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Study of galvanomagnetic effects in Bi–Sr–Ca–Cu–O films

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Abstract. Galvanomagnetic effect has been studied at 77 K on Bi–Sr–Ca–Cu–O films as a function of d.c. bias current. These films were prepared by spray pyrolysis and screen-printing techniques, with T_c (R = 0) 80 K and 100 K respectively. Magnetic field dependence of I_c of sprayed-film showed very small hysteresis whereas screen-printed film showed greater hysteresis. Application of small magnetic field on these films destroyed the zero-resistance state and a finite resistance was developed. The slope of the resistance vs magnetic field curve $\Delta R/\Delta H$ depended on the current flowing through the sample. To increase $\Delta R/\Delta H$, meander-shape pattern was prepared on the sprayed film. In general $\Delta R/\Delta H$ increased by a factor of 10^3 after sample patterning. The possibility of using these films as a sensitive magnetic field sensor is discussed.

Keywords. Galvanomagnetic effect; Magneto-resistor; Bi–Sr–Ca–Cu–O films; meander shape; spray pyrolysis; screen-printing; hysteresis.

1. Introduction

It is well established that the polycrystalline sample of high T_c superconductors is granular. Various superconducting grains form a network with weak links formed at grain boundaries (Kataria *et al* 1988). As a result, the critical current of these high T_c superconductors gets suppressed even on application of small magnetic fields. Nojima *et al* (1988) studied the potentiality of YBCO films for using as a sensitive magnetic sensor. In this paper we report the galvanomagnetic effects on Bi–Sr–Ca–Cu–O (2212)-sprayed films and on mixed phase screen-printed films with d.c. bias current as a parameter. The potentiality of these films in using as a magnetic sensor is discussed.

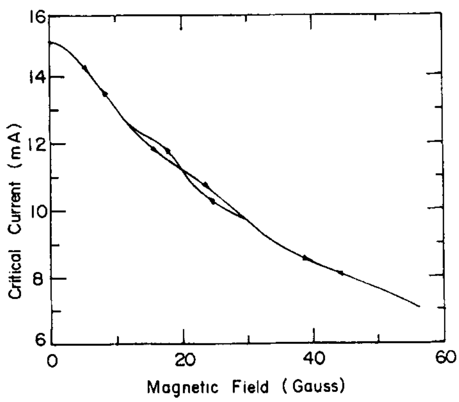
2. Experimental

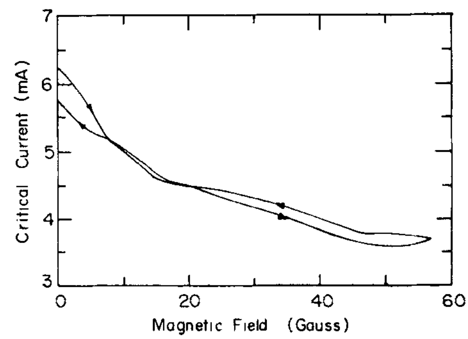
Single-phase 2212 Bi–Sr–Ca–Cu–O films with T_c (R = 0) 80 K were prepared on MgO (100) substrate by spray-pyrolysis technique (Walia *et al* 1989). Mixed-phase (predominently high T_c phase) Bi–Sr–Ca–Cu–O films were prepared using screen-printing technique with the starting composition 1112 (Chaudhry *et al* 1990). The T_c (R = 0) of the film was 100 K. Resistance and the critical current I_c of the films were measured using the standard four-probe technique. For I_c measurement the criterion of 1 μV/cm was used. The variation of the critical current was recorded with the applied magnetic field for both types of Bi–Sr–Ca–Cu–O films. Variation of the magneto-induced resistance of the films was studied for different currents through the films. A meander shape was carved manually on the 2212 film and the galvanomagnetic effect on this carved film studied.

3. Results and discussion

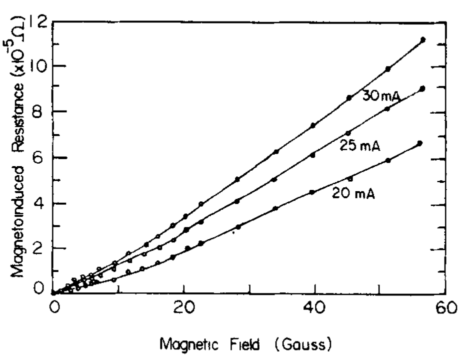
Figure 1 shows the magnetic field dependence of the critical current I_c of 2212 sprayed film. I_c decreases as the magnetic field is increased. The variation of I_c both with increasing and decreasing magnetic field is shown in figure 1. Figure 2 shows similar results on the screen-printed film. The magnetic field dependence of I_c for 2212 film shows negligibly small hysteresis whereas screen-printed film is highly hysteretic. This difference in hysteretic behaviour between the two types of films can be understood in terms of the trapping of magnetic flux occurring more in polyphase rather than in single-phase case.

