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Peculiarities of the time evolution of magnetoresistance of granular HTSC in a constant applied magnetic field

D.A. Balaev *, A.A. Dubrovskiy, K.A. Shaykhutdinov, S.I. Popkov, M.I. Petrov

Kirensky Institute of Physics, 660036, Krasnoyarsk, Russia

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ABSTRACT

The time evolution of the magnetoresistance of bulk YBCO + CuO composites at $T = 4.2$ K in constant applied magnetic fields was studied to clarify the mechanism of hysteretic behavior of magnetoresistance $R(H)$ of granular HTSC. The composites represent "model" granular HTSC with weakened Josephson coupling between superconducting (YBCO) crystallites. It was found for the first time that on the ascending branch of $R(H)$ dependence, the resistance at $H =$ const decreased with time while on the descending branch, the resistance increased with time in an applied constant magnetic field. In the range of low magnetic fields (below the minimum point of the descending branch of the R(H) dependence), the resistance at $H =$ const decreased again. Similar measurements performed on pure polycrystalline YBCO at $T = 77.4$ K have shown that the behavior of evolution of resistance with time is similar to that observed for the composite. This proves the peculiarity of time evolution of magnetoresistance to be a common feature of granular HTSCs. The behavior revealed is well described by the model of granular HTSC, where the intergrain media is in an effective magnetic field which is the superposition of the external field and the field induced by superconducting grains. The time evolution of resistance reflects the time relaxation of magnetization of HTSC grains due to the intragrain flux creep processes.

1. Introduction

In contrast to well-known relaxation of magnetization in HTSCs [1,2], the time evolution of resistance of granular HTSCs in an applied constant magnetic field has not yet been investigated. On the one hand, it is known that the magnetoresistance demonstrates hysteresis [3,4] and after application of the magnetic field, the remanent non-zero resistance relaxes with time [4–7]. On the other hand, the time evolution of magnetoresistance in an applied constant magnetic field has not been studied thoroughly. Only in Ref. [8] has the decrease in magnetoresistance with time been observed under the conditions when the external field was increased and then stabilized.

Granular HTSCs represent a relatively complicated system: the resistive response in an applied field is determined by dissipation processes at the intergrain boundaries which are Josephson junctions, while the magnetic induction in the intergrain media is the superposition of the applied magnetic field and local fields generated by dipole moments of superconducting grains. Analysis of time evolution of the resistance in constant applied magnetic fields gives additional confirmation of the mechanisms of hysteretic behavior of magnetoresistance, which has been the object of intense speculation recently [7,9–14].

The main aim of this work was to study the time evolution of the resistive response of granular HTSC in an applied magnetic field. The subjects of the investigations are two-phase granular Y–Ba–Cu–O based composites, which represent a "model" granular HTSC with artificially weakened Josephson coupling due to the effect of the non-superconducting component [13,15,16].

2. Experimental

The composite containing 77.5 vol% $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ (YBCO) and 22.5 vol% CuO (designated as YBCO + 22.5 CuO) was prepared by a rapid baking technique [13,16]. The critical current density of this composite material is about ≈ 0.3 A/cm^2 at 4.2 K (the transport critical current for a sample with parallelepiped form $1.5 \times 1.5 \times 8$ mm^3 is $\approx$7 mA). The $R(T)$ and magnetoresistance $R(H) = U(H)/I$ (where U is the voltage drop) dependences were measured by a standard four-probe technique. The magnetic field was applied perpendicular to the current direction. The magnetic field scanning velocity was about ≈ 300 Oe/min. After the applied field had changed from H = 0 to the fixed value $H_{inc} \approx 3$ kOe ("inc" and "dec" indexes mark increasing and decreasing branches of $R(H)$ dependence correspondingly), the time evolution of resistance $R(t)$ was measured. Then the magnetic field was increased up to the value $H_{inc} \approx 4.5$ kOe and the $R(t)$

* Corresponding author.
E-mail address: smp@iph.krasn.ru (D.A. Balaev).

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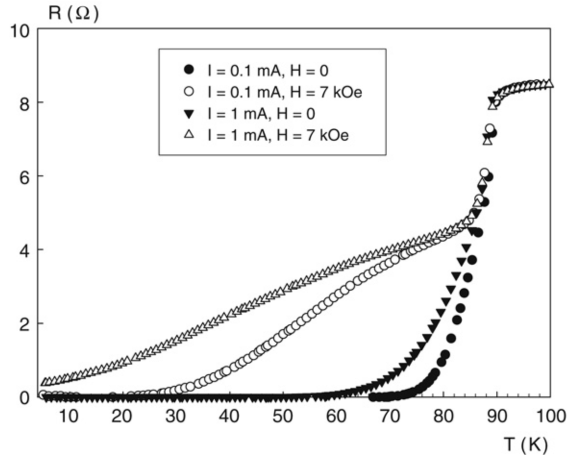

Fig. 1. The temperature dependences of resistivity of YBCO + 22.5 vol% CuO sample measured in zero applied field and in field $H = 7$ kOe.

