2004

Cryogenic magnetic field sensor based on the magnetoresistive effect in bulk Bi2212 + USr2CaO6

M. Ionescu
University of Wollongong, mionescu@uow.edu.au

B. Winton
University of Wollongong

Tania M. Silver
University of Wollongong, tsilver@uow.edu.au

S. X. Dou
University of Wollongong, shi@uow.edu.au

R. Ramer
University of New South Wales

APPLIED PHYSICS LETTERS VOLUME 84, NUMBER 26 28 JUNE 2004

Cryogenic magnetic field sensor based on the magnetoresistive effect in bulk Bi2212+USr_2CaO_6

M. Ionescu,[a] B. Winton, T. Silver, and S. X. Dou
Institute for Superconducting and Electronic Materials, University of Wollongong, Australia

R. Ramer
School of Electrical and Telecommunication Engineering, University of NSW, Australia

(Received 3 March 2004; accepted 4 May 2004; published online 17 June 2004)

A large magnetoresistive (MR) effect was observed in melt-textured (MT) Bi2212 in which USr_2CaO_6 was added in a proportion of 6 wt %. The resistivity measurements of MT Bi2212 +6 wt % USr_2CaO_6 show high sensitivity to applied dc fields, as compared to pure Bi2212, in particular at low fields, below 3 T, and in a temperature range between 45 K and 85 K. In this temperature range, the MR effect of MT Bi2212+6 wt % USr_2CaO_6 is two orders of magnitude larger than the MR effect in pure Bi2212, and display a maximum that may be tuned to a particular temperature within the above range, by changing the amount of added nonsuperconducting compound. A cryogenic sensor was built and tested at 77 K in low fields. It shows a good sensitivity and small (~1%) hysteresis of resistivity when the applied field was cycled between 0 T and 1 T. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1766398]

The most desirable operating temperature range for a cryogenic magnetic field sensor is at around the liquid-nitrogen temperature, (77 K). Currently, the cryogenic magnetic sensors commonly used are based on the Hall effect, or the magnetoresistive (MR) effect in semiconductors.[1] Both types of sensors are expensive. The emerging materials with possible applications as a cryogenic magnetic sensors are the colossal MR (CMR) materials. However, the possible application of CMR-based magnetic sensors at around 77 K may be limited due to a reduced sensitivity and a strong nonlinearity of the MR effect in these materials. Many polycrystalline high-temperature superconductors exhibit a MR effect, but this is usually small, within a narrow temperature range, close to their T_c.[2]

In previous studies, it has been shown that doping the bulk Y123 with CuO (Ref. 3) or with $BaPb_{1-x}Sn_xO_3$,[4] leads to a significant increase in the MR response at low magnetic fields as compared to pure Y123. The downside was a hysteretic behavior reported for the measured resistivity with the cycling of the applied field, due to strong intragrain pinning attributed to Y123.

In this work, we report the investigation of the MR effect in the Bi2212 phase, in which 6 wt % USr_2CaO_6 was added in the matrix. Experimentally, stoichiometric Bi2212 powder was mixed with 6 wt % USr_2CaO_6, and melt textured (MT) in air at 845 °C, producing disk-shaped samples with a typical density of 92%–94%, and with the (a,b) plane of Bi2212 unit cell perpendicular to the applied force. A second pellet was produced under similar conditions, using only pure Bi2212 powder, and was used as the reference sample. Rectangular-shaped samples were cut from the two MT disks, having the approximate dimensions of 2 mm×2 mm ×7 mm, and four contacts were attached using silver paste.

The resistivity of the two samples was measured by the four-point technique, between room temperature and 5 K, in external dc fields up to 9 T, using a dc current between 10 mA and 100 mA.

The x-ray phase analyses carried out on powder extracted from the MT Bi2212+6 wt % USr_2CaO_6, together with the simulated powder spectra for pure Bi2212 and pure USr_2CaO_6 powders, using the simulation parameters published in Refs. 5 and 6, respectively, indicate that the USr_2CaO_6 nonsuperconducting phase added in Bi2212 does not react with the host matrix, and it retains its identity as a separate phase.

The dependence of resistivity on temperature and applied magnetic field for Bi2212+6 wt % USr_2CaO_6 addition is presented in Fig. 1, and for pure Bi2212 in the inset of Fig. 1. For pure Bi2212, the temperature and field dependence of resistivity follows the expected trend with a metallic behavior, followed by a drop at around 93 K, where the transition between the normal and superconducting state takes place. With the increase of the applied field H, the transition becomes broader, and the "zero" value of resistivity is achieved at increasingly lower temperatures.

