INVESTIGATION OF TRANSPORT PROPERTIES OF $YBaCuO$-FILMS IN COURSE OF REACTOR NEUTRON IRRADIATION AT 25–30 K

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It is well known, that electric and magnetic properties of HTSC-materials considerably depend on the crystal defects.Irradiation allows to introduce defects in controllable manner, modifying properties of HTSC-material in desirable direction, which is very important both for applied researches and for fundamental ones to understand mechanisms of the high temperature superconductivity. The neutron irradiation is one of the most effective methods for the radiation modification of HTSC properties.

We have studied two $YBaCuO$-films (S1 and S2) produced by magnetron sputtering on $SrTiO_3$ substrates with the c axis along the normal to the latter. The film thickness was $d \sim 0.2$ μm. The I–V characteristics and the temperature behavior of resistivity were

measured in a four-probe dc arrangement, with the bridges $w = 100$ mm wide and $l = 2$ mm long produced by photolitography. The contacts were prepared by thermal deposition of gold in vacuum. The contact resistance did not exceed 0.5 Ohm, $T_c \approx 91$ K, $\Delta T \approx 1$ K, and $J_c \sim 10^7$ A/cm^{-2} at $T = 20$ K. The films were studied in a low-temperature channel of the WWR-M reactor at PNPI [1] with a fast ($E > 1$ MeV) neutron flux of $\sim 10^{13}$ cm^{-2}s^{-1} up to fluences $\Phi \sim 5 \cdot 10^{18}$ cm^{-2} at 25–30 K. The I–V and $R(T)$ measurements under irradiation were fully automated. The setup permitted voltage measurements on samples with a sensitivity of $\sim 10^{-8}$ V, temperature stabilization to within ~ 0.1 K. Measurements could be performed in *dc* magnetic fields of up to 0.2 T.

Fig.1 presents typical I-V dependencies obtained on unirradiated $YBaCuO$-films at various temperatures . The I–V characteristics reveal the switching effect over a broad temperature range (Fig.2). The switching effect and high critical current density (close to the theoretically predicted one) imply that the films are single-crystalline, the mechanism of disruption of such single-crystal bridges by superconducting current being connected with the onset of kinetic unpairing at the film edge [2], and the critical current, with the beginning of vortex motion. This permitted us to use the model of acontinues medium and of a resistive state associated with thermal activation of the Abrikosov vortice [3].in the analysis of I–V characteristics for single-crystal $YBaCuO$ films. Acceding to this model in the limit of the time τ spent by the vortex in the bound state to exceed that it spends drifting τ_a ($\tau_a \ll \tau$) and of not too small currents $J \gg kT/\alpha$, the I–V characteristic follow an exponential law [4]

$$E = B\omega_0\lambda \exp\left(-\frac{U - \alpha J}{kT}\right), \tag{1}$$

where ω_0 is the frequency; $\lambda = const(B)$ is the vortex mean free path; $B - \mu_0 H$ is the external magnetic field assumed to penetrate fully into film; U is the coupling energy; αJ is the work done by the vortex acted upon by the Lorentz force at a current density J, the parameters U, α, J being independent on B.

A $J_c(B)$ relation is displayed in Fig.3 for $T = 80$ K. The $J_c(B)$ dependence is seen to be fairly weak, indeed, as the magnetic field is varied from 0.01 to 0.08 T, the critical current drops only by 30%, thus arguing for the applicability of the independent vortex approximation.

The $J_c(B)$ dependence obtained in our experiment can be described by the classical expression

$$J_c(B) = J_c(0)\,(1 + B/B_0)^{-1} \tag{2}$$

The dashed line in Fig. 3 characterizes approximation with Eq.(2) with $B_0 = 0.12$ T.

Fig.4 presents the temperature behavior of J_c and $J_1 = kT/\alpha$ obtained approximating the I–V characteristics with Eq.(1) The value U/kT evaluated from this dependencies in the temperature range $80 < T < 90$ K is equal to 25, that is in agreement with the range $15 < U/kT < 50$ cited in [4]. The temperature behavior of J_c and J_1/kT is well approximated by relation

$$\begin{aligned} J_c &\sim (T_c - T)^x \\ T_1/kT &\sim (T_c - T)^x \end{aligned} \tag{3}$$

Relations of type (3) are provided by various pinning models. The values of $x = 1.4$ for J_c, and $x = 1.2$ for T_1/kT obtained in our experiment argue for mechanism of vortex pinning to plane grain boundaries.

