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Large magneto-resistance of high-T_C superconductor based composites to low magnetic fields at the liquid nitrogen temperature

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Abstract

The magneto-resistive effect in bulk 123YBCO + CuO and YBCO + Normal metal $BaPbO_3$ composites prepared by fast backing technique has been studied. The composites exhibit broadening of resistive transition in low magnetic fields (less than 200 Oe) for a wide temperature range. Experimental dependences of resistivity versus magnetic field at various transport current densities are presented and discussed. The HTSC based composites exhibit a much higher sensitivity to weak magnetic fields at liquid nitrogen temperature, as compared to that for the "pure" HTSC ceramics. This effect is attractive for possible practical applications and may be used in magnetic field sensor devices.

Keywords: HTSC; Magnetic field sensors; Magneto-resistance

1. Introduction

In Ref. [1] the preliminary results of study of magneto-resistive effect in composites YBCO + CuO and YBCO + metaloxide $BaPbO_3$ are presented. Broadening of resistive transition of the composites under the influence of weak magnetic fields (less than 200 Oe) is observed for a temperature range ~50–90 K [1] in contrast to "pure" polycrystalline HTSCs where this temperature interval is very narrow, typically amounting to several degrees (85–90 K for the yttrium HTSC [2]). In this report we present the results of detail study of magnetic field dependences of resistivity $\rho(H)$ of the composites.

2. Experimental

Composite samples with 70–85 vol.% of $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ (YBCO) and 30–15 vol.% CuO or 15 vol.% $BaPbO_3$ were prepared by fast backing technique described in [3,4]. Hereafter we denote composite samples as YBCO + VCuO and YBCO + $V$$BaPbO_3$ where V is vol. content of CuO and $BaPbO_3$ respectively, the vol. content of $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ is $100 - V$.

The $\rho(H)$ dependences have been measured by standard four-probe technique. The samples have been cooled in zero magnetic field (the Earth magnetic field has not been screened). The transport current was perpendicular to magnetic field direction. The value of critical current density j_C was determined from the initial part of current–voltage characteristic using the standard criterion 1 μV/cm.

3. Results and discussion

The character of $\rho(H)$ dependence of composites is found to depend on the relationship between bias current j and critical current j_C. If current j is less than its critical value, $j/j_C < 1$ (case 1), there is a part of $\rho(H)$ where $\rho \leqslant 10^{-6}$ Ω cm, see Fig. 1a and c. Starting from some threshold field H_C nonlinear $\rho(H)$ dependence

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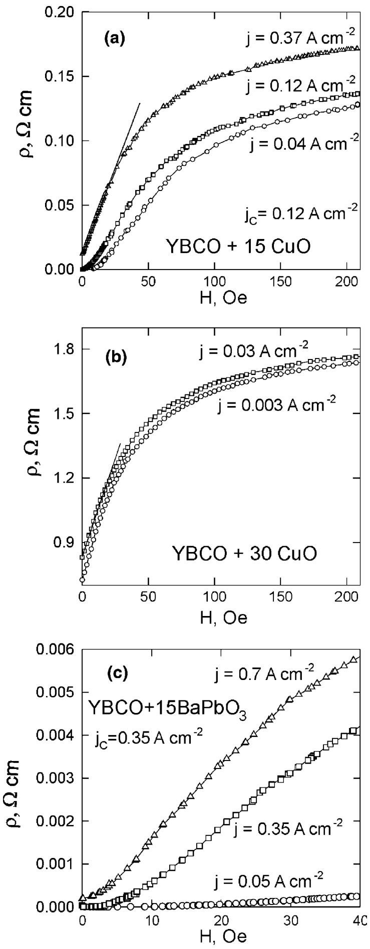

Fig. 1. Resistivity versus field for different values of j.

takes place ($H_C \approx 10$ Oe for sample YBCO + 15CuO at $j = 0.04$ A/cm^2, $H_C \approx 9$ Oe for YBCO + 15BaPbO$_3$ at $j = 0.05$ A/cm^2). The $\rho(H)$ curve measured at current $j \approx j_C$, (case 2), grows from the point of origin. Further increasing of transport current, $j > j_C$, (case 3), transforms the initial part of the $\rho(H)$ curve, which starts to growth from some non-zero value $\rho(H = 0)$. Under the condition of the case 3 the $\rho(H)$ dependences of composites with insulator (CuO) and metaloxide (BaPbO$_3$) demonstrate different behaviours. The $\rho(H)$ dependence of sample YBCO + 15BaPbO$_3$ is nonlinear in the whole field range, see Fig. 1c. On the other hand, the initial part of the $\rho(H)$ dependences of composites YBCO + 15CuO is linear in the range $0 \leqslant H \leqslant 20$ Oe (Fig. 1a and b). The values $d\rho/dH$ in this range are 2.5 mΩ cm/Oe for sample YBCO + 15CuO and 17.5 mΩ cm/Oe for sample YBCO + 30CuO. The parameter $d\rho/dH$ is sensitivity of resistivity to magnetic field. The values $d\rho/dH$ obtained on YBCO + CuO composites are two to three orders of magnitude more than those obtained on "pure" YBCO ceramics in [5,6] ($d\rho/dH \sim 0.15$ mΩ cm/Oe [5], and ~0.005 mΩ cm/Oe [6]). Sample YBCO + 30CuO has negligibly small value j_C (77 K) (less than 10^{-5} A/cm^2). For this reason the $\rho(H)$ curves measured at various j for this sample have the same form as for the case 3. In the range $|H| \leqslant 37$ Oe the $\rho(H)$ curves of composites at 77 K are reversible.

The magneto-resistive effect of polycrystalline HTSC is explained as follows [2,5]. Each grain-boundary (which is Josephson junction and is very sensitive to magnetic field) in percolation traces of transport current flowing through polycrystalline HTSC contribute to the electrical response of the whole sample. The composites represent Josephson junction network, in which the non-superconducting component forms the barriers separating HTSC crystallites [3,4]. Due to high resistivity of CuO in low temperature range the composites YBCO + CuO possess large values of ρ in the normal state [3]. This result in high sensitivity of resistivity of the composites to low magnetic fields as compared to that for "pure" HTSC ceramics.

The reported facts point the possible use of HTSC based composite materials as bulk magnetic field sensors operating at 77 K in a wide range of applications in electronic devices. We can list the following types of possible application of the HTSC based composites as active elements of magnetic field sensors.

(i) Detection of a magnetic field in a range $0 \leqslant H \leqslant 20$ Oe using the linear part of $\rho(H)$ dependence.
(ii) The technique of multiply increasing of resistance with respect to some value $\rho(H = 0)$ for digital operations in microelectronic devices. Large values of $\rho_0 = (\rho(H) - \rho(H = 0))/\rho(H = 0)$ (up to thousands per cent) may be achieved on the composites with respect to $\rho(H = 0) \sim 0.2$–10 mΩ cm at 77 K $\rho_0 = 685\%$ at $H = 35$ Oe for sample YBCO + 15CuO at $j = 0.37$ mA/cm^2 and $\rho(H = 0) = 12$ mΩ cm. For sample YBCO + 15BaPbO$_3$ $\rho_0 = 2450\%$ at $j = 0.7$ A/cm^2, $\rho(H = 0) = 0.19$ mΩ cm.
(iii) The response of sensor resistance at some threshold magnetic field value H_C (case 1).

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