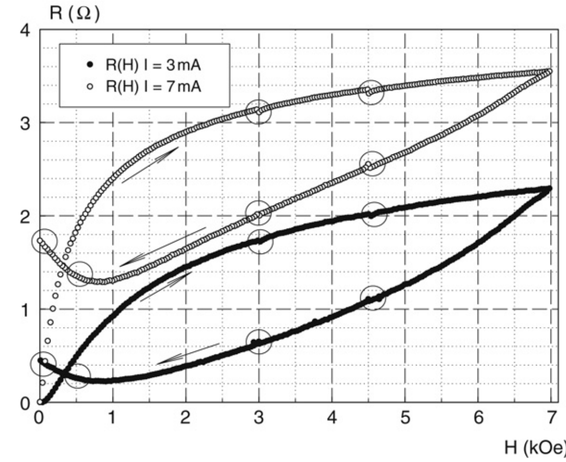

Fig. 2. Hysteretic $R(H)$ dependences of YBCO + 22.5 vol% CuO sample at $T = 4.2$ K. Bias current is $I = 3$ and 7 mA. The points marked are the fields where the time evolution of resistivity was measured. Arrows indicate the direction of field change.

dependence was measured again. Then the applied magnetic field was increased up to the value $H = 7$ kOe, and then decreased with the same velocity down to the value $H_{dec} \approx 4.5$ kOe. The $R(t)$ evolution was measured in this field again. Similar measurements of $R(t)$ evolution were made in applied fields $H_{dec} \approx 3$ kOe, $H_{dec} \approx 0.5$ kOe and $H_{dec} = 0$. Every set of measurements of $R(t)$ dependences presented in this paper were made within one cycle of the applied magnetic field, although heating/cooling of the sample did not change the character of evolution of the $R(t)$ dependences. When one set of $R(H)$ and $R(t)$ measurements was finished, the sample was heated above T_C and then cooled in zero applied magnetic field. A similar set of measurements of the same specimen was made for the magnetization hysteretic loop $M(H)$ and the time relaxation of magnetization $M(t)$ using a vibrating sample magnetometer.

3. Results and discussion

Fig. 1 shows the $R(T)$ dependences of YBCO + 22.5 vol% CuO sample at bias current $I = 0.1$ mA and 1 mA at $H = 0$ and $H = 7$ kOe. The sharp drop in resistance (it is independent of the bias current and slightly broadened in a field $H = 7$ kOe) at $T_C = 93.5$ K corresponds to the transition of YBCO grains (this temperature coincides with T_C obtained from magnetic measurements). The smooth part of the $R(T)$ dependences corresponds to the transition of the Josephson junction network realized in the composites. The broadened resistive transition in the applied field is evidence of weakened Josephson coupling in the composite. The value of this part of the $R(T)$ dependence at the onset of the smooth transition ($\sim$91 K) is independent of both the transport current and the magnetic field. So it is the normal resistance of the Josephson junction network, i.e. the maximal response of magnetoresistance due to the Josephson junctions.

The $R(H)$ dependences of the composite sample at $T = 4.2$ K are shown in Fig. 2. These dependences show hysteretic behavior typical for granular HTSC. The detailed study of hysteresis of $R(H)$ of YBCO-based composites at various values of transport current was performed in [13].

The data for the time evolution of magnetoresistance at magnetic fields stabilized at different points of the ascending ($H = H_{inc}$) and descending ($H = H_{dec}$) branches of $R(H)$ curve are presented in Fig. 3. It can be seen that the resistance decreases with time in fields for the ascending branch of the $R(H)$ curve. In contrast, when the field is removed and then stabilized, the resistance increases with time ($H_{dec} = 4.5$ kOe and $H_{dec} = 3$ kOe). In the range of fields below the minimum point of $R(H)$ dependence, the resistance at $H_{dec} =$ const again decreases with time (see data for $H_{dec} = 0.5$ kOe and $H_{dec} = 0$). All the $R(t)$ data are linear in R, $\ln(t)$ co-ordinates.

