Effect of ion bombardment on the critical current of $YBa_2Cu_3O_7$ films

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The superconducting $YBa_2Cu_3O_7$ films, fabricated by the laser-deposition method, were obtained by bombarding them with 3.6-MeV He^{++} ions. It has been established that I_c of the films is degraded faster than T_c as a result of ion bombardment, that an increase in ΔT_c and ρ precedes a decrease in T_c, and that the critical current of $YBa_2Cu_3O_7$ films is more sensitive to ion bombardment than that of the Nb_3Sn films.

Study of the effect of radiation defects on superconductors can contribute substantially to the understanding of the nature of their higher critical parameters. The effect of ion bombardment on the critical temperature of $YBa_2Cu_3O_7$ films was studied by Antonenko *et al.*[1,2] They found that these films are an order of magnitude more sensitive to ion bombardment than the Nb_3Sn films. We have studied the effect of ion bombardment on the critical current of $YBa_2Cu_3O_7$ films and on the behavior of I_c versus B and T.

The $YB_2Cu_3O_7$ films were fabricated by the method of pulsed laser sputtering

TABLE I.

Sample	T_{cH}, K	T_c, K	T_{cK}, K	d, μm	$I_{c\,max}$ (T= 4.2 K, B = 0 T)	I_c (T = 77 K, B = 0 T)
1	89.0	84.7	76.4	1.0	4×10^2 A/cm^2	–
2	90.0	89.4	88.9	0.26	1.6×10^6 A/cm^2	5×10^5 A/cm^2

from superconducting ceramic targets of stoichiometric composition. An ABO_3 crystal structure was formed directly during the deposition without a subsequent heat treatment.[3] As substrates we used sapphire and $SrTiO_3$. The $SrTiO_3$ plane was oriented perpendicular to the [100] axis of the substrate. The films with a rigid orientation of the crystallographic [001] axis perpendicular to the sample's surface revealed an epitaxial growth.

The critical temperature T_c of the samples was determined by a resistive method from the midpoint of the transition from the normal state to the superconducting state and the width of the T_c transition was determined from the 0.9ρ–0.1ρ level, where ρ is the resistivity of the film near the transition. The critical current was measured by the four-contact method from the I-V characteristics of a narrow strip (bridge) of the film using a setup described elsewhere.[4] The critical current was defined as that current at which a voltage of 2.5 μV was measured across the potential contacts of the samples. The density of the critical current I_c was calculated by dividing the total critical current by the cross section of the bridge. The measurements in magnetic field were carried out in a geometry in which the magnetization vector B was parallel to the surface of the sample and perpendicular to the current (see the inset in Fig. 2). The principal characteristics of the films before the bombardment are given in Table I, where T_{cN} and T_{cK} are the temperatures which correspond to 0.9ρ and 0.1ρ, respec-

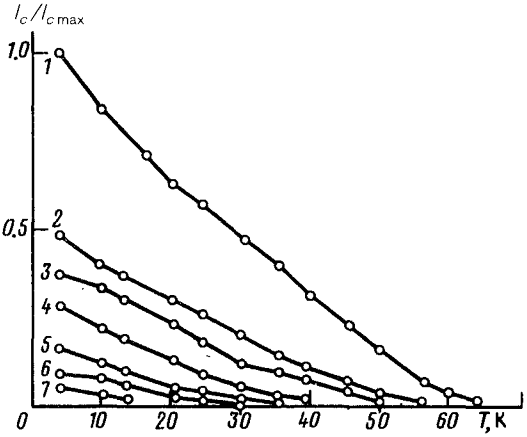

FIG. 1. The temperature dependence of $I_c/I_{c\,max}$ at various ion flux levels. $B = 0$, sample 1: 1—$F = 0$; 2—$F = 1\times10^{15}$ cm^{-2}; 3—$F = 2\times10^{15}$ cm^{-2}; 4—$F = 3\times10^{15}$ cm^{-2}; 5—$F = 4\times10^{15}$ cm^{-2}; 6—$F = 5\times10^{15}$ cm^{-2}; 7—$F = 6\times10^{15}$ cm^{-2}.

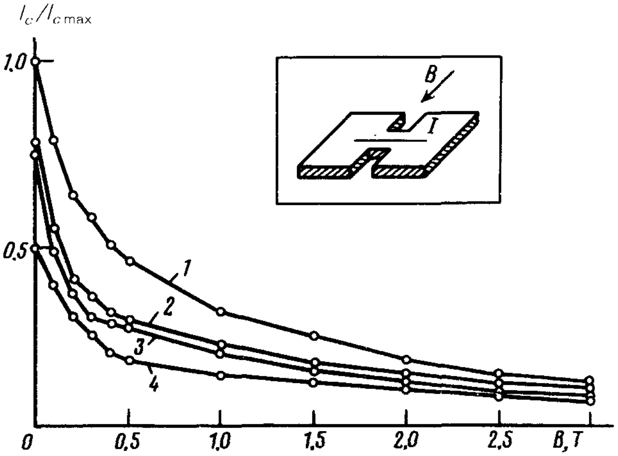

FIG. 2. $I_c/I_{c\,\max}$ versus the magnetic field induction B for various ion flux levels. $T = 77.6$ K, sample 2: 1—$F = 0$; 2—$F = 2.5\times10^{14}$ cm^{-2}; 3—$F = 5\times10^{14}$ cm^{-2}; 4—$F = 1\times10^{15}$ cm^{-2}.

tively; d is the film thickness; and $I_{c\,\max}$ is the maximum measured critical current density for each film sample.

