FLUX CREEP IN IRRADIATED $Bi_2Sr_2CaCu_2O_y$ SINGLE CRYSTAL

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We report our measurements of the magnetization relaxation $M_r(t)$ in irradiated $Bi_2Sr_2CaCu_2O_y$ (Bi – 2212) single crystal at different temperatures and calculate the pinning potential U_o in a wide temperature range. The observed nonlogarithmic time decay has been discussed in framework of dimensional 3Д – 2Д crossover model.

1. Introduction

The high-T_c superconductor Bi – 2212 is the most interesting material from possible applications point of view. For instance, in the tapes of Bi – 2212/Ag the values of critical currents $J_c \approx 10^5$ A·cm^{-2} have been obtained at 4.2 K and for 25 T [1]. However, the J_c values drop sharply with temperature rising, and such $J_c(T)$ behavior is connected with a low laying irreversibility line (IL) B_{irr} in Bi-based compound [2]: the J_c vanish above IL. The nature of IL is not clear yet. The HTSC are characterized by rather weak flux pinning by lattice defects and, ergo, by the strong relaxation rate of their remnant magnetization even at low temperatures, due to the flux motion across low energy pinning barrier U_o. In our earlier work [3] we studied the isothermal magnetization and IL at different temperatures in Bi – 2212 single crystal including the electron irradiated state. It is known that IL is very sensitive to anisotropy and to structural defects. To use irradiation experiments permit to introduce the defects in a controlled manner. In [3] it was shown that after irradiation IL shifted towards higher magnetic fields, but the very fast drop of B_{irr} around 20 – 30 K was kept. The magnetic relaxation data in irradiated Bi – 2212 single crystal, no doubt, can be complete our understanding of anomalous behavior of its magnetic features. The purpose of the present investigation of Bi – 2212 is determine from the relaxation experiments the relaxation rate and the pinning potential U_o in a wide temperature region in initial and irradiated state.

2. Experimental

The single crystal of Bi – 2212 with T_c = 85 K were grown by spontaneous crystallization from flux melt. The magnetic characteristics were obtained using VSM technique at external field (H||c) over temperature range from 4.2 K to ~ 80 K. For each measurement run the crystal was heated to ≈ 100 K, and prior to cooling was held in zero field for some minutes. The magnetic field was then switched on and the relaxation of remnant magnetization $M_r(t)$ have been recorded for ≈ 1 h after the field reached zero. Then the crystal was irradiated by fast electrons of E = 4MeV and fluences up to $2\cdot10^{18}$ cm^{-2} and remeasured.

3. Results and discussion

Since the remnant magnetization M_r obtained in the limiting hysteresis loop regime, in accordance with the Bean model, is proportional to the critical current density in the crystal, and if the temperature dependence of $M_r(T)$ is determined by the flux creep, the $M_r(T)$ values decrease linearly with the temperature rising:

$$M_r(T)/M_r(O) \approx J_c/J_{co} \approx 1 - (T/U_o)\ln(t_1/t_o).$$

The magnetization was found to relax logarithmically with time t (for t ≥ 10 s) in the temperature range 4.2 – 80 K except the region near ~ 20 – 25 K. Our magnetic relaxation data (Fig.) are accurately described by the empirical relation $M_r = M_r(o) - S\ln t$ which is the evidence of the validity of flux creep model (except the vicinity of ~ 20 K). Fig. shows the temperature dependence of normalized decay rate $S \equiv d(\ln M)/d(\ln t) = T/U_o$ for Bi – 2212 single crystal. The value of S equal to ≈ 0.035 (4.2 K) in initial state starts increasing with the temperature and reaches ≈ 0.085 at 15 K. Then S decreases and amounts to minimum at 20 – 30 K. Some increasing of the rate S is observed above ~ 40 K. The values of U_o are ≈ 10 – 15 meV at T ≤ 20 K and ≈ 110 – 130 meV at T > 20 K. $U_o(T)$ dependence reveals the sharp jump near ~ 20 K. The comparison of S(T) and $J_c(T)$ (inset, light symbols) curves permit to infer about the change of the flux lattice structure dynamics at ≈20K: a very dramatic jump of the relation rate S (ergo, U_o/T) is leading to strongly weaking of $J_c(T)$ dependence.

Upon the irradiation by fast electrons the crystal demonstrated an increase in critical currents (inset, dark symbols) by a factor 1.3 (4.2 K) and 1.5 (50 – 70 K). $M_r(t)$ obeys to logarithmically law excluding the domain of ~ 20 – 25 K. The relaxation rate S (Fig.) is smaller than that before irradiation: S ≈ 0.025 (4.2 K) and ≈ 0.065 (15 K). The activation energy was calculated and U_o ≈ 15 – 20 meV and 120 – 140 meV below and above ~ 20 K, respectively.

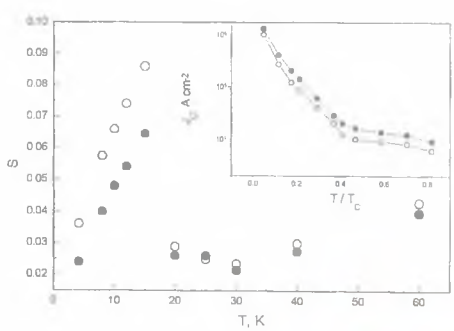

Fig. S – T and J_c – T (inset) plots for [illegible] irradiated Bi – 2212.

There are a bit contradictory explanations of anomalous behavior of magnetic properties of Bi – 2212 [4]. The extreme anisotropy, small coherence length and weak interlayer coupling are typical for this system. Under certain conditions the similar system can undergo a dimensional crossover from 3Д to 2Д pinning. The appearance of the transition from 3Д flux lattice to 2Д pancake vortices may particularly be stipulated in H||c case [4]. From the comparison of the temperature dependencies of the IL [3], Jc and S the 3Д – 2Д crossover it should be connected with dimensional crossover manifesting in a sharp change of these characteristics at 20 – 25 K. The temperatures of 20 – 25 K are the boundary ones below that 3Д flux lattice penetrates the whole sample; above 20 – 25 K the 2Д pancake vortices are observed, the IL and J_c sharply decrease and around 20 K the nonlogarithmic behavior of S takes place. Under irradiation the values of B_{irr}, J_c increase, S diminishes, but the character of their temperature dependencies on the whole is kept.

4. Conclusion

The measurements of remnant magnetization in Bi – 2212 single crystal have been performed at 4.2 – 80 K. The M_r decays is found to decrease logarithmically with time except of the domain of 20 – 25 K. After electron irradiation the relaxation rate become smaller. The values of U_0 are equal to 10 – 15 meV (15 – 20 meV) and 110 – 130 meV (120 – 140 meV) before and after irradiation, respectively. The data are explained in terms of dimensional 3Д – 2Д crossover.

References

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