Negative magnetoresistance in granular HTSC with trapped magnetic flux

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Abstract

Magnetoresistive properties of Bi-based ceramic HTSC with trapped magnetic flux are investigated at the temperatures near superconducting transition. The effect of trapped field and transport current values and orientations on the field dependence of magnetoresistance $\Delta R(H)$ is studied. It is found that for the magnetic field parallel and the current perpendicular to trapping inducing field the dependence $\Delta R(H)$ is nonmonotonic and magnetoresistance turns out to be negative for small fields, $H < H_{\rm inv}$. The magnetoresistance sign inversion field $H_{\rm inv}$ and the maximum value of negative magnetoresistance increase a little superlinearly with the trapped magnetic field and decrease somewhat with transport current. The results are explained in the framework of model of magnetic flux trapping in grains or superconducting loops embedded in weak links matrix.

Key words: granular superconductor; magnetic field trapping; magnetoresistance

1. Introduction

The magnetic flux trapping (MFT) in high temperature superconductors (HTSC) essentially changes their magnetic properties (magnetic moment, susceptibility, characteristics of magnetic field penetration and screening) [1,2] as well as their transport properties, in particular, resulting in the additional resistance, so-called frozen magnetoresistance in the region of superconducting transition [3,4].

Thus the investigation of properties of HTSC with trapped magnetic flux is interesting in itself and also can provide useful information about nature of magnetic flux trapping in HTSC, particularly in granular HTSC.

We studied here the magnetoresistance in granular Bi-HTSC with trapped magnetic flux and for the first time observed and explained the phenomenon of negative magnetoresistance.

2. Experiment

Measurements were made on the ceramic HTSC of nominal composition $Pb_{0.5}Bi_2Sr_3Ca_4Cu_5O_{16}$.

The resistive transition in the samples begins at a temperature $T_{\rm c} = 108 - 110\ K$ and width of transition is $\Delta T_{\rm c} = 10\ K$. The value of $\Delta T_{\rm c}$ in investigated ceramics highly depends on current density and magnetic field increasing to $20 - 30\ K$ for $j = 0.1\ A/cm^2$ and $H = 10\ Oe$.

The MFT bringing about the frozen magnetoresistance also essentially (up to $30\ K$) increases the transition width $\Delta T_{\rm c}$.

Magnetic flux trapping was realized at $T = 77.4\ K$ usually in ZFC regime by field pulse of duration 30 *sec* and magnitude $H_{\rm i} = 30 - 200\ Oe$ and sometimes in FC regime. After MFT the field dependences of magnetoresistance $\Delta R(H)$ for various values and orientations of pulse field $H_{\rm i}$, and transport current j were measured.

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3. Results and Discussion

Figure 1 shows the magnetoresistance field dependences measured for various values of the angle α between the directions of field H and pulse field H_i for $j \perp H$ and $j \perp H_\mathrm{i}$. Note, that when α increases the field of inversion of magnetoresistance sign H_inv and maximum value of NMR decrease and phenomenon of negative magnetoresistance disappears at $\alpha \to \pi/2$.

Magnitude of the inversion field H_inv(and also depth of a minimum on dependence $R(H)$) a little superlinearly increase with trapped magnetic field H_t (fig. 2).

Field of magnetoresistance sign inversion H_inv and maximum value of negative magnetoresistance weakly decrease as transport current increases (approximately on 15% as j increases to 0.3 A/cm^2). Note, that negative magnetoresistance is absent at $H \parallel H_\mathrm{i} \parallel j$.

It is well known that the granular HTSC can be considered as Josephson medium. Its magnetoresistance is determined by destruction of weak links network by magnetic field. Near resistive transition region of the medium the MFT occurs in granules or in superconducting loops formed by granules and weak links. Owing to this the arising trapped magnetic fields (TMF) are highly non-uniform and vary in sign [4]. Such TMF can not be detected by SQUID or Hall probes, but results in frozen magnetoresistance. The sign-varying TMF can be characterized by its effective value H_teff which is equal to the external field that causes the same magnetoresistance as the trapped fields do.

