Magnetic Flux Trapping in Granular HTSC near Superconducting Transition

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Abstract

The temperature and field dependences of the trapped magnetic fields and of the frozen magnetoresistance of (Pb)Bi-Sr-Ca-Cu-0 ceramics and Bi-based magnetron films are investigated. It is found that in the resistive transition region of granular Bi-HTSC the trapped magnetic fields became highly inhomogeneous and alternating in sign at scale of less than 50 μm. Unlike ceramic the films have critical temperature of trapping lower than the upper temperature of magnetoresistance disappearance. The experimental results are explained by a model in which the magnetic flux is trapped in superconducting loops embedded in Josephson weak links medium. The loops nature which is essentially different for films and ceramics is discussed. Observed temperature and field dependences of trapped field are in good agreement with those calculated for normal law of the loops distribution on critical fields.

Key words: granular superconductor; magnetic field trapping; magnetoresistance

1. Introduction

Magnetic flux trapping (MFT) in a resistive transition region of granular HTSC is not studied enough up to now. The main reason of this is that in this case the magnetic fields trapped in superconducting (SC) regions are closed through normal regions of the HTSC. As a result the arising trapped magnetic fields (TMF) must be sign-varying and can be unobserved by Hall probe and SQUID magnetometer.

Fortunately, these sign-varying TMF destroy the superconductivity of weak links network and so give rise to frozen magnetoresistance (FMR) [1] and the letter can be used for MFT investigations in the region of resistive transition of granular HTSC [2].

Below we present the results of comparative study of the temperature and field dependences of FMR and TMF in (Pb)Bi- ceramics and Bi-based magnetron-sputtered films.

2. Samples and measuring techniques.

Two HTSC systems with extended resistive transition were studied: ceramics of nominal composition $Pb_{0.5}Bi_2Sr_2Ca_2Cu_3O_{11}$ with upper transition temperature $T_c = 108 - 110 \ K$ and width of transition $\Delta T_c = 10 - 15 \ K$ and magnetron-sputtered films of nominal composition $Bi_2Sr_2Ca_2Cu_3O_{10}$ with $T_c = 80 - 82 \ K$ and $\Delta T_c = 20 - 40 \ K$.

The ceramics samples dimensions were $3\times4\times8 \ mm^3$, films dimensions - $3 \ \mu m \times 4 \ mm \times 8 \ mm$.

The MFT was realized by applying the magnetic fields of magnitude $H_i = 1$ -200 Oe. In ZFC regime the field pulse duration was 30 sec. Measurements of magnetic field and mean value of TMF were made by Hall probe with sensitivity area of $150 \times 450 \ \mu m^2$. The threshold sensitivity and experimental error of Hall apparatus were 0.1 Oe. The resistivity measurements were made by the four-point method with device sensitivity of $10^{-5} \ \Omega$.

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3. Results and Discussion

The resistive transition width in studied samples essentially increases (by $20 - 30\ K$) as a result of MFT or application of the magnetic field $H = 20 - 200\ Oe$. Moreover the FMR reaches the values equal to a magnetoresistance (MR) caused in ceramics by field $H = 20\ Oe$ at $T = 77.4\ K$ and in films by $H = 100\ Oe$ at $T = 10\ K$(Fig. 1), while the averages of TMF measured by Hall probe are negligible (< 0.1 Oe).

It means that the local TMF which determine the FMR in the granular systems really are rather high ($\sim 100\ Oe$) and sign-varying at scale of less than $50\ \mu m$.

The sign-varying TMF can be characterized by an effective value H_{teff} equal to an external field that causes the same magnetoresistance as the trapped fields do. Using this definition the dependences $H_{\text{teff}}(H_i, T)$ were determined from FMR and MR measurements.

The other typical feature of films FMR and MR dependences on temperature is that the FMR and hence TMF disappear at temperature T_{tc} which is lower by $\sim 10\ K$ than the temperature of magnetoresistance disappearance T_{mc}. In ceramics the temperatures of FMR and MR disappearance coincide, however critical temperature of trapping T_{tc} as determined from $H_{\text{teff}}(T)$ turns out to be by $3 - 5\ K$ higher than T_{mc} .

