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The Irreversibility Fields of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ Film on Polished Silver Substrate

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Superconducting $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film was prepared on a highly polished, untextured silver substrate. A superconducting transition temperature ($T_{c,50\%}$) of 114.7 ± 0.3 K was obtained from the resistance versus temperature measurements for different applied ac currents. The density of the critical current measured by transport method was found to be 11.4×10^3 A/cm^2 at 77 K in the self field. This value is smaller than the value calculated from ac susceptibility data: 53×10^3 A/cm^2 at 77 K. The magnetical broadening of the resistivity transition to the superconducting state was observed. The irreversibility fields of the thallium based film were obtained from magnetoresistive measurements for both parallel to the c-axis and parallel to the ab plane showing the anisotropy according to the magnetic field direction. The irreversibility fields as a function of temperature were successfully fitted by the power law.

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1. Introduction

One of the most interesting high temperature superconductors (HTS) is thallium based films which can exist in the following phases: Tl-1223, Tl-2223, Tl-2213, and Tl-1212. These materials are good candidates for the fabrication of the second generation of HTS tapes (coated conductors) as well as for the fabrication of the microwave filters for wireless telecommunication [1]. Unique properties of superconducting devices like an extremely small energy consumption and a picosecond range switching speed force to develop so-called superconductor digital electronics which can also use thallium base HTS [2]. The wide researches on lead doped thallium superconductors (Tl-1223) showed that critical current densities of more than 10^6 A/cm^2 may be achieved for Tl-1223 films on single-crystalline lanthanum aluminate as substrate [3–6]. Current investigation showed that *c*-axis oriented Tl-1223 films may also be prepared on silver [7, 8] by a two-step preparation technique. This method is based on the application of Tl-free precursor material onto the substrate by screen-printing followed by a high-temperature thallination process. Thus vacuum techniques are avoided in the fabrication of the superconducting film facilitating the preparation of superconducting thallium films. In this paper we have focused our attention on the magnetical broadening of the transition to the superconducting state as well as on the irreversibility fields of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film prepared on highly polished silver measured by ac resistance technique.

2. Experimental

The preparation procedure and the characterization of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ films on mechanically polished, untextured silver substrates has been published [7]. The silver substrates were first polished with a suspension of 1 μm Al_2O_3 powder, then with a suspension of 0.3 μm Al_2O_3 powder, followed by a 0.03 μm SiO_2 suspension. A suspension of the Tl-free precursor powder of appropriate amount of PbO, $Ba(CH_3COO)_2$, $SrCO_3$, $CaCO_3$, and $Cu(CH_3COO)_2 \cdot H_2O$ was made via the malic acid gel method and dissolved in terpineol. The paste was applied via screen-printing onto the silver substrate. The coated silver was wrapped in silver foil together with a thallium source. The source consisted of a compacted mixture of Tl-free precursor material with the respective amount of Tl_2O_3. The samples were heated with 5 K min^{-1} to 860°C. The heating rate from 860°C to the sintering temperature of 900°C was 1 K min^{-1}. All heat treatment steps were carried out under flowing oxygen for 4 hours. The cooling rate was 5 K min^{-1}. The film was analyzed by energy dispersive X-ray fluorescence spectroscopy (EDX) to learn about the overall composition of the superconducting material. The results point to a nominal overall composition of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ within the error limits of the analytical method. The $\langle 113 \rangle$ direction of Ag is almost parallel to the [001] direction of Tl-1223. One may say that the Tl-1223 grains grow epitaxially on the Ag matrix. The thickness of the superconducting film, determined by optical microscopy, was 1.8 μm, the width 0.7 mm and the length 2 mm. X-ray diffraction (XRD) studies with Ni-filtered Cu K_α radiation including pole-figure measurements were performed on an X'Pert instrument (Panalytical, Netherlands). Measurements of the resistance versus temperature were carried out using the four-point ac method. Electrical contacts were made by silver paint. The temperature from 77 K to 300 K was monitored by a Lake Shore temperature controller employing a chromel–gold + 0.07% iron thermocouple with an accuracy of ±0.05 K. A Stanford SR 830 lock-in nanovoltmeter served both as a source for ac currents with a frequency of 7.432 Hz and amplitudes up to 85 mA and as a voltage meter. The dc magnetic field, for which an electric field on the sample of 1 μV/cm was measured, was considered to be the irreversibility field at a given temperature.

