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Magnetoresistance Study of *c*-Axis Oriented YBCO Thin Film

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The *c*-axis orientation $YBa_2Cu_3O_\delta$ thin film was prepared directly on MgO substrate by the pulse laser deposition. The thickness of the film is 170 nm. The superconducting critical temperature is $T_{c50\%} = 87.5$ K and the width of superconducting transition is $\Delta T = 1.8$ K. The temperature dependences of magnetoresistance were measured up to 90 kOe. The widths of the transition to the superconducting state versus applied magnetic field were derived and they were fitted using the formula: $\Delta T = CH^m + \Delta T_0$. The irreversibility fields as a function of temperature were obtained and fitted by the de Almeida and Thouless-like equation: $H_{\rm irr} = H_{\rm irr0}(1-T/T_{c0})^n$. The irreversibility field at the liquid nitrogen temperature was calculated and it is $H_{\rm irr} = 43.8$ kOe when the applied magnetic field is parallel to the *c*-axis.

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1. Introduction

The advanced development of the preparation of high temperature superconductors (HTS) films and tapes has opened new opportunities for large-scale applications including power system components such as electrical motors, generators, power transmission cables, transformers, magnets, and superconducting magnetic energy storage devices [1–3]. Extensive investigations have been focused on optimizing the fabrication and processing techniques of HTS wires and tapes [4] giving the high values of critical current densities and irreversibility fields. One of the highest reported critical current densities of the first generation (1G) bismuth based tapes was about 115 kA cm^{-2} and the irreversibility fields are $H_{\rm irr} = 72.8$ kOe and $H_{\rm irr} = 5.5$ kOe for the parallel and perpendicular direction respectively at 77 K [5–7]. The critical current densities of the second generation (2G) REBaCuO 1:2:3 based tapes reach over 10^6 A cm^{-2} [8].

In this paper the temperature dependences of the magnetoresistance of the *c*-axis orientation $YBa_2Cu_3O_\delta$ thin film prepared on MgO substrate were studied and the field dependences of the transition width as well as temperature dependences of the irreversibility fields are reported and analyzed.

2. Experiment

The sample was prepared by the pulsed laser deposition (PLD) on single crystal (100) one side polished MgO substrate. PLD setup (Neocera) was running on excimer laser (Coherent COMPexPro 110F) with a wavelength of 248 nm. Pulse energy was 200 mJ and repetition rate was 10 Hz. During deposition substrate temperature and O_2 partial pressure were set to 750 °C and 100 mTorr, respectively. Deposition lasted 50 min. After deposition O_2 partial pressure was set to 300 Torr and sample was cooled to 400 °C with ramp 3 °C/min and then annealed in this temperature for 30 min. The target used during film preparation was made from powder obtained by the standard solid-state reaction technique, pressed at a pressure of 0.7 GPa and sintered at 940 °C for 72 h. The distance between target and substrate was 9 cm. The film thickness was determined using X-ray fluorescence (XRF) spectrometer and it was 170 nm. X-ray diffraction (XRD) on the film on MgO substrate showed excellent *c*-axis orientation and no secondary phases were detected in the XRD spectra [9].

The temperature dependences of the magnetoresistance were measured using the standard four-points ac method option of the Quantum Design PPMS apparatus with 90 kOe superconducting magnet. The measurements were carried out for the *c*-axis parallel to the applied magnetic field.

3. Results and discussion

The temperature dependences of the magnetoresistance for the parallel magnetic field orientations with respect to the *c*-axis are shown in Fig. 1.