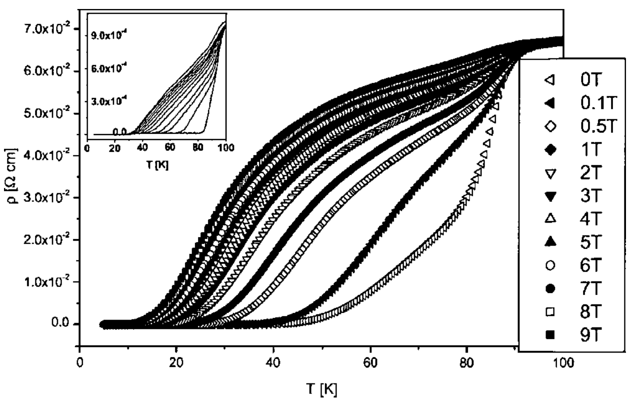

FIG. 1. Dependence of resistivity on temperature and applied field, $\rho(T,H)$, for MT Bi2212+6 wt % USr_2CaO_6. Inset: Dependence of resistivity on temperature and applied field, $\rho(T,H)$, for MT Bi2212.

[a]Electronic mail: mionescu@uow.edu.au

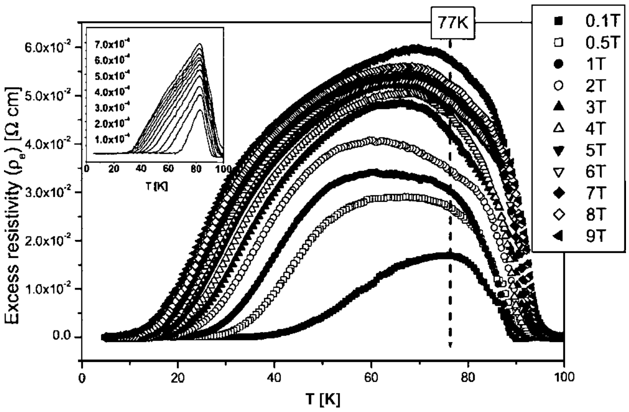

FIG. 2. Excess resistivity (ρ_e) for MT Bi2212+6 wt % USr_2CaO_6. Inset: Excess resistivity (ρ_e) for MT pure Bi2212.

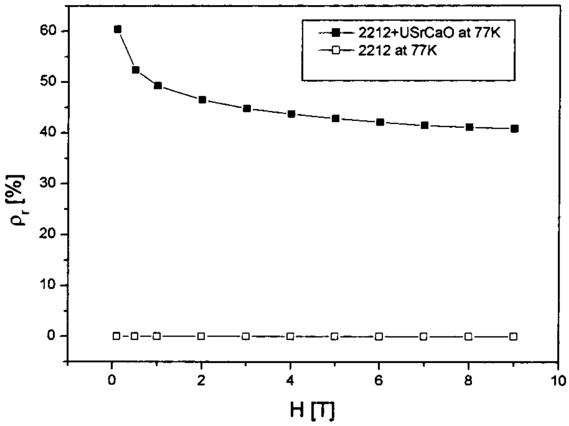

FIG. 3. The field dependence of the relative variation of resistivity (ρ_r), at 77 K, for Bi2212+6 wt % USr_2CaO_6 and pure Bi2212.

In the case of Bi2212+6 wt % USr_2CaO_6, the temperature and field dependence of resistivity is different. Between the room temperature and the onset of the superconducting state, the resistivity increases with a decrease in temperature. The width of the normal to superconducting transition is broader as compared to the transition of pure Bi2212, but the onset of the transition also takes place at around 93 K. With the increase of the applied field *H*, the transition broadens even further.

The broadening of the resistive transition for polycrystalline superconductors in applied dc fields was explained previously.[7] The grain boundaries represent weak links, and the intergrain connectivity is achieved via a Josephson current. Thus, a polycrystalline superconductor may be viewed as a network of junctions, and in applied dc fields, the Josephson current is suppressed to a larger or smaller extent, depending on the particular properties of the grain boundaries. The typical signature for this interaction is the increase in the overall resistance of the sample.

The increase in resistivity due only to the presence of the applied magnetic field, called excess resistivity, is a better way to compare the MR effect in pure Bi2212 and Bi2212 +6 wt % USr_2CaO_6 samples. Excess resistivity (ρ_e) at a particular temperature (T) due only to the presence of an applied field (H) is define as $\rho_e = \rho(T,H)\text{-}\rho(T,H=0)$. Excess resistivity was calculated for Bi2212+USr_2CaO_6 addition and pure Bi2212, and the result is presented in Fig. 2 and the inset of Fig. 2, respectively. A comparison between these two figures revealed that the excess resistivity or the size of the MR effect, is two orders of magnitude larger in Bi2212 +6 wt % USr_2CaO_6 addition than in pure Bi2212. The size of the MR effect is more significant at low applied fields, below 0.5 T, and at moderate applied fields, below 3 T. In the same time, the temperature range of the of the MR effect has increased from approximately 70 K–90 K in the case of pure Bi2212 to approximately 40 K–90 K for Bi2212 +USr_2CaO_6.

The maximum of the excess resistivity for pure Bi2212 is situated above 77 K, and the maximum for Bi2212 +6 wt % USr_2CaO_6 is situated below 77 K. This suggests that the maximum of the MR effect in Bi2212 may be tuned to different temperatures within a certain range with the addition of appropriate amounts of the nonsuperconducting USr_2CaO_6 phase. These characteristics of the MR effect in Bi2212+6 wt % USr_2CaO_6 suggest that this composite may be used as magnetic field sensor at cryogenic temperatures.

