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DEPENDENCE OF T_c ON THE ELECTRIC FIELD IN $YBa_2Cu_3O_{7-y}$ FILMS

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Abstract. The influence of the electrostatic field perpendicular to the current on the temperature dependence of the resistance of $YBa_2Cu_3O_{7-y}$ films is investigated and it is shown that in the T_c region the direction of the change of electric resistance and transition temperature depends on the direction of the electric field.

Key words: high-temperature superconductivity, YBaCuO films, transition temperature, resistance, electric field.

It is generally known that in high-temperature superconductors (HTSC) the superconductive transition temperature T_c depends on the concentration of holes (electrons). The change of holes concentration in 1—2—3 and 2—1—4 compounds is determined by the variation of oxygen content and the concentration of impurities (Sr, Ba, etc.) [1–5]. However, it is possible to change T_c also by nonchemical means, changing, for example, the concentration of free carriers by the electric field. The effect of the electric field perpendicular to the current has been demonstrated in low-T_c superconducting thin films in [6, 7] and, recently, in [8]. In perovskite-pseudoferroelectric $Ba(Pb, Bi)O_3$ a change of T_c and the superconductivity transition width in the electric field has been observed in [9]. The carrier concentration in YBaCuO ($n = 3.6 - 7.0 \cdot 10^{27}$ m^{-3} [10]) that is lower than in metals allows one to expect comparatively greater relative concentration changes in the electric field. A special interest in the influence of the electric field on T_c is connected with some new possibilities of the investigation of the high-temperature superconductivity mechanism. Electric field effects enable also the elaboration of superconducting field effect transistors and tunnel junction devices. In this work the influence of the electric field on the T_c of relatively thick polycrystalline films is experimentally investigated.

$YBa_2Cu_3O_{7-y}$ films of $\simeq 0.5$ μm thickness on $LaGaO_3$ and Al_2O_3 substrates were prepared in the laboratory of superconductivity of Tallinn Technical University by the method of laser sputtering with the use of an ELI-94 excimer laser on XeCl (308 nm) (H. Vallaste and Ö. Palmre [11]). Ceramic specimens of $YBa_2Cu_3O_{7-y}$ with small y were used as targets. The temperature of the sample holder was approximately 700 °C. The pressure of oxygen in the chamber was 13.3 Pa. No following annealing of the samples in oxygen was performed. Note that the superconductive characteristics of the films used strongly depend on the quality of the substrates.

The temperature dependences of resistance were measured in a liquid nitrogen cryostat or in nitrogen vapour (80—300 K) by four-point ac mode with the current up to 2.10^{-4} A. Nickel contacts were pressed onto the Ag layers evaporated on specimens. Temperature was measured with a Cu-constantan thermocouple glued onto the surface of the substrate beside the HTSC layer. The thermocouple reading error was not more than 0.4 K. The electrostatic field intensity up to 10^7 Vm^{-1} was applied through the substrate and a 50 μm thick mica plate. The dielectric constants ε of these materials are not more than 15 [12]. One of the electrodes was YBaCuO film, the other, Al foil glued onto the mica plate (see the inset in Fig. 1). Most films had a metallic behaviour of conductivity. This means that in the chemical formula $YBa_2Cu_3O_{7-y}$ y is small, To minimize the measurement errors we used slow cooling and heating (0.1 Ks^{-1}). The temperature dependences of resistance were compared under the same cooling or heating conditions.

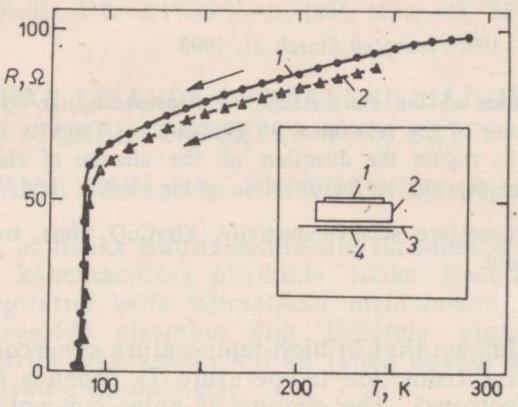

Fig. 1. Temperature dependence of $YBa_2Cu_3O_{7-y}$ film resistance: *1* — without field, *2* — with —4 kV on the field electrode. Inset: the scheme of electric field application to the film: *1* — superconductor, *2* — substrate, *3* — mica plate, *4* — field electrode.