At the zero field the critical temperatures for this tape are as follows: $T_{c50\%} = 87.5$ K, $T_{c0} = 85.8$ K and the width of superconducting transition is $\Delta T_0 = 1.8$ K. One can notice a significant broadening of the superconducting transition with the application of the external

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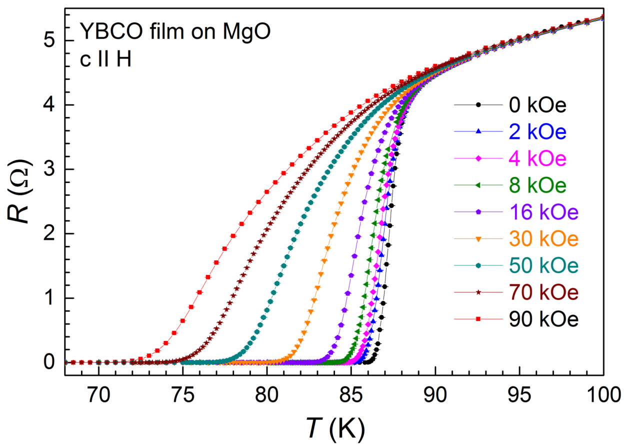

Fig. 1. Temperature dependences of the magnetoresistance of the c-axis orientation $YBa_2Cu_3O_\delta$ thin film on MgO for the parallel magnetic field orientations with respect to the c-axis.

magnetic field, which is typical for HTS [10, 11]. Some authors try to explain this phenomenon with the vortex structure and flux motion mechanism [12, 13]. One can expect that the resistive transition from the normal to the superconducting state of HTS hides many interesting physical phenomena [14] and this is possibly a key to understand the mechanism of a superconductivity of these materials. From this point of view the attention is paid to the width of the resistive transition that is usually defined as: $\Delta T = T_{90\%} - T_{10\%}$ and its dependence on the applied magnetic field. To take advantage of the experimental curves that are shown in Fig. 1 the widths of the transition versus applied magnetic fields were derived and they are shown in Fig. 2. One can notice that at the zero applied magnetic field the width of the resistive transition is small and rises remarkably when the magnetic field is increased. The width of the resistive transition starts from $\Delta T_0 = 1.8$ K at the zero applied magnetic field and reaches $\Delta T = 12.2$ K at 90 kOe. The width of the resistive transition can generally be described in the following form [14]:

$$\Delta T = CH^m + \Delta T_0, \qquad (1)$$

where $m = 2/3$ and ΔT_0 means the width at the zero applied magnetic field. The exponent m is related to the exponent n that appears in the temperature dependence of the irreversibility field by the relation: $m = 1/n$. The coefficient C depends on the critical current at zero magnetic field as well as on the critical temperature. The experimental data presented in Fig. 2 were well fitted using Eq. (1) (the solid lines in Fig. 2). For each direction the two parameters m and C were used as the fit parameters in Eq. (1). The width of the resistive transition at the zero applied magnetic field $\Delta T_0 = 1.8$ K was taken from the experimental data. The parameters m and C obtained from the fitting procedure are 0.84 ± 0.03 and 0.24 ± 0.03, respectively. The critical exponent derived from this fit is generally greater than the theoretical $m = 2/3$ in Eq. (1). The greater parameter m corresponds to a more three-dimensional vortex structure [15] and it means that the pinning force is not too strong. On the other hand, the density of the critical current of this film obtained from the ac susceptibility using the Bean model reach high value: $J_c = 1.2 \times 10^7$ A/cm^2 at 77 K in the self magnetic field [16].

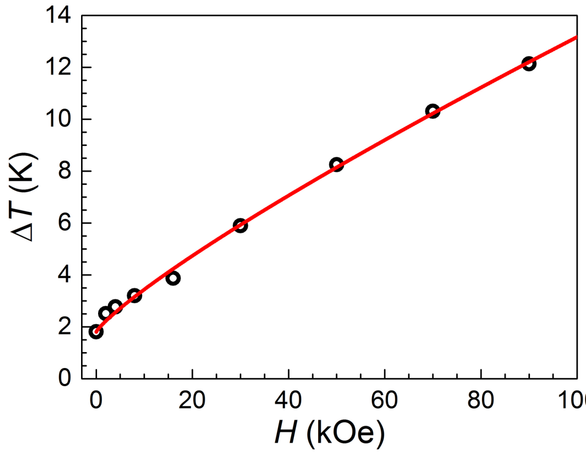

Fig. 2. Width of the transition versus the applied magnetic field. Solid line is the fit to Eq. (1).