Near current channels the TMF are directed mainly opposite to the field H_i which induced MFT . So the application of the magnetic field $H \parallel H_\mathrm{i}$ reduces the resulting field affecting the channels weak links, the sample resistance falls and the negative magnetoresistance (NMR) appears.

The above notions can be easily confirmed by model calculation. Indeed, the resistance of current channels is determined by distribution function of weak links on critical fields $g(H_\mathrm{c})$ and distribution function of the trapped magnetic fields near weak links $f(H_\mathrm{t})$. Taking into account, that the weak links turn to a normal state when their critical field H_c becomes less than resulting field $\mid \mathbf{H}_\mathrm{t} - \mathbf{H} \mid = (H_\mathrm{t}^2 + H^2 - 2 \cdot H_\mathrm{t} \cdot H \cdot \cos\alpha)^{1/2}$, one can write the medium magnetoresistance as

$$\Delta R(H) = R(H) + R(0)$$

$$R(H) = \int_0^{H_\mathrm{i}} f(H_\mathrm{t}) \cdot \int_0^{|\mathbf{H}_\mathrm{t}-\mathbf{H}|} g(H_\mathrm{c})\, \mathrm{d}H_\mathrm{c}\, \mathrm{d}H_\mathrm{t}$$

The normal distribution of weak links on critical fields and exponential distribution of the trapped fields were used at calculation:

$$g(H_\mathrm{c}) \sim \mathrm{e}^{-\left(\frac{H_\mathrm{c}-H_\mathrm{cm}}{\Delta H_\mathrm{c}\cdot\sqrt{2}}\right)^2} \ , \ \ f(H_\mathrm{t}) \sim \mathrm{e}^{-\frac{H_\mathrm{t}}{H_\mathrm{teff}}} \ ,$$

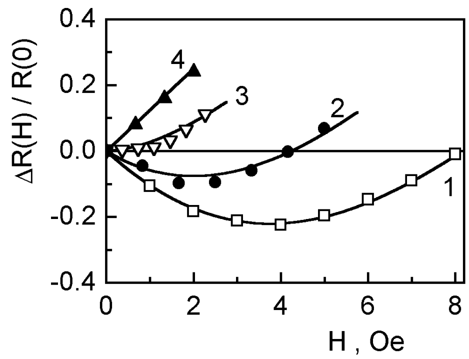

Fig. 1. Field dependences of magnetoresistance of Bi(Pb) - ceramics with TMF at various angles between fields H and H_i: $1 - \alpha = 0,\ 2 - \alpha = \pi/4,\ 3 - \alpha = \pi/2,\ 4 - \alpha = \pi$. Solid curves show calculation results.

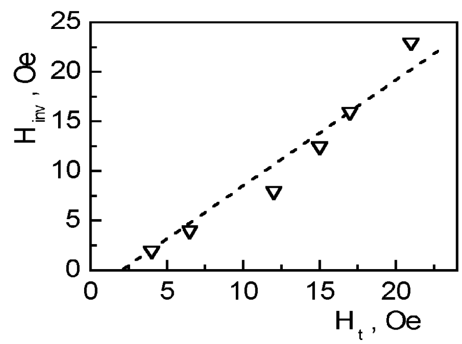

Fig. 2. Dependence of magnetoristance sign inversion field on effective trapped field $H_\mathrm{inv}(H_\mathrm{t})$.

H_cm -mean critical field, ΔH_c - standard deviation.

The results of model calculation of $\Delta R(H)$ of a sample with TMF are shown on Figure 1 by solid lines.

We note the good agreement of the calculated and experimental field dependences of NMR. Used values of parameters , $H_\mathrm{teff} = 6.1\ Oe$, $H_\mathrm{cm} = 5\ Oe$ and $H_\mathrm{c} = 4.5\ Oe$, are close to those determined from frozen magnetoresistance measurements.

Thus, the observed phenomenon of negative magnetoresistance can be explained in the framework of the model of Josephson medium in which MFT occurs in granules or in superconducting loops and the trapped magnetic fields are highly non-uniform and sign-varying.

References

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