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Fabrication and Properties of Thin-Film Heterostructures: High-Temperature Superconductor/Solid Electrolyte/Electrodes

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Thin-film heterostructures, $Y_1Ba_2Cu_3O_x$/solid electrolyte/electrodes, have been fabricated, and their electrical properties have been investigated. It is shown that by electrochemical injection-extraction of oxygen one can locally and reversibly change the character of the conductivity and superconducting transition temperature of thin-film $Y_1Ba_2Cu_3O_x$.

1 Introduction

IT is known that the electrical properties of $Y_1Ba_2Cu_3O_x$ change from that of a dielectric to that of a superconductor by varying the oxygen concentration.[1] This allows one to fabricate circuits based on superconducting materials by locally varying the oxygen composition of the films.

2 Results and Discussion

For this purpose, the authors fabricated thin-film heterostructures, $Y_1Ba_2Cu_3O_x$/solid electrolyte/electrodes. The structures were used as modified electrochemical oxygen pumps. Voltage between the electrode and the layer of high-temperature superconductor (high-T_c) induces the transfer of oxygen through the layer of the solid electrolyte from the atmosphere to the layer of the superconductor, or vise versa depending on the polarity of the voltage. The heterostructures were fabricated by the consecutive deposition of the layers—$Y_1Ba_2Cu_3O_x$, the solid electrolyte, and electrode—on the sapphire substrates (Fig. 1). The solid solution $(Bi_{1.4}Y_{0.6}O_3)_{0.95}(ZrO_2)_{0.05}$ was used as the solid electrolyte. This material was selected because its lattice parameters and thermal expansion coefficient are close to that of $Y_1Ba_2Cu_3O_x$.

The layers of high-T_c and solid electrolyte were prepared by pulse laser evaporation.[2] The bilayer film of Ag/In_2O_3 was used as an electrode. The layer of Ag is a reversible electrode for oxygen. The In_2O_3 layer protects the solid electrolyte from the diffusion of Ag. These layers were deposited by thermal evaporation. To determine the properties of the heterostructures, investigations of the current through the structures versus time, at a constant voltage between the layer of high-T_c and electrode, were carried out (Fig. 2). Investigations were performed in the temperature range 400 to 500 °C. It was found that the ionic transport number of the solid electrolyte varied from 0.7 to 0.9. The oxygen diffusion coefficient in the layer of superconductor ranged from 3×10^{-10} to 1×10^{-7} sm^2/s, and the equilibrium time of the high-T_c film with oxygen was 100 to 1 s.

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Electrochemical variation of the electrical properties of the $Y_1Ba_2Cu_3O_x$ film was carried out. For this purpose, the voltage was applied between the electrode (+) and the high-T_c film at 500 to 550 °C. As a result, the electrochemical extraction of the oxygen from the $Y_1Ba_2Cu_3O_x$ film took place. To control this process, the current passing through the heterostructure and the conductivity of the high-T_c film were measured. After obtaining equilibrium, the structure was cooled to room temperature in about 10 s. Four-point probe resistance measurements showed that after the oxygen extraction the conductivity of the $Y_1Ba_2Cu_3O_x$ film exhibited a semiconductor character (Fig. 3, curve 1). The injection of oxygen into the film was carried out at the following voltages: 20, 40, 60, and 80 mV (the electrode potential had a – sign) (Fig. 3, curves 2 through 5). The injection-extraction of oxygen was performed repeatedly; electrical prop-

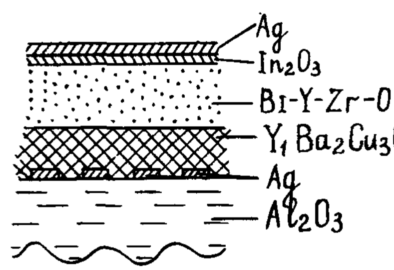

Fig. 1 Layout of the thin-film heterostructure: Ag(0.1μm); In_2O_3(0.05μm); Bi-Y-Zr-O(1.5μm); $Y_1Ba_2Cu_3O_x$(1μm).

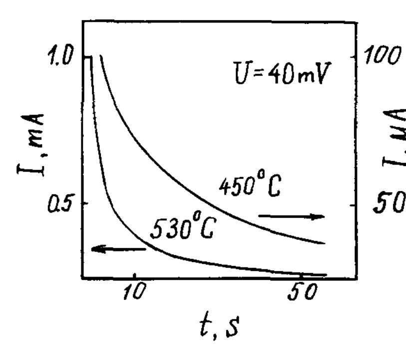

Fig. 2 Current vs time curves for heterostructure subjected to a potential of 40 mV at 450 °C and 530 °C.

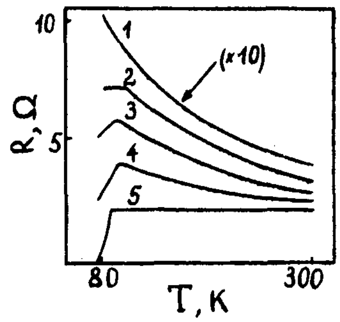

Fig. 3 Resistance vs temperature for $Y_1Ba_2Cu_3O_x$ film after extraction (1) or injection (2-5) of oxygen by applying different voltage to the heterostructure: 1 + 80 mV; 2–20 mV; 3–40 mV; 4–60 mV; 5–80 mV (the sign of the controllable electrode potential is indicated).

erties of the film changed reversibly without any degradation of the heterostructure properties. Thus, high-T_c/solid electrolyte/electrode heterostructures may be used for investigations of high-T_c and for fabrication of superconducting-controllable circuits.

References

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