Inspite of nearly the same initial parameters of the both films, the effect of neutron irradiation on $R(T)$ dependencies was different. The film S1 revealed decrease of T_c with irradiation, but as to the film S2 increase in T_c up to fluence $\Phi = 1.8 \cdot 10^{18}$ cm^{-2} and slight decrease at higher fluences were observed (Fig.5). Maximum critical temperature for the film S2 had value of 98 K, the increase of superconducting transition width and normal phase resistance occurring in both films (Figs.6a,6b).

The $J_c(T)$ dependencies for the S1 film at different neutron fluences are well fitted by Eq.(3) with $1.5 < x < 2$, the parameter x being independent of the neutron fluence (Fig.7).

Fig.7 also presents the $J_c(\Phi)$ dependence for $T = 80$ K. The fall off of J_c with neutron fluence is seen to follow an exponential law

$$J_c(\Phi) = J_c(0)\exp(-k\Phi), \tag{4}$$

The critical current should obey such a dose dependence in the case where the current-carrying capacity of the material is determined only by the fraction of the superconducting phase, provided the critical current density in the superconducting phase J_c^s does not depend on irradiation [5]. In our case k is equal to $1 \cdot 10^{-18}$cm^{-2}.

Calculations made using Eq.(1) showed the pinning energy U to be independent of neutron fluence, the value of U/kT lying in the range 20–25.

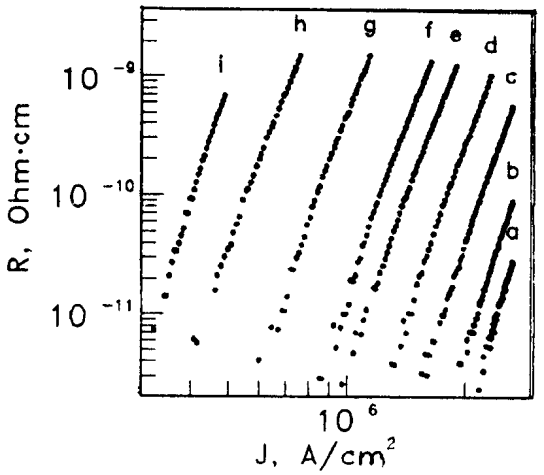

Fig.1. Resistivity vs. current density for film S1 at different temperatures before irradiation ($B = 0$)

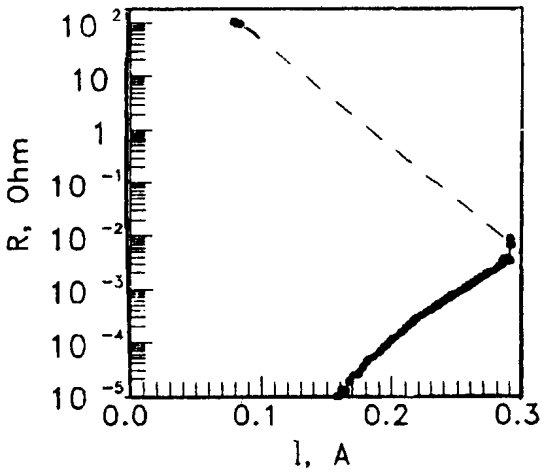

Fig.2. Typical dependence of resistance vs. current with switching effect for unirradiated film S1 ($B = 0$, $T = 83$ K)

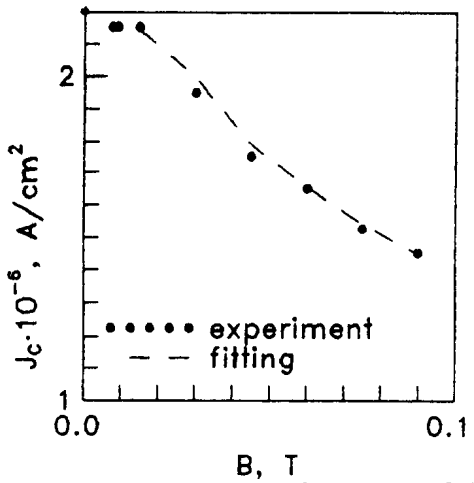

Fig.3. Critical current density as a function of magnetic field for unirradiated film S1 (T = 80 K); dashed line is the approximation with Eq.(2)