The measurements of ac resistance versus temperature and magnetic field exhibit a certain non-zero level of voltage which could not be reduced by the phase shift adjustment of the measuring bridge lock-in circuit. That is because of large dispersion in silver substrate. This effect is also responsible for the observation of non-zero level resistance below T_c.

3. Results and discussion

The measurements of the X-ray diffraction on the superconducting film showed good c-axis orientation (Fig. 1). No secondary phases were detected in the XRD spectra. Pole-figure measurements showed that the in-plane alignment was poor [7].

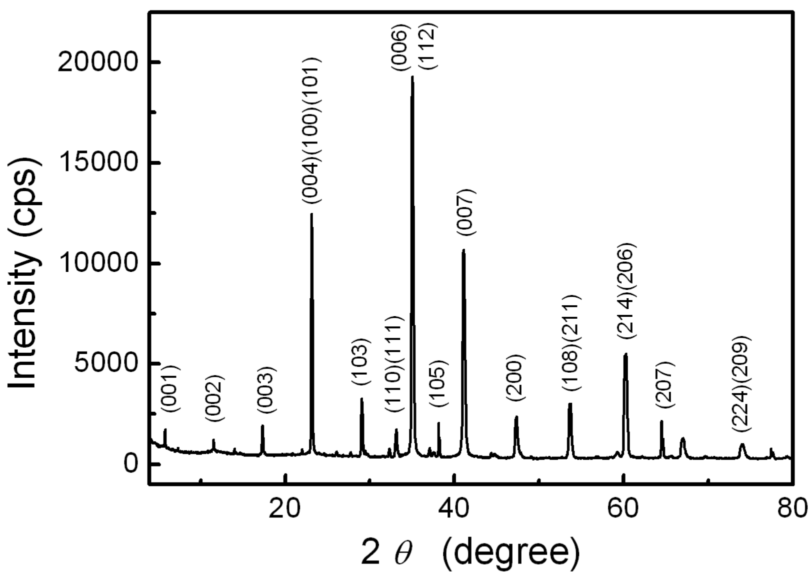

Fig. 1. X-ray diffraction of a $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film on polished silver. Ni-filtered Cu K_α radiation. No secondary phases were detected in the XRD spectra.

The resistance versus temperature for different values of applied ac current is shown in Fig. 2. From these measurements we obtained the critical temperature at 50% resistance ($T_{c,50\%}$). A significant resistive broadening of the transition width occurred with the applied current and T_c is shifted to lower temperatures

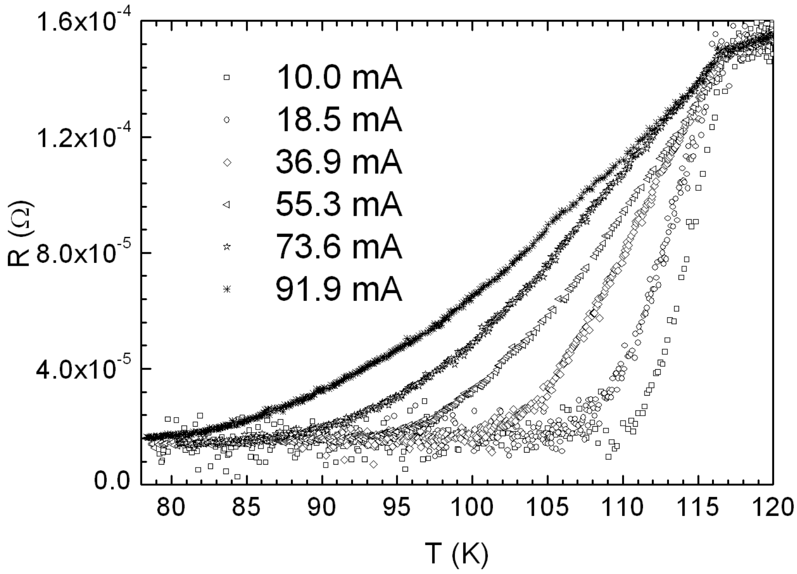

Fig. 2. The resistance versus temperature for different values of applied ac current (selected curves).

