CRITICAL CURRENT ENHANCEMENT AND FLUX PINNING IN IRRADIATED BKBO SINGLE CRYSTAL

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Measurements of magnetization versus temperature, field and time are performed using VSM technique in single crystal of $Ba_{0.58}K_{0.42}BiO_3$ (BKBO) irradiated by fast electrons (E = 4 MeV) and maximum fluency of $2 \cdot 10^{18} cm^{-2}$ for a fields up to 6 T in the range from 4.2 K to 25 K. The results are discussed in the terms of the stronger flux pinning in the crystal with radiation defects.

Introduction

The BKBO superconductor with its isotropic conduction, the high value of T_c (≈29—31 K), and a coherence length ξ (≈45—70 Å) sufficiently large compared to the lattice constant is a very interesting and promising material for the fabrication of electronic devices. It should be noted the most successful SIS and SIN structure using BKBO have been already obtained [1—3] and these results are most important among those of oxide superconductors up to now. The knowledge of characteristics of devices under irradiation is necessary and to use electron irradiation experiments permit to introduce the defects in a controlled manner. But at the same time there are practically not works dealing with investigation of electron irradiated copperless bismuthate superconductors as BKBO.

The goal of present study is to measure the critical currents and magnetization relaxation in irradiated single crystal of BKBO.

Experimental

The single crystal of $Ba_{0.58}K_{0.42}BiO_3$ was grown by the electrochemical deposition method from the KOH flux melt. The growth technique is reported elsewhere [4]. The induction measurements at field ~3 Oe taken on dark blue crystal of 1 × 1 × 0.5 mm^3 size reveal the T_c = 29 K. The transition width ΔT did not exceed ~3 K. The X-ray analysis showed that the single crystal is single phase cubic perovskite.

The magnetization measurements were carried out using an automatic vibrating sample magnetometer (VSM) with a sensitivity of 10^{-6} emu at fields up to 6 T over the temperature range from 4.2 K to T_c. The hysteresis loops were recorded at continuously varying magnetic field at rate of 5 kOe/min in ZFC regime. The critical current density value, J_c, were estimated with the use of the Bean model [5]. Relaxation of the remanent magnetization, $M_r(t)$ was measured at different temperatures in the time interval 0—1 h. The time dependence of $M_r(t)$ was analyzed according to next relation [6]:

$$dM/dlnt = -kT/(M_r U_{eff}), \quad (1)$$

where U_{eff} is an activation energy of the flux creep or the effective pinning potential. That value could be determined from the slope of curves of M/M_t versus lnt.

The single crystal of BKBO was irradiated by fast electrons with energy 4 MeV and fluences up to $2 \cdot 10^{18} cm^{-2}$ at room temperature and remeasured.

Results and discussion

The field dependences of the critical current densities for BKBO at different temperatures are shown in Fig. 1. The value of J_c(4.2 K) estimated from the hysteresis loop width ΔM is $4.1 \cdot 10^4$ Å · cm^{-2} (zero field). With the temperature rise the J_c diminished rapidly: for instance, J_c(4.2 K)/J_c(15 K) relation is equal to ~3 for zero field. Note with increasing magnetic field J_c decreases for all temperatures: at 4.2 K Jc(0 T)/Jc(6 T) ≈ 140. Upon irradiation T_c-value changed somewhat and was reduced by ~3 K at maximum fluence. As shown at Fig. 1, the irradiation leads to essential enhancement of the critical currents what has been observed in whole temperature range. At zero field the J_c(4.2 K) value increases by a factor ~2.7 compared to the starting one; at 10 K and 15 K the corresponding factor is ~2. At 4.2 K Jc(0 T)/Jc(3 T) is equal to ~18 for irradiated state, but in initial state this relation is ~25 (Fig. 1). It should be noted that the similar values are obtained for 15 K.

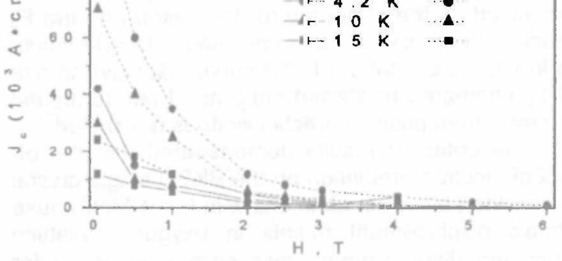

Fig. 1. J_c — H plots at different temperatures for BKBO single crystal in starting (—) and irradiated (---) state

The remanent magnetization $M_r(t)$ was found to relax logarithmically with time t (t ≥ 10 s) at all measured temperatures. This process is described by the empirical relation $M = M_r + Blnt$, that provides the validity of the thermally actived flux creep model [7] for 4.2—25 K. The calculation [8] shows the creep effects will not affect the $J_c(H)$ dependencies in BKBO in cited temperature domain. Then we restricted our measurements of $M(t) \leq 25$ K and we calculated the true value of the $J_c(H)$.

