The effect of magnetisation relaxation of superconducting grains on time relaxation of the resistance of granular HTSC in constant applied magnetic field.

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In order to clarify the mechanism of hysteretic behavior of magnetoresistance of granular HTSC the magnetoresistance curves \( R(H) \) and time evolution of the resistance in constant applied magnetic fields have been studied in granular YBCO at \( T=77 \) K. It was found that on ascending branch of \( R(H) \) dependence the resistance at \( H=\text{const} \) decreased with time while on the descending branch the resistance increased with time in applied constant magnetic field. For the range of low magnetic fields (below the minimum point of the descending branch of \( R(H) \) dependence) the resistance at \( H=\text{const} \) decreased again. The behavior observed is well described by the model of granular HTSC, where the intergrain space is in effective magnetic field which is the superposition of the applied field and the field induced by superconducting grains. The time evolution of resistance reflects processes of time relaxation of magnetization of HTSC grains due to the intragrain flux creep.

1. Introduction

It is well-known that the magnetoresistance \( R(H) \) of granular HTSCs demonstrates hysteresis [1,2] and after applying of the magnetic field the remanent non-zero resistance relaxes with time [3,4]. Recent study of time evolution of the magnetoresistance \( R(t) \) of HTSC-based composites in applied constant magnetic field [5] have shown that \( R(t) \) exhibits interesting peculiarity. Such study proves model of behavior of granular HTSC in magnetic field when transport current passes through sample, which is the object of wide recent speculations [4-9].

The aim of this study was examination of time evolution of the magnetoresistance \( R(t) \) of pure polycrystalline YBCO in a constant magnetic field. This may indicate that the peculiarity of \( R(t) \) evolution observed on HTSC-based composites [5] is inherent to usual (non-composite) granular HTSC.

2. Experimental

The \( \text{YBa}_2\text{Cu}_3\text{O}_7 \) (YBCO) samples was prepared by standard solid state reaction technique. The critical current density of this composite material is about \( 60 \) A/cm\(^2\) at \( 77.4 \) K (the transport critical current for sample of a parallelepiped form \( 1\times1\times8 \) mm\(^3\) is \( \approx 600 \) mA). The \( R(T) \) and magnetoresistance \( R(H) = \frac{U(H)}{I} \) (\( U \) – is the voltage drop) dependences were measured by standard four-probe technique. Magnetic field was applied perpendicular to the current direction. The magnetic field scanning velocity was about \( \approx 3 \) Oe/sec. After the applied field changed from \( H=0 \) to the fixed...
value \( H_{\text{inc}} \approx 100 \text{ Oe} \) (“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 \( H_{\text{inc}} \approx 150 \text{ Oe} \) and the \( R(t) \) dependence was measured again. Further the applied magnetic field was increased up to the value \( H = 250 \text{ Oe} \), and then decreased with the same velocity down to the value \( H_{\text{dec}} \approx 150 \text{ Oe} \). The \( R(t) \) evolution was measured in this field again. Similar measurements of \( R(t) \) evolution were made in applied fields \( H_{\text{dec}} \approx 100 \text{ Oe} \), \( H_{\text{dec}} \approx 30 \text{ Oe} \) and \( H_{\text{dec}} = 0 \). Every set of measurements of \( R(t) \) dependences presented in this paper were made within one cycling of applied magnetic field, although heating/cooling of the sample did not change the character of evolution of \( R(t) \) dependences. When the one set of \( R(H) \) and \( R(t) \) measurements was finished the sample was heated above \( T_{\text{C}} \) and then cooled in zero applied magnetic field. Similar set of measurements of the same specimen were made for magnetization hysteretic loop \( M(H) \) and time relaxation of magnetization \( M(t) \) using vibrating sample magnetometer.

