that they depend on a sign of electric field

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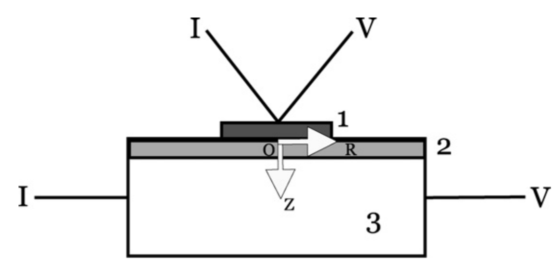
applied to a heterostructure, they also display memory effect. On one hand, EIE can be used to develop storage devices (so-called "nonvolatile memory applications"). On the other hand, it demonstrates similar behavior of SCESs and shows the way for investigation of the microscopic nature of the fundamental properties of this system.

In different studies the resistive switching times differ by orders of magnitude. In the research works [9,11] performed on the single crystals slow processes are observed, they are interpreted as oxygen diffusion through vacancies in the depletion layer of the interface. In [21] resistive switching is demonstrated on a PrCaMnO–Ag film heterojunction in the pulsed mode with pulse duration 300 and 100 picoseconds. At the same time the relaxation processes of several minutes duration were also studied in this work. The similar studies were performed in [11,13] in the Cr-doped perovskite Ti, Zr oxides. It was shown in this work that CER depends on a number and amplitude of pulses and did not saturate if the pulse duration varies from 1 ms to 1 s. The question raises on whether these contradictory data are caused by the difference in properties of various perovskite oxides or by properties of SCES film structures which are extremely sensitive to elastic stresses, defects.

In this work time characteristics of EIE and CER of the heterostructures based on the HTSC $Bi_2Sr_2CaCu_2O_{8+y}$ (BSCCO) single crystals are studied. The current–voltage characteristics (CVC) were recorded in quasi-stationary mode (slow scan 10^{-3} Hz), the signal shape was sinusoidal at the frequencies in the range 10^{-2}–10^5 Hz and time behavior of the heterojunction resistance was measured under stepwise voltage applied in the pulsed mode. It should be noted that in this experimental work we performed *in situ* studies of variation in electrical properties under action of sinusoidal alternating electric field, measurements of the voltage–current characteristics in the pulsed mode, and also recorded oscilloscope current and voltage patterns in the heterojunction. In the previous studies individual pulses of various duration were applied, variation in resistance of the heterostructure was measured in the direct current mode. The heterojunctions were prepared on the basis of BSCCO single crystals. A silver film was deposited on a cleaved or as-grown surface of the single crystal (see Scheme 1). The voltage–current characteristics of the heterojunctions were measured at the frequencies 10^{-3}–10^5 Hz, the temperature dependencies of resistance of the metastable phases were recorded and the voltage and current oscilloscopic patterns from the heterojunction were displayed for the 250 ns to 10 s passing pulses. A pulse generator with the short voltage rise time and an oscilloscope with the transmission band up to 300 MHz gave a possibility to study time processes (relaxation) in the time range 10^3–10^{-7} s. Frequency limitations appeared due to induction of the electric leads.

A typical voltage–current characteristic of the BSCCO/Ag heterojunction in quasi-stationary mode is shown in Fig. 1. We shall consider this characteristic in detail, because it is important to understand the peculiar features of this effect for further



Scheme 1. 1—normal electrode; 2—degraded part of the single crystal; 3—bulk non-degraded part of the single crystal; I, V—electric leads.

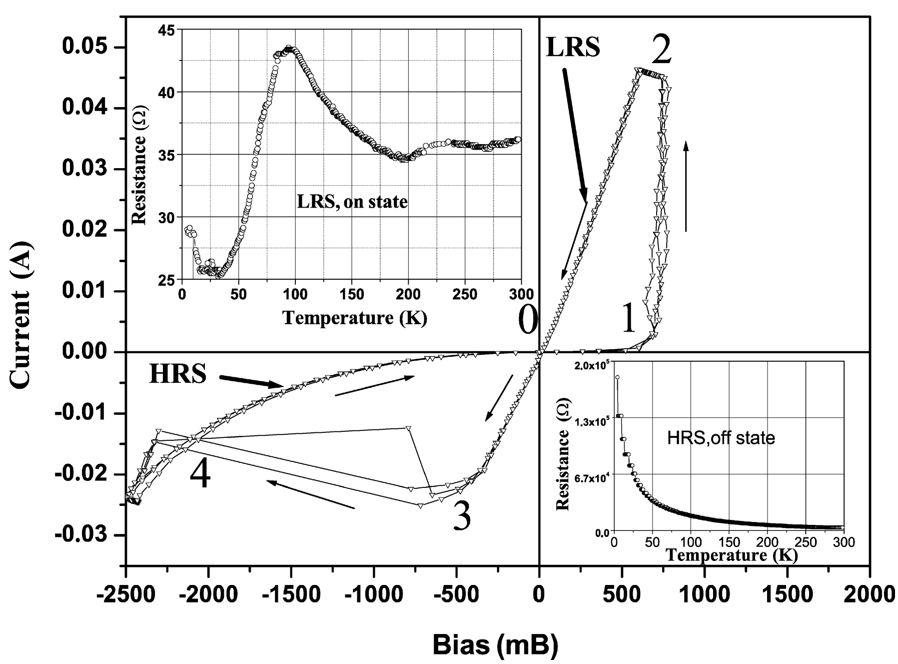


Fig. 1. An example of a voltage–current characteristics of BSCCO/Ag heterojunction with the resistive switching. Temperature dependencies of resistance of metastable states are shown in the insets: in the right corner is the high resistive switched-off state, in the left corner is the low resistive switched-on state with the superconducting transition.

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