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MAGNETIC MECHANISMS OF SUPERCONDUCTIVITY

Current-Controlled Magneto-Resistive Effect in Bulk Y–Ba–Cu–O + CuO Composites and Their Application as Magnetic-Field Sensors at 77 K[1]

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Abstract—We have studied the magneto-resistive effect in bulk $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ + CuO composites prepared by the fast-sintering technique. It has been found that the composites exhibit large magnetoresistance in low magnetic fields (<100 Oe) in a broad temperature range (tens of kelvins below the critical temperature T_c). The HTSC-based composites exhibit a much higher sensitivity to weak magnetic fields at liquid-nitrogen temperature as compared to pure HTSC ceramics. By choosing a proper bias current j, it is possible to control the shape of the resistivity–magnetic field $\rho(H)$ characteristic of the composites and to vary the parameter $R_0 = \{R(H = 0) - R(H)\}/R(H = 0)$. Under the condition $j > j_c$ (where j_c is the critical-current density), large values of the magnetoresistance R_0, up to thousands percent, are obtained in the range of weak magnetic fields (tens of oersteds) at 77 K. This effect is attractive for practical applications of these composite materials as active elements of magnetic-field sensors. The sign of the magneto-resistive effect is positive in contrast to that of manganese oxides. This may be important for some devices.

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1. INTRODUCTION

In our previous paper [1], we reported preliminary results of the study of magnetoresistive (MR) effect in bulk YBCO + CuO composites. A broadening of the resistive transition is observed in these composites under the influence of weak magnetic fields (less than 200 Oe) in a temperature range of ~50–90 K in contrast to “pure” polycrystalline HTSCs where this temperature interval is very narrow, typically amounting to several kelvins [2]. Studying magnetic-field dependences of resistivity $\rho(H)$ of these composites shows that the character of their $\rho(H)$ curves depends on the relationship between the bias current j and the critical current j_c [3]. If $j < j_c$, there is a region in the $\rho(H)$ curve where $\rho \le 10^{-6}$ Ω cm. Starting from some threshold field H_C, the $\rho(H)$ dependence is nonlinear. The $\rho(H)$ curve measured at a current $j \approx j_c$ grows from the very origin. A further increase in the transport current ($j > j_c$) transforms the initial part of the $\rho(H)$ curve; it begins growing from some nonzero value $\rho(H = 0)$. This case is most attractive (for the technique of multiply increasing resistance with respect to some value $R(H = 0)$) for digital operations in microelectronic devices [4].

In this report we pay attention to the *current-controlled* MR effect and to the value of the parameter $R_0 = \{R(H = 0) - R(H)\}/R(H = 0)$ in the YBCO + CuO composites for the case $j > j_c$ at 77 K.

2. EXPERIMENTAL

The procedure of the preparation of the HTSC of composition $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ was standard. Composite samples with 70–85 vol % HTSC and 30–15 vol % CuO (high purity CuO powder was used) were prepared using the “fast-baking technique” [5]. This technique provides the absence of a chemical interaction of the composite components, so that their physical properties remain unchanged. Hereafter, we denote composite samples as YBCO + *V*CuO, where *V* is the volume content of CuO; the volume content of $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ is 100 – *V*).

The transport measurements were performed using the standard four-probe technique. Typical dimensions of the samples were 1 × 1 × 8 mm^3. During measurements, the samples were in a nitrogen atmosphere. The current–voltage characteristics (CVCs) were measured under constant-current (dc) conditions. The applied dc transport-current density was varied up to ~1 A/cm^2 (bias current of ~30 mA). This value of current did not result in a self-heating of the sample. The accuracy of determining “zero resistivity” was ~10^{-6} Ω cm. For the generation of dc magnetic fields of up to 500 Oe, a cop-

[1] The text was submitted by the authors in English.