Fig. 2 illustrates the temperature dependencies of the rate of relaxation —S(T) connected with the pinning potential by expression:

$$S = (1/M)(dM/d\ln t)\,|_t = -1/[(U_{eff}/kT) - \ln(t/\tau)] \quad (2)$$

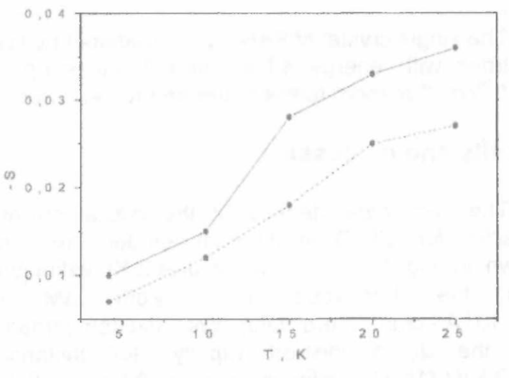

Fig. 2. The temperature dependence of the relaxation rate for BKBO single crystal in starting (-) and irradiated (- -) state

The relaxation rate S increases with temperature and for initial state that enhancement exceeds the factor of ~3.5. The corresponding value for irradiated state amounts to ~2.5. Under irradiation |S| reduces slightly at low temperatures (4.2—10 K) and more noticeably at high ones (15—25 K). The decrease of the relaxation rate |S| induced by irradiation evidences that the radiation defects are effective pinning centers providing, along with initial defects, sufficiently high critical currents in BKBO.

Special attention is given to calculation of the volume pinning force density $F_p = J_c \cdot B$ (in our case B = H). That characteristic is helpful to order to understand the true pinning mechanism of flux lattice in the crystal. As it was demonstrated in Fig. 3, $F_p(H)$ curves at all temperatures are similar and peak F_{pmax} exists in each $F_p(H)$ curve. The pinning force value increased as the temperature decreased and the F_p reaches the maximum at same magnetic field value. In irradiated crystal the $F_p(H)$ curves display the rise of F_p compared to started state at all temperatures; the maximum position practically does not shifted.

The obtained results demonstrated that the effect of electron irradiation on the BKBO single crystal is considerable. Fast electrons with E = 4 MeV cause atomic displacement mainly in oxygen sublattice since the displacement cross section value σ_d for oxygen atoms is $(5\div6)\cdot10^{-23}$ cm^2 [9], i. e. several times less than σ_d for metal atoms. The degradation of T_c by ~3 K under irradiation, as shown by C_d estimation, is achieved at 10^{-4} dpa in oxygen sublattice.

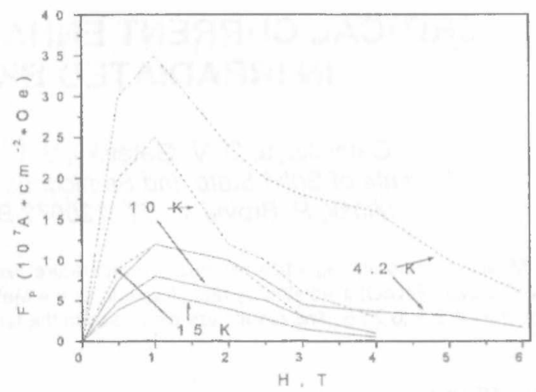

Fig. 3. F_p — H plots at different temperatures for BKBO single crystal in starting (—) and irradiated state (---)

It was found that the critical current density J_c is enhanced in irradiated state and that enhancement accompanied by the diminishing of relaxation rate and increasing of the pinning forces F_p.

Observed results is assumed to be caused by interaction radiation defects including oxygen vacancies with background defects which are also effective pinning centers in initial crystal.

Conclusion

The measurements of magnetization and relaxation rate in single crystal of $Ba_{0.58}K_{0.42}BiO_3$ with $T_c = 29$ K have been performed at 4.2—25 K for fields up to 6 T. After irradiation by fast electrons with E = 4 MeV and fluences up to $2\cdot10^{18}$ cm^{-2} the critical currents J_c and the pinning force F_p increase and remanent relaxation rate S decreases.

References

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