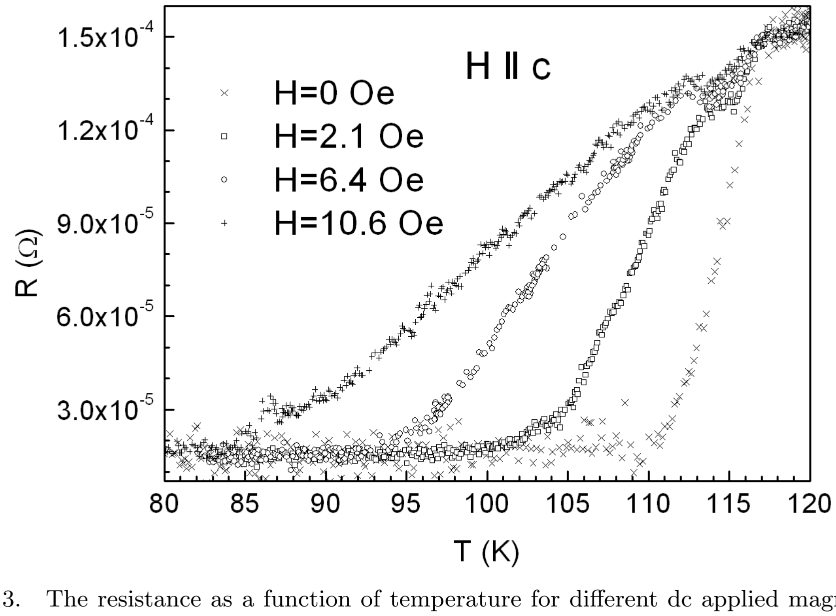

Fig. 3. The resistance as a function of temperature for different dc applied magnetic fields of direction $H \parallel c$ (selected curves).

with increasing current. Therefore, we plotted the critical temperature versus critical current density and after extrapolation to zero critical current density we obtained the critical temperature value of $114.7 \div 0.3$ K. The density of the

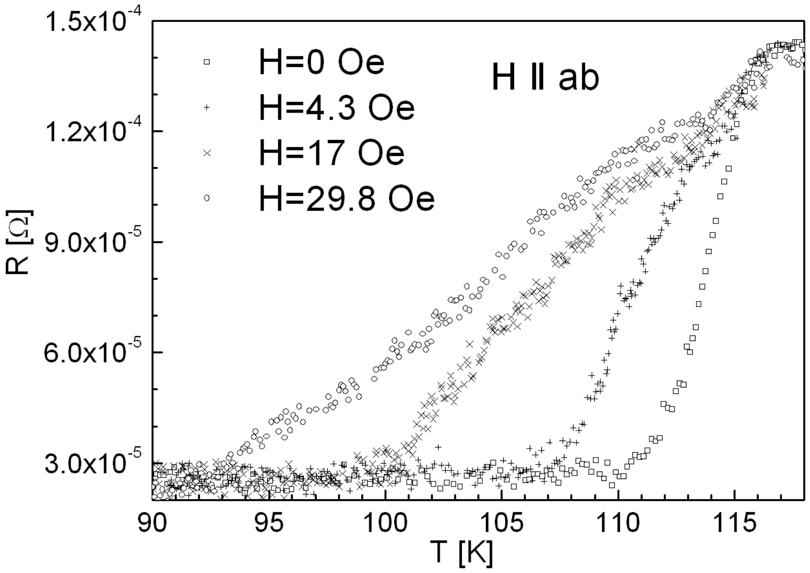

Fig. 4. The resistance as a function of temperature for different dc applied magnetic fields of direction $H \parallel ab$ (selected curves).

critical current measured by transport method using 10^{-6} V criterion was found to be 11.4×10^3 A/cm^2 at 77 K in the self field. This value is smaller than the value calculated from ac susceptibility data: 53×10^3 A/cm^2 at 77 K [9].