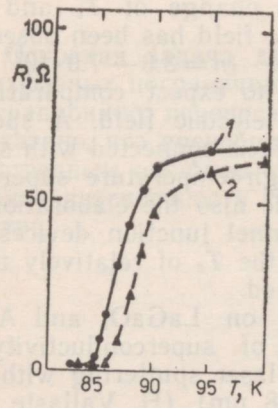

Fig. 2. Temperature dependence of $YBa_2Cu_3O_{7-y}$ film resistance: *1* — without field, *2* — with —4 kV on the field electrode.

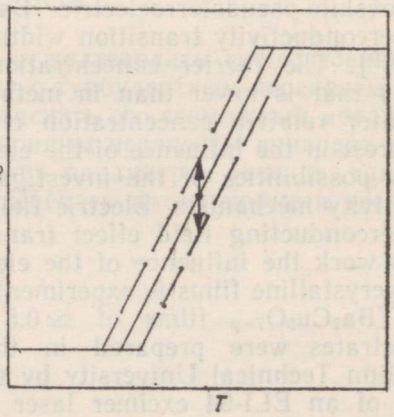

Fig. 3. The scheme of the superconductive transition shift in the electric field.

Figs. 1 and 2 (near T_c) show temperature dependences of resistance in the cooling conditions for $YBa_2Cu_3O_{7-y}$ film on $LaGaO_3$ substrate without the electric field (curves *1*) and with negative electric voltage on the field electrode *4* (inset in Fig. 1) switched on around 300 K (curves *2*). Zero and half-fall-down resistance in the electric field shifted to higher temperature approximately by 1 K. Thus T_c shifted by 1 K in the field of $1 \cdot 10^7$ Vm^{-1}. This T_c shift was observed in a few cooling-heating cycles as in [13]. In $Ba(Pb, Bi)O_3$, at T_c being 7.3 K, the electric field of $1 \cdot 10^6$ Vm^{-1} increased T_c by 0.3 K [9], in $YBa_2Cu_3O_{7-y}$ ceramic, by 2—6 K [13]. In $YBa_2Cu_3O_{7-y}$ with hole conductivity this polarity should increase the number of holes in the near-surface region of the specimen and decrease the resistance. Positive electric voltage should decrease the number of holes and, in principle, T_c should decrease, but no noticeable shift of T_c was observed. These problems need further investigation.

In the films used the electric field influences the resistance of the surface layer. This influence on the superconductive phase in the volume of the specimen is possible if there occur areas with different conductance. The reasons for the conductance variations can be the imperfections of the film growing (for example, dielectric layers by stoichiometry or crystal structure damage) or degradation of the film in air [14, 15]. The mechanism of the influence of the electric field on conductivity is then different. This point of view is supported by a decreased critical current density. The electric field effects on superconductive properties were observed on very thin monocrystalline $YBa_2Cu_3O_{7-y}$ films [16–18].

In order to check whether the observed T_c shifts could be caused by other factors, for example, by a temperature gradient, the temperature of the specimen in nitrogen vapour was stabilized at a temperature near T_c according to the maximal resistance drop (see scheme in Fig. 3). The resistance did not change within the time needed for measuring. The voltage switch-on changed resistance by a few per cent. The voltage switch-off returned resistance to nearly the initial value. The direction of the resistance change depended on the electric field direction. The change decreased with repeated voltage switch-ons. It is possible that this decrease is connected with diffusion processes or degradation of the surface superconducting layer in the electric field, observed in the ceramic $YBa_2Cu_3O_{7-y}$ [13, 15].

In conclusion it can be said that in certain conditions a T_c shift of not very thin $YBa_2Cu_3O_{7-y}$ films in the electric field is observable.

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T_c SÕLTUVUS ELEKTRIVÄLJAST $YBa_2Cu_3O_{7-y}$-KILEDES

Boris SORKIN

On uuritud vooluga risti suunatud elektrivälja mõju takistuse sõltuvusele temperatuurist $YBa_2Cu_3O_{7-y}$-kiledes ning näidatud, et T_c piirkonnas sõltub elektritakistuse ja siirdetemperatuuri muutuse suund elektrivälja suunast.

ЗАВИСИМОСТЬ T_c ОТ ЭЛЕКТРИЧЕСКОГО ПОЛЯ В $YBa_2Cu_3O_{7-y}$-ПЛЕНКАХ

Борис СОРКИН

Исследовано влияние поперечного току электрического поля на температурную зависимость сопротивления $YBa_2Cu_3O_{7-y}$-пленок. Показано, что в области T_c направление изменения электрического сопротивления и температуры перехода зависит от направления электрического поля.