In spite of the unexpected behavior of the time evolution of the magnetoresistance in the applied magnetic field, the results obtained are well explained by the effect of time relaxation of magnetization of superconducting grains and, as a consequence, the change with time of the magnetic induction in the intergrain media. The magnetization hysteretic loop of the composite sample at 4.2 K is shown in Fig. 4. When the applied field $\boldsymbol{H}$ is increased, the magnetization is negative and dipole moments of HTSC grains induce the field $\boldsymbol{B}_{ind}$ co-directed to $\boldsymbol{H}$ (for the case $\boldsymbol{H} \perp \boldsymbol{I}$) in the intergrain separations [10–13]. Therefore, the total field in the intergrain media B_{tot} is $H + B_{ind}$ for the case $H = H_{inc}$. When H_{inc} is stabilized, the module of magnetization relaxes with time (arch-like peculiarities on the $M(H)$ curve of Fig. 4 correspond to the measurements of the time relaxation of magnetization).[1] The relaxation of magnetization results in a decrease in B_{ind} and, hence, in a decrease in B_{tot}. So far, the dissipation of granular HTSC is determined by processes of destruction of supercurrent carriers in the intergrain media (Josephson junctions) and the resistance diminishes with time like B_{tot}. When the external field is decreased, the module of magnetization decreases and then M is positive, see Fig. 4 (such behavior is typical of HTSCs and may be described by the critical state model [17]). In this case, the field induced by dipole moments in the intergrain separations is directed contrary to the applied field, $B_{tot} = H - B_{ind}$. This results in hysteretic behavior of magnetoresistance: $R(H = H_{inc}) > R(H = H_{dec})$.

The relaxation of magnetization with time at $H_{dec} =$ const leads to less contribution of B_{ind} to B_{tot}. Therefore, B_{tot} increases with time and resistance grows, see Fig. 3. When H_{dec} is less than the minimum point of $R(H_{dec})$ dependence, the field induced by dipole moments of HTSC grains predominates the external one, $|B_{ind}| > |H|$. In this case, the relaxation of magnetization (Fig. 4) results in a decrease in B_{tot} and, hence, the resistance relaxes, see Fig. 3. The remanent magnetization of HTSC grains induces a field in the intergrain media, $B_{tot} = B_{ind}$, and this field is the cause of non-zero remanent resistance which relaxes with time in the same way as the remanent magnetization.

[1] The relative change of magnetization $M(t)/M(t = 0)$ is $\sim$8%–15% for $t = 4000$ s. The experimental data are linear in M, $\ln(t)$ co-ordinates. The values of the pinning potential U_p determined with the Anderson expression $M(t)/M(t_0) = 1 - k_B T/U_p \times \ln(t)$ are $\sim$15–28 meV ($T = 4.2$ K). These values are typical for the intragrain flux creep in YBCO [2].