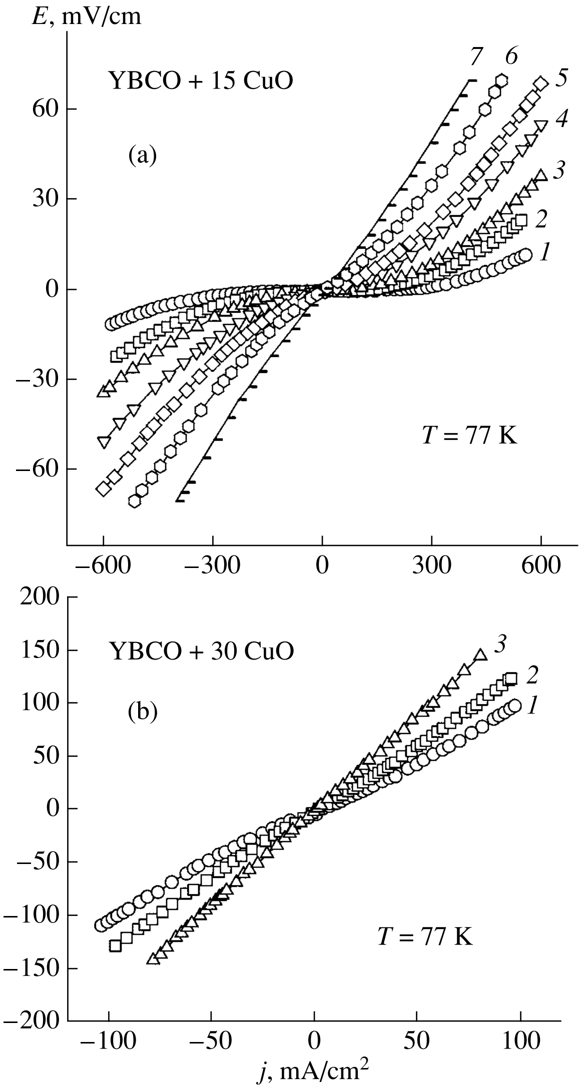

Fig. 1. CVCs of YBCO + CuO composites at 77 K measured at various magnetic field strengths: (a) (*1*) $H = 0$, (*2*) 4, (*3*) 15, (*4*) 27, (*5*) 38, (*6*) 64, and (*7*) 207 Oe; and (b) (*1*) $H = 0$, (*2*) 23, and (*3*) 207 Oe.

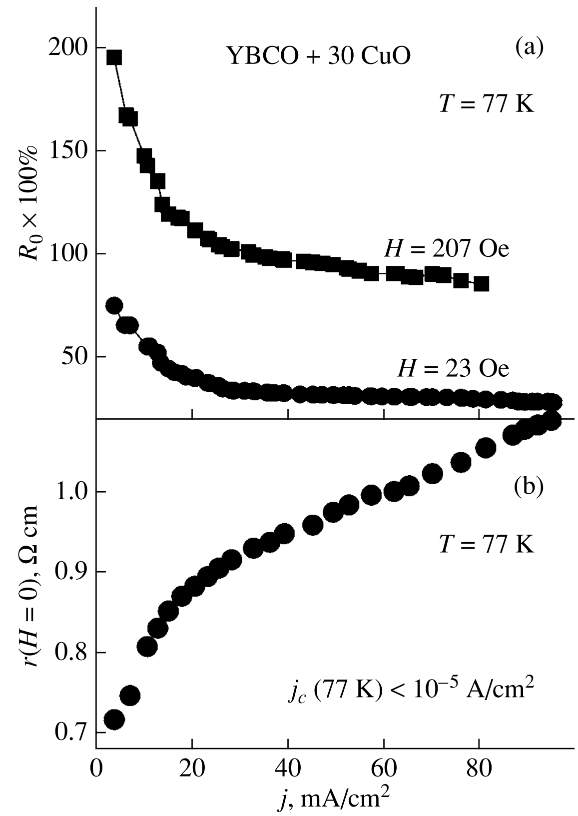

Fig. 2. R_0 dependences on the transport current j at various (a) H and (b) $\rho(H = 0)$ for the YBCO + 30 CuO sample.

per solenoid was used. The transport current was perpendicular to the magnetic-field direction. The samples were cooled in a zero magnetic field (the Earth magnetic field was not shielded).

