ELSEVIER

Journal of Alloys and Compounds 442 (2007) 209–212

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

Critical currents of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ films on untextured silver substrates

W.M. Woch[a,*], R. Zalecki[a], A. Kołodziejczyk[a], C. Deinhofer[b], G. Gritzner[b]

[a] Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Al. Mickiewicza 30, PL 30-059 Kraków, Poland
[b] Institute for Chemical Technology of Inorganic Materials, Johannes Kepler University, A 4040 Linz, Austria

Received 20 June 2006; received in revised form 7 August 2006; accepted 30 October 2006

Abstract

Superconducting $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ films were prepared on highly polished, untextured silver substrates. A superconducting transition temperature (T_c) of 114.9 ± 0.1 K was obtained from the resistivity *versus* temperature measurements for different applied ac currents. The temperature dependence of the critical current was fitted with a power law: $J_c(T) = J_c(0)[1 - T/T_c]^n$ with $n = 2$. The critical current in self-field at 77 K was found to be 8×10^3 A/cm^2. The temperature dependence of the real and imaginary parts of ac susceptibility was measured for different amplitudes of ac magnetic field. Only a small differences of the ac susceptibility for parallel and perpendicular fields with respect to the film surface were observed.

PACS: 74.25.Sv; 74.78.Bz

Keywords: High T_c superconductors; Flux pinning and creep; Tl-1223 film

1. Introduction

Current research on practical applications of cuprate superconductors focuses on the fabrication of coated conductors. The vast majority of papers deals with the preparation of yttrium–barium–cuprate (YBCO) layers on metal substrates such as textured nickel and nickel alloys covered with suitable buffer layers. Studies on lead doped thallium superconductors (Tl-1223), however, 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 [1–4]. Recent investigation showed that *c*-axis oriented Tl-1223 films may also be prepared on silver [5,6] 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 critical currents of $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ films prepared on highly polished silver by ac resistance and susceptibility techniques.

2. Experimental

2.1. Preparation of the superconducting film

A detailed description of the preparation 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 [5]. 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 h. Cooling rate was 5 K min^{-1}. The film was analyzed by energy dispersive X-ray fluorescence spectroscopy (EDS) 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 thickness of the superconducting film, determined by optical microscopy, was 1.8 μm, the width 0.7 mm and the length 2 mm.

---

[*] Corresponding author. Tel.: +48 12 617 2589; fax: +48 12 634 1247.
E-mail address: wmwoch@agh.edu.pl (W.M. Woch).

0925-8388/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2006.10.172

2.2. Apparatus and experimental procedure

X-ray diffraction (XRD) studies with Ni-filtered Cu Kα radiation including pole-figure measurements were performed on an X'Pert instrument (Panalytical, The 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 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 189 Hz and amplitudes up to 85 mA and as a voltage meter. The applied current for which a voltage drop of 0.1 μV was measured was considered to be the critical current at a given temperature.

The real and imaginary ac susceptibility as a function of ac magnetic field was measured for $H_{ac} \parallel a$–b and $H_{ac} \parallel c$ by the standard mutual bridge operating at the frequency of 189 Hz.

The measurements of ac resistance and ac susceptibility *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 responsible for the observation of non-zero level resistance below T_c as well as small negative value of imaginary part of susceptibility.

3. Results and discussion

X-ray diffraction of the superconducting film showed some *c*-axis orientation. No secondary phases were detected in the XRD spectra. Pole-figure measurements showed that the in-plane alignment was poor [5].

Resistance as a function of temperature for different values of applied ac current is shown in Fig. 1. From these measurements we obtained the critical temperature at 50% resistance (T_c). A significant resistive broadening of the transition width occurred with the applied current and T_c is shifted to lower temperatures 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 114.9 ± 0.1 K.

A close inspection of the resistive transitions revealed a kink around 111 K in all of the measured resistance *versus* temperature curves (see arrow in Fig. 1). We attribute this phenomenon to a slightly different phase composition in the grain boundaries because the inter-grain superconducting weak links are responsible for the temperature dependence of the resistance.

The critical current density as a function of temperature in which zero resistance level is reached is shown in Fig. 2. We

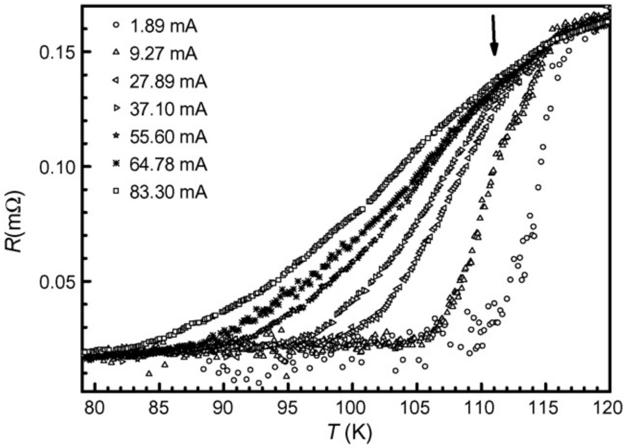

Fig. 1. Resistance of a $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film on silver as a function of temperature for different values of transport currents (selected curves). The arrow shows the kink on the resistive transitions at about 111 K (see text).