An important operating characteristic for a potential sensing device, is the relative variation of the measured parameter. In our case, this parameter is the relative variation of resistivity (ρ_r) in an applied field *H*, defined as $\rho_r = \rho(H=0)/\rho(H)$, where $\rho(H)$ is the resistivity in an applied dc field *H*, and $\rho(H=0)$ is the resistivity in the absence of the applied field. Expressed in percentage, the field dependence of the relative variation of resistivity was calculated for Bi2212 and Bi2212+6 wt % USr_2CaO_6, and the result is presented in Fig. 3 for the temperature of 77 K. We see that at this temperature, the ρ_r for Bi2212+6 wt % USr_2CaO_6 is large enough to be used in sensor devices, in particular at low fields, below 3 T. For comparison, ρ_r for pure Bi2212 changes very little with the applied field *H*.

In order to demonstrate the concept of a cryogenic sensor based on this material, practically, a sensor with the active part of Bi2212+6 wt % USr_2CaO_6 was constructed. The actual dimensions of the active part were 5.8 mm × 2.1 mm and a thickness of 0.45 mm. Four contacts were attached using low resistance silver paste. The sensor was placed at 77 K, inside an electromagnet, together with a calibrated digital Hall probe (DTM-132). The variation of sensor resistivity was measured at 77 K, in low magnetic fields, using a current of 10 mA, and plotted as a function of applied field measured by the Hall probe. The result is shown in Fig. 4.

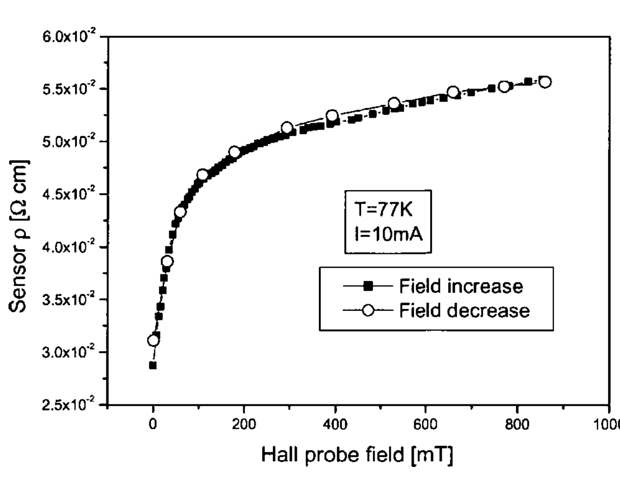

FIG. 4. The change of sensor resistivity at 77 K, when the applied dc field was cycled between 0 T and 1 T. The probe current used was 10 mA.

We note that when the applied field was cycled between 0 T and 1 T, a small hysteretic behavior (of ~1% at 400 mT) of sensor resistivity was observed, due to measurement errors. Also, a number of different Bi2212+6 wt % USr_2CaO_6 samples were produced and measured in the same way, and the results were similar within approximately ±1%.

The sensor aging upon repeated cycling in a higher field and at a temperature up to 300 K is currently under investigation, aiming to answer questions such as the calibration drift on cycling, and to find an appropriate encapsulation material for the active part.

In conclusion, we show that the resistivity of MT Bi2212+6 wt % USr_2CaO_6 possesses a high sensitivity to applied dc fields, as compared to pure Bi2212. The MR effect of MT Bi2212+6 wt % USr_2CaO_6 is large at low fields, below approximately 3 T, in the temperature range from ~45 K to ~85 K, where it displays a maximum that may be changed by modifying the amount of added nonsuperconducting compound. A cryogenic sensor, using MT Bi2212 +6 wt % USr_2CaO_6 as the active part, was built and tested at 77 K in low fields.

[1] H. Nojima, S. Tsuchimoto, and S. Kataoka, Jpn. J. Appl. Phys., Part 1 **27**, 746 (1988).
[2] A. C. Wright, K. Zhang, and A. Erbil, Phys. Rev. B **44**, 863 (1991).
[3] M. I. Petrov, D. A. Balaev, K. A. Shaihutdinov, and K. S. Aleksandrov, Semicond. Sci. Technol. **14**, 798 (2001).
[4] M. I. Petrov, D. A. Balaev, D. M. Gokhfeld, S. V. Ospischev, K. A. Shaihutdinov, and K. S. Aleksandrov, Physica C **314**, 362 (1999).
[5] A. A. Levin, Y. I. Smolin, and Y. F. Shepelev, Zh. Neorg. Khim. **38**, 1755 (1993).
[6] W. A. Groen and D. J. W. Ijdo, Acta Crystallogr., Sect. C: Cryst. Struct. Commun. **43**, 1033 (1987).
[7] M. Tinkham, Phys. Rev. Lett. **61**, 1658 (1988).