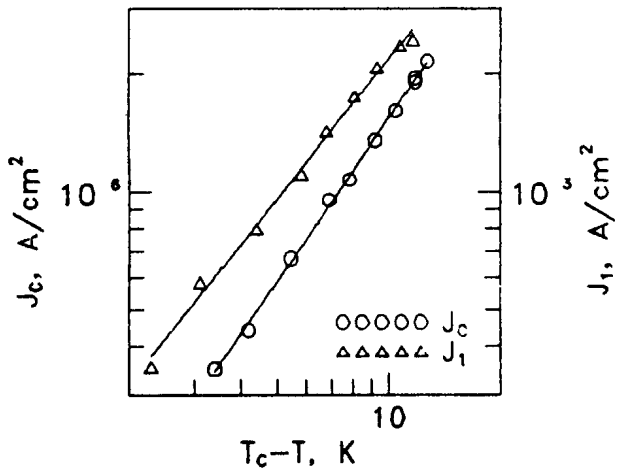

Fig.4. Temperature dependences of critical current density and parameter J_1 for unirradiated film S1 (B = 50 mT)

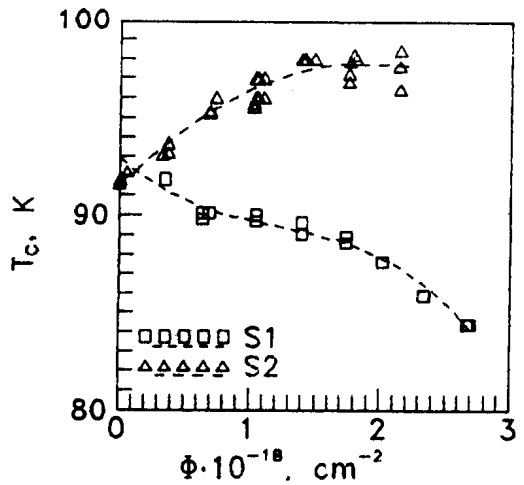

Fig.5. Dependences of critical temperature on neutron fluence for the films S1 and S2

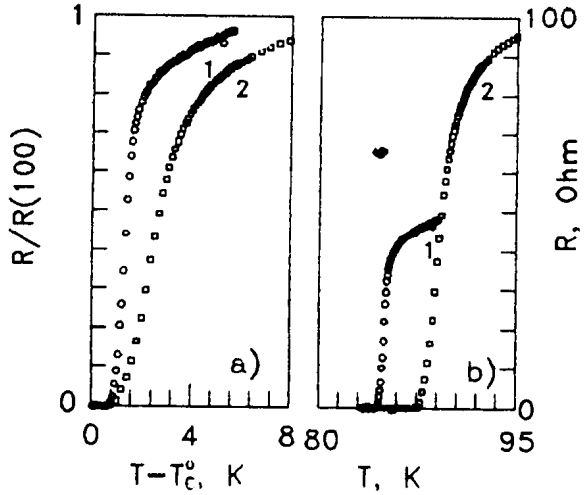

Fig.6. Temperature dependences of the resistance for the film S2; 1 — $\Phi = 0, 2$ — $\Phi = 2.2 \cdot 10^{18}$ cm^{-2}.
a) normal scale, T_c^o is the zero resistance temperature;
b) real scale

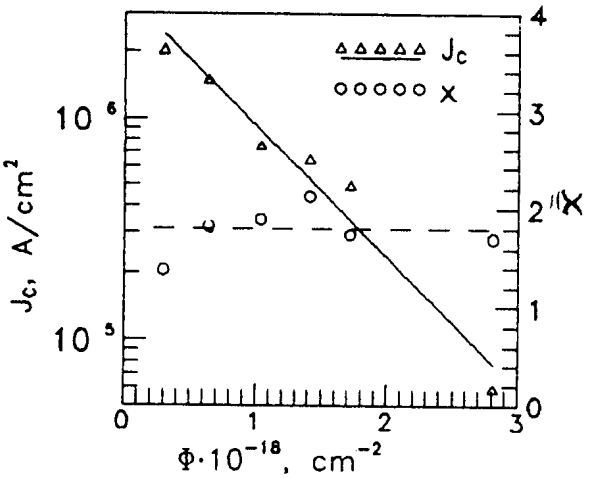

Fig.7. Critical current density and parameter x as function of neutron fluence for the film S1 at $T = 80$ K

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