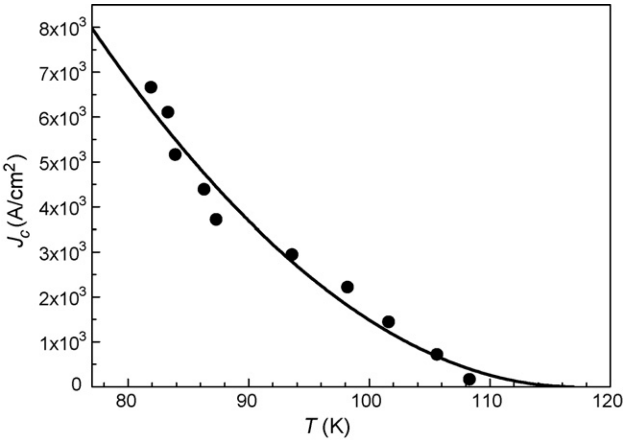

Fig. 2. Critical current density as a function of temperature in self-field (closed circles) of a $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film on silver. The solid line is the theoretical fit of Eq. (1).

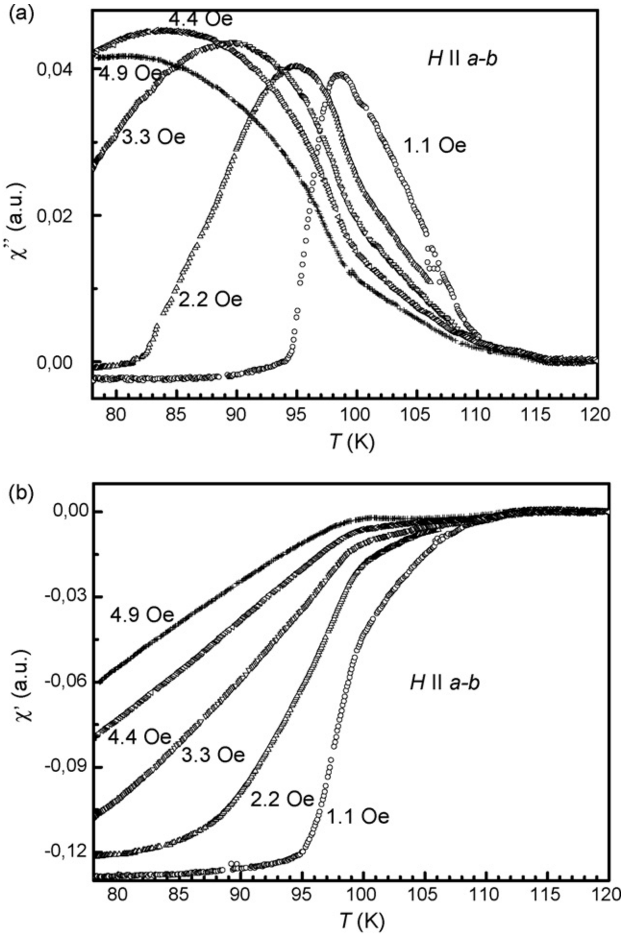

Fig. 3. Imaginary (a) and real (b) ac susceptibility as a function of temperature for different ac magnetic field for $H \parallel a$–b of a $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film on silver.

assumed that the dependence is due to thermally activated flux flow [7,8], the same as in our previous paper [4] and may be described by the following equation:

$$J_c(T) = J_c(0)\left[1 - \frac{T}{T_c}\right]^n, \tag{1}$$

where $J_c(0)$ is the critical current density at 0 K, T_c is the critical temperature and n is a fitting parameter which may vary between 1.5 and 2.0 for high-temperature superconductors [4]. Fitting Eq. (1) to the experimental data (see solid line in Fig. 2) yielded a critical current density at 0 K ($J_c(0)$) of $7 \pm 2 \times 10^4$ A/cm^2 and an n value of 2.0 ± 0.2. The high error of critical current at 0 K comes from the numerical fitting. The critical current density in self-field at 77 K, calculated from Eq. (1) using the parameters given above, was found to be $8 \pm 0.6 \times 10^3$ A/cm^2.

The real (χ') and imaginary (χ'') parts of ac susceptibility were measured as a function of the ac applied magnetic field both parallel to the c-axis and to the a–b plane (Figs. 3 and 4). We noticed that the superconducting film shows small differences of the susceptibility plots. It means that the demagnetizing field is not very effective here and the differences of ac susceptibilities for $H \parallel a$–b and $H \parallel c$ are not very significant. One can conclude that superconducting weak links of Tl-1223 films on untextured silver are weaker than for our a–b aligned samples of the same type superconductor prepared on single-crystalline lanthanum aluminate [1,2,4].