The samples were bombarded by 3.6-MeV He^{++} ions in a vacuum. The ion flux F was $(2.5\text{-}60)\times10^{14}$ cm^{-2}, which was measured within $\pm 5\%$. The sample holder was cooled with water. To attain ion bombardment uniformity, the sample was scanned mechanically along the ion beam. After each bombardment we measured the critical current as a function of the magnetic field, the temperature, ρ, T_c, and ΔT_c.

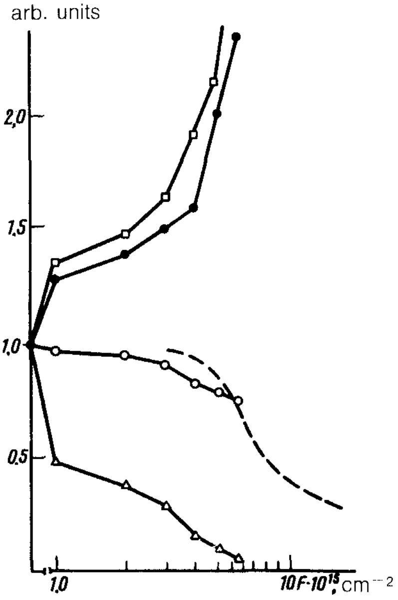

FIG. 3. T_c/T_{c0}, I_c/I_{c0}, $\Delta T_c/\Delta T_{c0}$, and ρ/ρ_0 versus the ion flux F, sample 1: □—$\rho/\rho_0(F)$; ●—$\Delta T_c/\Delta T_{c0}(F)$; ○—$T_c/T_{c0}(F)$; Δ—$I_c/I_{c0}(F)$ at $T = 4.2$ K, $B = 0$ T; dashed line—I_c/I_{c0} for Nb$_3$Sn films.

Figures 1 and 2 show the curves of $I_c/I_{c\,\max}(T)$ and $I_c/I_{c\,\max}(B)$ for various ion fluxes. Figure 3 shows the plots for $I_c/I_{c0}(F)$, $T_c/T_{c0}(F)$, $\Delta T_c/\Delta T_{c0}(F)$, and $\rho/\rho_0(F)$, where I_{c0}, T_{c0}, ΔT_{c0}, and ρ_0 are respectively the critical current density, the critical temperature, the superconducting transition width, and the electrical resistivity during the transition from the normal state to the superconducting state before the bombardment. Figure 3 also shows a plot of $I_c/I_{c0}(F)$ for Nb_3Sn films which were bombarded in a similar way.

The following conclusions were drawn from the analysis of the results:

●The critical current decreased sharply as a result of bombardment, causing the ratio I_c/I_{c0} to depend on the temperature and magnetic field. An increase in the magnetic field to 0.5 T causes the ratio I_c/I_{c0} to decrease and then to increase to fields of 3 T. The ratio I_c/I_{c0} decreases with increasing temperature.

●At the boiling point of liquid nitrogen an increase in the critical current density was not observed even at low ion flux levels. The behavior of the functional dependence $I_c(B)$ at various flux levels suggests, however, that $I_c/I_{c0}(B)$ may increase in fields $B > 3$ T as a result of ion bombardment.

●The critical current I_c degrades much faster than T_c; i.e., a decrease in I_c as a result of ion bombardment is not determined solely by the decrease in T_c.

●An increase in ΔT_c and ρ precedes a decrease in T_c.

●At a flux level of 4×10^{15} cm^{-2} the $\rho(T)$ curve undergoes a change, before the transition to the superconducting state, from a metallic behavior to that of a semiconductor.

●The critical current I_c degrades in $YBa_2Cu_3O_7$ films much faster than it does in Nb_3Sn films (the flux level which reduces the critical current of $YBa_2Cu_3O_7$ films by half is 8 or 10 times lower than that of Nb_3Sn).

●The shape of the $I_c(T)$ curves does not change markedly as a result of increasing the ion flux level.

●An increase in the ion flux level causes T_{cK} to decrease much faster than T_{cN} and T_c.

A possible reason for the degradation of the superconducting properties could be the damage sustained in the oxygen and copper sublattices in the $YBa_2Cu_3O_7$ structure.[2]

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[1] S. V. Antonenko, V. V. Evstigneev, V. F. Elesin *et al.*, Effect of ion bombardment on the Properties of High Temperature Oxide Superconductors, Proceedings of the Working Conference on High Temperature Superconductivity, Sverdlovsk-Zarechnyi, July 7–10, 1987.

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