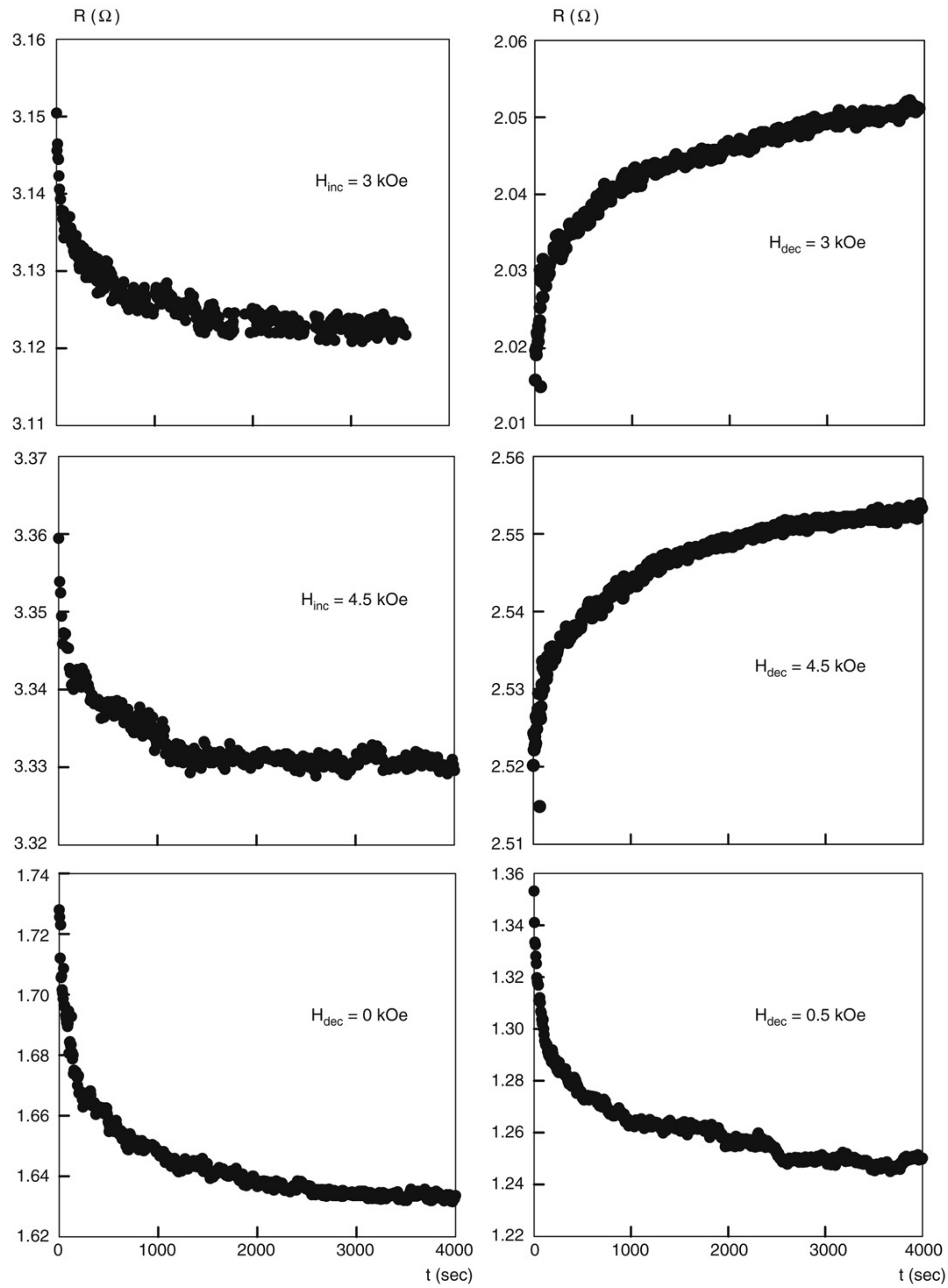

Fig. 3. The time evolution of resistance of YBCO + 22.5 vol % CuO sample at various constant applied fields ($T = 4.2$ K). Bias current is $I = 7$ mA.

The results obtained are typical not only for the HTSC-based composites studied in this paper. We have also performed measurements of the time evolution of the resistance on pure granular $YBa_2Cu_3O_7$ in constant applied fields up to the 250 Oe at $T = 77.4$ K. The behavior of both the $R(H)$ and $R(t)$ dependences is similar to that reported here for the HTSC-based composites.

Thus, in the present paper for the first time, the change in character of the time evolution of the resistance of granular HTSC in a constant applied magnetic field is revealed. On the ascending branch of $R(H)$, the resistance diminishes with time in a stabilized magnetic field after the field was increased, but it increases with time in a stabilized magnetic field after the field was decreased. However, in the field range lower than the minimum point of the descending branch of the $R(H)$ dependence, the resistance again relaxes with time. The behavior observed supports the model explaining the hysteretic behavior of magnetoresistance of granular HTSC [10,11,7,13]. The intergrain media is a sensitive "resistive sensor" reacting to the effective field. This field is the superposition of the external field and the field induced by dipole moments of superconducting grains. The relaxation of magnetization of the HTSC grains leads to a change with time of the contribution of the induced field and, hence, to the time evolution of magnetoresistance. Dipole moments of HTSC grains give different contributions to the effective field on the ascending

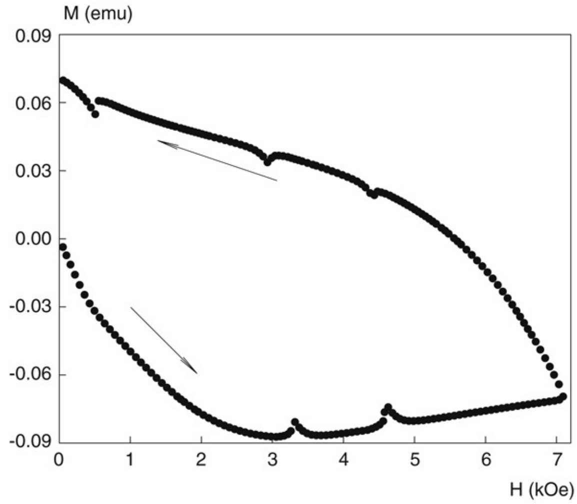

Fig. 4. The $M(H)$ dependence of YBCO + 22.5 vol% CuO sample. Temperature is $T = 4.2$ K. Arrows indicate the direction of field change.

and descending branches of the $R(H)$ curve and in the range of descending fields lower than the minimum of $R(H)$ dependence, the induced field predominates the external one. This results in the specific character of time evolution of magnetoresistance of granular HTSC in constant magnetic fields observed in this work.

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