3. Results and discussion

The figure 1 shows the \( R(H) \) dependences of YBCO sample at bias current \( I = 150 \text{ mA} \) up to \( H = 250 \text{ Oe} \) at \( T = 77.4 \text{K} \). Inset in this figure shows the \( M(H) \) dependence at the same conditions. These dependences show hysteretic behavior typical for granular HTSC. The detail study of hysteretic \( R(H) \) curves of granular HTSC at various values of transport current was performed in [7-9]. It is seen that these curves have apparent peaks on the front and back branches. These peaks correspond to the points of relaxation measurements.

\[ \text{Figure 1. The } R(H) \text{ dependence of YBCO sample in bias current } I= 150 \text{ mA}. \text{ On the inset shown } M(H) \text{ dependence in the same conditions.} \]

The data of time evolution of magnetoresistance and of magnetization in magnetic fields stabilized in different points of ascending \((H = H_{\text{inc}})\) and descending \((H = H_{\text{dec}})\) branches of \( R(H) \) curve are presented on the figure 2. It can be seen that the resistance decreases with time in fields for ascending branch of \( R(H) \) curve. In contrast, when field is removed and then stabilized the resistance increases with time \((H_{\text{dec}} = 150 \text{ Oe} \) and \( H_{\text{dec}} = 100 \text{ Oe})\). In the range of fields below the point of minimum of \( R(H) \) dependence the resistance at \( H_{\text{dec}} = \text{const} \) again decreases with time (see data for \( H_{\text{dec}} = 30 \text{ Oe} \) and \( H_{\text{dec}} = 0 \)). All the \( R(t) \) data are linear in \( R, \ln(t) \) co-ordinates. It is apparent that the module of magnetization decreases with time both for ascending \((M = M_{\text{inc}})\) and descending \((M = M_{\text{dec}})\) branches of \( M(H) \) dependence. Such behavior is typical for HTSC [10].

Unexpected behavior of time relaxation of the resistance is well explained by affect of time relaxation of magnetization of superconducting grains and by the change with time of the magnetic...
induction in the intergrain media. Granular HTSC’s represent system complicated enough: the resistive response in 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 applied magnetic field and local fields generated by dipole moments of superconducting grains. When the applied field $H$ is increased the magnetization is negative and dipole moments of HTSC grains induce in the intergrain separations the field $B_{\text{ind}}$ co-directed to $H$ (for the case $H \perp I$) [2,6,7,9]. Therefore, the total field in the intergrain media $B_{\text{tot}}$ is $H + B_{\text{ind}}$ for the case $H = H_{\text{inc}}$. When $H_{\text{inc}}$ is stabilized the module of magnetization relaxes with time. The relaxation of magnetization results in decrease of $B_{\text{ind}}$ and, hence, to the decrease in $B_{\text{tot}}$. So far the dissipation of granular HTSC is determined by processes of destroying of supercurrent carriers in the intergrain media (Josephson junctions) the resistance diminishes with time like $B_{\text{tot}}$. When the external field is decreased the module of magnetization becomes less and then $M$ is positive, see the figure 1. In this case the field induced by dipole moments in the intergrain separations is directed contrary to the

Figure 2. The time evolution of the resistance (the left scale) and of magnetization (the right scale) in an applied magnetic fields.
applied field, $B_{tot} = H - B_{ind}$. This results to hysteretic behavior of magnetoresistance: $R \left( H=H_{inc} \right) > R \left( H=H_{dec} \right)$.

The relaxation of magnetization with time at $H_{dec} = \text{const}$ leads to less contribution of $B_{ind}$ to $B_{tot}$. Therefore, $B_{tot}$ increases with time and resistance grows, see the figure 2. When $H_{dec}$ is less than the point of minimum 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 (figure 2) results in decrease of $B_{tot}$ and, hence, the resistance relaxes, see the figure 2. The remanent magnetization of HTSC grains induces field in the intergran 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 remanent magnetization does.

Thus, results of this work support the model of granular HTSC developed in previous works [2,6,7,9] and prove that the peculiarity of time evolution of magnetoresistance observed on HTSC based composites [5] is typical for each granular HTSC.

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