3. RESULTS

Figure 1 shows CVCs of (a) YBCO + 15CuO and (b) YBCO + 30CuO samples in various applied magnetic fields at 77 K. Nonlinear CVCs are typical of composites which represent networks of Josephson junctions [6]. The YBCO + 15CuO composite (Fig. 1a) possesses a critical current $j_c \approx 0.12$ A/cm^2 at $H = 0$. The YBCO + 30 CuO sample has no critical current at 77 K. Details of the resistive transition in these composites can be found in [1]. With increasing magnetic field, the CVCs of these composites change markedly. The MR effect in these composites arises from a network of Josephson junctions that take place in these materials. CuO forms barriers separating HTSC crystallites. Each junction in percolation paths of the transport current flowing through the composite contributes to the electrical response of the whole sample. Due to the high resistivity of CuO in the low temperature range, the YBCO + CuO composites possess large values of ρ in the normal state [3]. This results in a high sensitivity of resistivity of these composites to low magnetic fields as compared to that of "pure" HTSC ceramics.

Figures 2a and 3a show the dependences of the parameter $R_0 \times 100\%$ as a function of the transport-current density. These plots have been obtained using data of Fig. 1. The MR effect is seen to rich a large magnitude for relatively low magnetic fields. The value of the resistivity $\rho(H = 0)$ is an important parameter that determines the value of R_0. If $\rho(H = 0)$ is too small (less than 10^{-6} Ω cm in the nondissipative state), the utilization of the MR effect can be problematic. A more suitable condition for the practical application would be the variation of resistivity in relation to a not-too-small value of $\rho(H = 0)$. Figures 2b and 3b show the dependences of $\rho(H = 0)$ as functions of j for the composites under consideration. These plots were obtained using

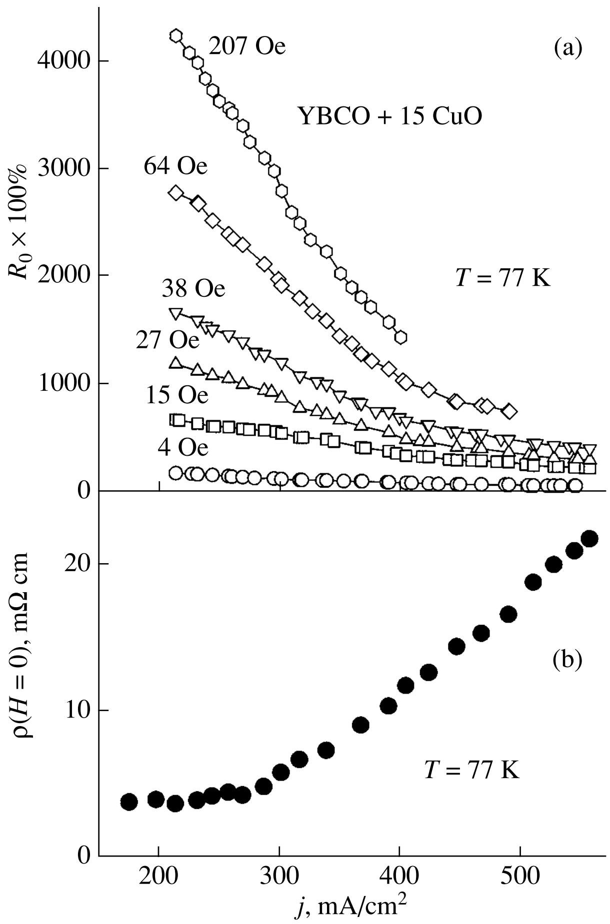

Fig. 3. R_0 dependences on the transport current j at various (a) H and (b) $\rho(H = 0)$ for the YBCO + 15 CuO sample.

data of Fig. 1 for $H = 0$. As can be seen from Figs. 2b and 3b, the values of $\rho(H = 0)$ are large enough (0.004–1 Ω cm). By varying the transport current j, we can obtain a necessary magnitude of R_0 at a given value of the magnetic field.

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