The measurements of the resistance as a function of the temperature for different dc magnetic fields for two orientations: $H \parallel c$ and $H \parallel ab$ are shown in Fig. 3 and Fig. 4. One can notice pronounced broadening of the resistive transition under the influence of applied magnetic field as well as its distinct anisotropy. We assumed that the temperature at which the whole sample stayed superconducting (resistance equal to zero), separates the reversibility from the irreversibility region. These temperatures, which are commensurate with dc applied magnetic field, were extracted from the magnetoresistance measurements and are shown in Fig. 5. One can observe and it is in good agreement with other published data [6, 10] that the applied magnetic field can move the vortices from the pinning center much easily for $H \parallel c$ than for $H \parallel ab$. The irreversibility fields as a function of temperature were fitted using the following power function [11]:

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

where T_{c0} is the zero resistance temperature at zero applied magnetic field (it was taken from experiment), H_{irr0} is irreversibility field at zero temperature (it is a fitting parameter), and n is a fitting parameter as well. Equation (1) fits experimental data very well. It means that the irreversibility line separates the vortex glass from the liquid vortex state. The experimental and calculated values are col-

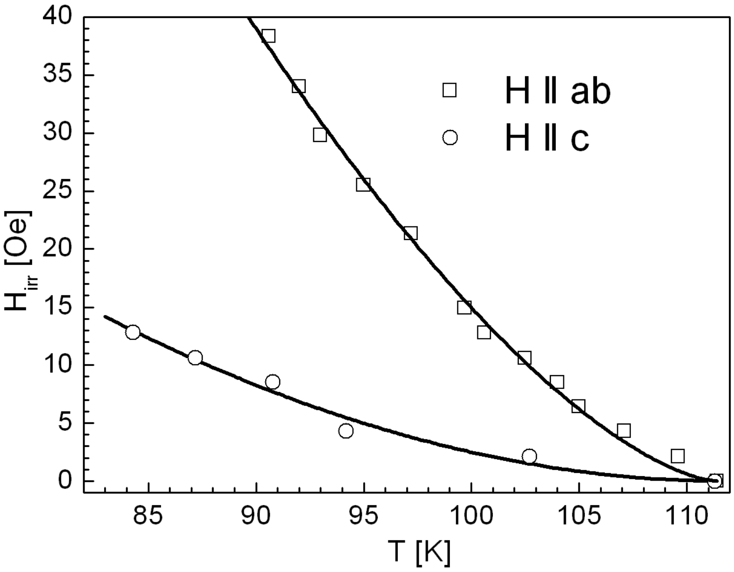

Fig. 5. The irreversibility fields versus temperature for two directions of applied magnetic field: $H \parallel c$ and $H \parallel ab$. The solid lines are the fittings to Eq. (1).

TABLE

Fitting parameters for the temperature dependence of the irreversibility fields according to Eq. (1).

	H_{irr0} [Oe]	T_{c0} [K]	n	H_{irr}(77 K) [Oe]
$H \parallel c$	189±24	111.3±0.3	1.9±0.3	20
$H \parallel ab$	480±42	111.4±0.3	1.52±0.05	80

lected in Table. According to our previous thallium based film investigations [6] we found that for $H \parallel c$ the exponent is $n < 3/2$ and for $H \parallel ab$ the exponent is $n > 3/2$. For the present $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film we got an inverse result (see Table).

4. Conclusion

The conclusions of the paper are twofold:

1. The applied magnetic field widens the resistivity transition showing the anisotropy according to field direction: $H \parallel c$ and $H \parallel ab$. The influence of the applied magnetic field takes place in relatively low fields values.
2. The irreversibility fields were obtained from magnetoresistivity measurements. Their temperature dependences are well described by Eq. (1) with anisotropic parameters n.

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