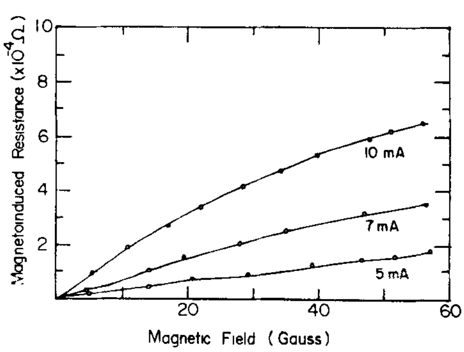
Figure 3 shows the magnetic field dependence of the induced resistance in sprayed film with a d.c. bias current as a parameter. As the magnetic field was applied to the film a resistance appears and this increases with increase of magnetic field, as well as with d.c. bias current. This characteristic was found to depend on the direction of the magnetic field. The magneto-induced resistance was maximum for the magnetic





Figures 1 and 2. Magnetic field dependence of the critical current I_c at 77 K. **1.** 2212-sprayed film. **2.** Mixed phase screen-printed Bi–Sr–Ca–Cu–O film.





Figures 3 and 4. Variation of magneto-induced resistance with the magnetic field for different biasing current. **3.** Sprayed film. **4.** Screen-printed Bi–Sr–Ca–Cu–O film.

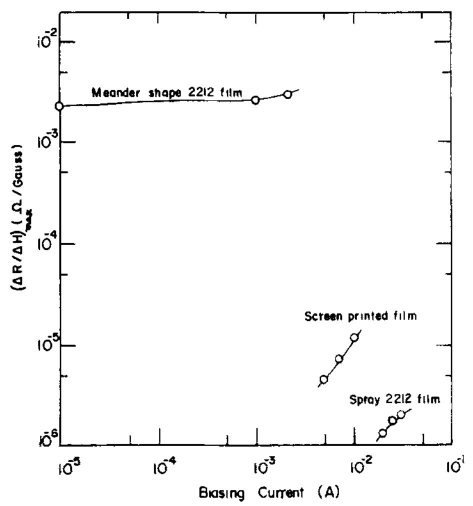


Figure 5. Dependence of $(\Delta R/\Delta H)_{max}$ on the current for the 2212-sprayed film, mixed phase screen-printed film and 2212-patterned film.

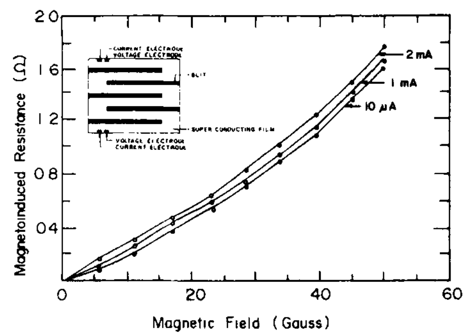


Figure 6. Magnetic field dependence of the induced resistance for the meander-shape (2212)-patterned film with d.c. bias current as a parameter. Inset shows the schematic drawing of the meander-shape pattern.

field perpendicular to the plane of the film, while it was minimum for the parallel magnetic field. This observation of the directional dependence of the magneto-induced resistance is different from magnetically isotropic case of YBCO (Nojima *et al* 1988). This may be due to the high orientation of the 2212 film, with the reflection planes being perpendicular to the film surface, whereas YBCO have randomly-oriented planes. Figure 4 shows the magnetic field dependence of the induced resistance in the screen-printed film, with the d.c. bias current as a parameter.

Magnetic field dependence of the induced resistance of both types of films was also studied, both for increasing and decreasing magnetic field. 2212 film exhibited very little hysteresis whereas screen-printed film showed greater hysteresis.

The physical mechanism of this magneto-resistive effect can be understood as follows. High T_c Bi–Sr–Ca–Cu–O superconductor is granular in nature. In the superconducting films there are very thin layers of normal phase across grains or granular point contacts which act as weak coupling. These weaklinks (Kataria *et al* 1988) display Josephson effects. The materials thus can be considered as a superconducting Josephson weaklink network. The critical current of individual weaklink is magnetic field-dependent. Weaklinks with extremely low critical current can turn normal while the rest of the weaklinks may be superconducting. This leads to the growth of resistance.

The appearance of the magneto-induced resistance in the Bi–Sr–Ca–Cu–O films suggests the possibility of using these films as a magnetic field sensor. The sensitivity of these films for using it as a magnetic sensor can be judged by seeing the maximum increase in resistance with the applied field, $(\Delta R/\Delta H)_{max}$. Figure 5 shows the variation of $(\Delta R/\Delta H)_{max}$ for 2212-sprayed films and mixed phase screen-printed films. $\Delta R/\Delta H$ was slightly higher for the screen-printed film as compared to the 2212-sprayed film. This is due to the difference in the coupling strength of weaklinks between the superconducting grains of the two types of films. Although $(\Delta R/\Delta H)_{max}$ is higher for the screen-printed films, noise measurement showed that these films exhibit greater noise compared to sprayed films, which makes them unsuitable for sensitive device applications.

To increase $\Delta R/\Delta H$ in the 2212 film, the path of current through the film was increased by patterning a meander shape structure (see figure 6). After patterning, the room temperature resistance of the film increased by 500 times that of the unpatterned film. In the meander-shape patterned film the current has to flow through a longer and narrower path, so that the magneto-induced resistance is also increased. Figure 5 also shows variation of $(\Delta R/\Delta H)_{max}$ for the patterned film with the bias current $(\Delta R/\Delta H)_{max}$ showing increase by a factor of 10^3 after patterning the sprayed film. This shows greater potential for its wide application as a magnetic sensor.

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