The most important curve on the H–T phase diagram of HTS is the irreversibility line [17, 18] that separates the vortex glassy from the vortex liquid state. This line is determined by the temperature dependence of the irreversibility fields above that the flowing current forces the vortices to move. It means that energy dissipation appears and supercurrent vanishes. From this point of view the irreversibility field of HTS plays a similar role to that of the upper critical field in classical superconductors. The temperature dependence of the irreversibility fields can be described by the following relation:

$$H_{\rm irr} = H_{\rm irr0}\left(1 - \frac{T}{T_{c0}}\right)^n, \qquad (2)$$

where $H_{\rm irr0}$ is the irreversibility field at 0 K, T_{c0} is the zero critical temperature at zero magnetic field and the exponent n, which is theoretically $3/2$, can vary in the wide range and depends on the vortex properties. One can assume [19] that the temperature at which the whole sample stayed superconducting (resistance equal to zero) at the given magnetic field separates the reversibility from the irreversibility region. The data $H_{\rm irr}(T)$ were extracted from the magnetoresistance measurements and they are shown in Fig. 3.

The experimental data of $H_{\rm irr}(T)$ were successfully fitted using Eq. (2) with the two fit parameters: n and $H_{\rm irr0}$ (solid lines in Fig. 3). The zero field critical temperature $T_{c0} = 85.8$ K was taken from the experiment. The fit procedure delivers the following fit parameters values: $n = 1.17 \pm 0.02$ and $H_{\rm irr0} = 650 \pm 22$ kOe. This value of the exponent in Eq. (2) is comparable to the inverse of the exponent m defined in Eq. (1) that gives 1.19. Taking advantage of the fit parameters the irreversibility

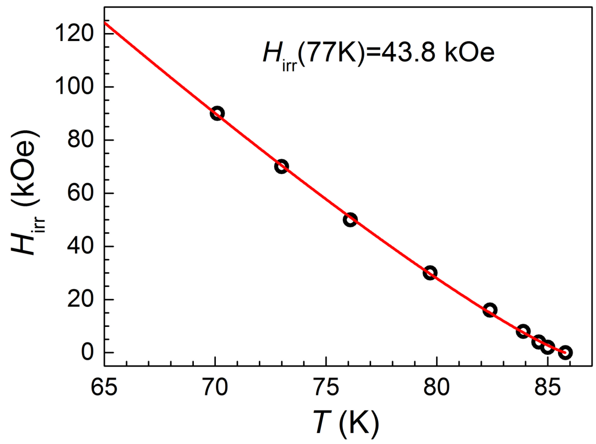

Fig. 3. Irreversibility fields as a function of temperature. Solid line is the fit to Eq. (2).

field at the liquid nitrogen temperature was calculated and it is $H_{\rm irr} = 43.8$ kOe.

4. Conclusions

The c-axis orientation $\rm YBa_2Cu_3O_\delta$ film on MgO possesses good superconducting parameters: the critical temperature $T_{c50\%} = 87.5$ K, the width of the superconducting transition $\Delta T_0 = 1.8$ K and the high critical current density $J_c = 1.2 \times 10^7$ A/cm^2 at 77 K in the own magnetic field. The thickness of the film is 170 nm. The width of superconducting transition versus magnetic field was fitted using Eq. (1). The parameters m and C obtained from the fitting procedure are 0.84 ± 0.03 and 0.24 ± 0.03, respectively. The critical exponent derived from this fit is generally greater than the theoretical $m = 2/3$ and it corresponds to a more three-dimensional vortex structure. It means that the pinning force is not too strong. On the other hand, the density of the critical current of this film reaches really high value. The experimental data of $H_{\rm irr}(T)$ were successfully fitted using Eq. (2) with the two fit parameters: n and $H_{\rm irr0}$. The fit procedure delivers the following fit parameters values: $n = 1.17 \pm 0.02$ and $H_{\rm irr0} = 650 \pm 22$ kOe. The value of the exponent n is comparable to the inverse of the exponent m : $1/m = 1.19$. Taking advantage of the fit parameters the irreversibility field at 77 K was calculated and it is $H_{\rm irr} = 43.8$ kOe when the applied magnetic field is parallel to the c-axis.

Acknowledgments

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