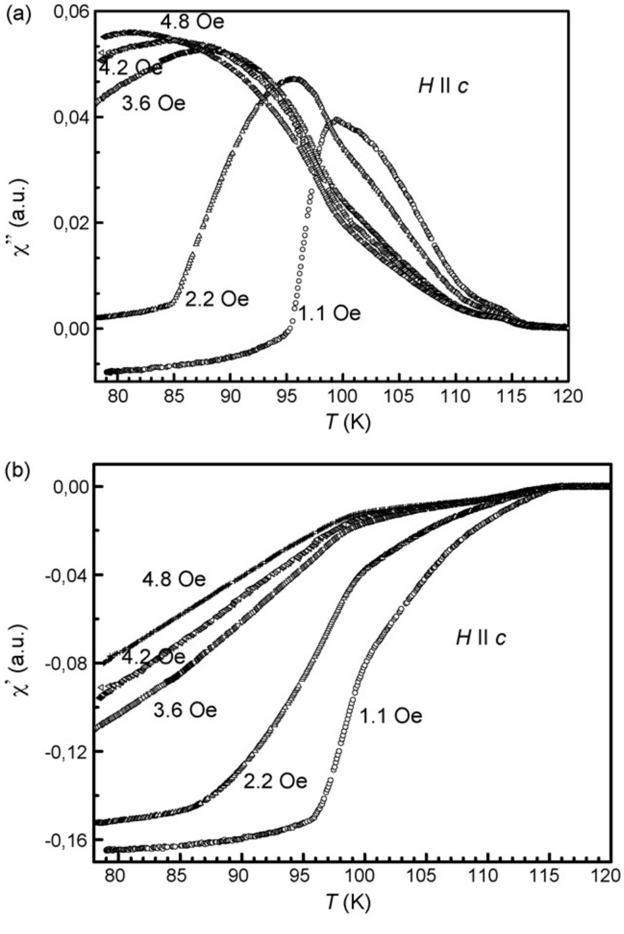

Fig. 4. Imaginary (a) and real (b) ac susceptibility as a function of temperature for different ac magnetic fields for $H \parallel c$ of a $(Tl_{0.5}Pb_{0.5})(Sr_{0.85}Ba_{0.15})_2Ca_2Cu_3O_z$ film on silver.

The critical current density may also be derived from the position of the peak of the imaginary part of susceptibility χ'' at different ac magnetic fields employing the Bean critical state model and its extensions [9]. At the peak at given temperature the ac field H_{ac} penetrates into the sample and the critical current induced by the magnetic fields is equal to the critical current density. The Bean model yields the following equation [10]:

$$J_c = \frac{2H_{ac}}{d}, \tag{2}$$

where d is the sample dimension perpendicular to the ac magnetic field. Using Eq. (2) we calculated the critical current density for different temperatures and obtained a critical current density of 5.3×10^4 A/cm^2 at 77 K. This value is almost one order of magnitude higher than the value obtained from transport measurement. Such a difference between critical current densities derived from the magnetic and from transport measurements, however, is not unusual and has been observed for a number of superconductors.

4. Summary and conclusions

The temperature dependence of the resistance for different applied ac currents as well as the ac susceptibility as a function of temperature for different ac magnetic fields were measured and analyzed. The temperature dependence of the inter-grain critical current density was determined from those data. The dependence obeyed a power law yielding a critical current density of 8×10^3 A/cm^2 at 77 K in the self-field. This value is about an order of magnitude smaller than the value calculated from ac susceptibility data. The temperature and the magnetic field dependences of ac susceptibility did not exhibit any significant differences in fields parallel and perpendicular to the surface of the film. It was concluded that superconducting weak links of Tl-1223 films on untextured silver are weaker than of the same superconductor prepared on single-crystalline lanthanum aluminate studied in our previous paper [4].

Acknowledgements

This work was financially supported by the Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, through the statutory funds and from the Ministry of Science and Higher Education, Poland and by the Fonds zur Förderung der wissenschaftlichen Forschung in Österreich (Austrian Science Foundation, project 17 420-N07).

References

[1] O. Heiml, G. Gritzner, Supercond. Sci. Technol. 15 (2002) 956.
[2] O. Heiml, G. Gritzner, S. Tönies, H.W. Weber, J. Kečkéš, B. Ortner, Supercond. Sci. Technol. 15 (2002) 1592.

[3] K. Przybylski, O. Heiml, G. Gritzner, Physica C 423 (2005) 63.
[4] W.M. Woch, R. Zalecki, A. Kołodziejczyk, O. Heiml, G. Gritzner, Physica C 434 (2006) 17.
[5] C. Deinhofer, G. Gritzner, Supercond. Sci. Technol. 17 (2004) 1196.
[6] B.J. Kim, Y. Matsui, S. Horiuchi, D.Y. Jeong, C. Deinhofer, G. Gritzner, App. Phys. Lett. 85 (2004) 4627.
[7] Y. Yeshurun, A.P. Malozemoff, Phys. Rev. Lett. 60 (1988) 2202.
[8] M. Tinkham, Phys. Rev. Lett. 61 (1988) 1658.
[9] C.P. Bean, Phys. Rev. Lett. 8 (1962) 250.
[10] J.R. Clem, Physica C 153–155 (1988) 50.