One can give the following picture of the change in the state of a granular film as the temperature is lowered. At $T_{\text{mc}} < T < T_{\text{c}}$ the individual granules undergo transition to the SC state and the film resistance begins to decrease, while magnetoresistance and magnetic flux trapping are insignificant. At $T < T_{\text{mc}}$ the weak links that are very sensitive to magnetic fields arise between granules. Besides the additional drop in resistance this gives rise to magnetoresistance. As the temperature decreases lower than T_{tc} the closed SC loops are formed. In these loops the MFT occurs, resulting in the frozen magnetoresistance due to the destruction of the weak links of SC channels.

Unlike the above the MFT in ceramics can occurs in grains as they undergo transition in SC state. However, the FMR can appear only when the weak links arise between grains. We suppose that in ceramic samples the MFT is realized in closed loops of 2223 phase formed on the surface of grains of 2212 phase [3].

The experiments on remagnetization of samples affirm the loops model, which unlike Bean model predicts equal values of FMR obtained as a result of single and of double remagnitization.

The SC loops model [2] can be used for quantitative comparison with experimental data. For example let us consider field dependences of TMF. In the FC regime the MFT occurs in all loops. In loops with critical fields $H_{\text{c}} < H_{\text{i}}$ the TMF are proportional to H_{c}, in loops with $H_{\text{c}} > H_{\text{i}}$ - to H_{i} and one can write:
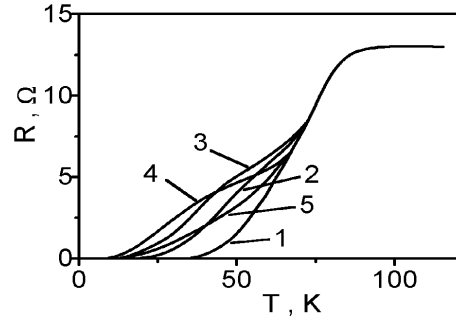

Fig. 1. Temperature dependences of the Bi-HTSC film resistance. 1 - resistance in zero field, 2 and 3 - magnetoresistance for $H = 40\ Oe$ and $H = 95\ Oe$, 4 and 5 - FMR for $H_i = 200\ Oe$ at heating from 5 K in FC and ZFC regimes.
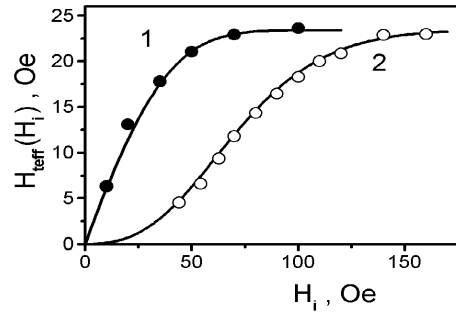

Fig. 2. Effective trapped field dependence on inducing pulse field for ceramics, $H_{\text{teff}}(H_i)$. 1- FC and 2- ZFC regimes. Solid line - calculated curves.

$$H_{\text{teff}}(H_{\text{i}}) = \int\limits_0^{H_{\text{i}}} H_{\text{c}} \cdot f(H_{\text{c}})\,\mathrm{d}H_{\text{c}} + H_{\text{i}} \cdot \int\limits_{H_{\text{i}}}^{\infty} f(H_{\text{c}})\,\mathrm{d}H_{\text{c}}\ (1)$$

Here f(Hc) is the loops distribution function on Hc.

For ZFC case the second term in (1) is absent.

A good agreement of calculation results with experimental data, e. g. for ceramics at $77.4\ K$ was obtained for normal distribution of loops on H_{c} with mean critical field $H_{\text{teff}} = 32\ Oe$ and standard deviation $\Delta H_{\text{c}} = 24\ Oe$ (Fig. 2).

So the loops model gives the proper description of MFT near SC transition of granular HTSC.

References

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