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Temperature and Magnetic Field Dependences of Critical Current of Thallium-Based Superconducting Films

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The critical current densities of three superconducting thallium-based films, prepared by screen printing, were measured as a function of temperature and applied magnetic field. The degradation of critical current densities was investigated for two different magnetic field orientations with respect to the sample plane — parallel and perpendicular.

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1. Introduction

$TlSr_2Ca_2Cu_3O_x$ (Tl-1223) superconductors with their critical temperatures between 110 and 120 K and good flux pinning properties have a wide application potential. Thick films of superconducting cuprates are generally fabricated by *ex situ* techniques. They have considerably lower critical current densities than thin films prepared for example by laser ablation, molecular beam epitaxy, and magnetron sputtering techniques. This results from their polycrystalline structure, poor alignment of the superconducting crystallites and porosity. Screen printing is one of the well established and not complicated methods of fabrication of the highly textured Tl-1223 thick films. Within last years considerable progress in improving electrical transport properties in such films was made. High-purity, well aligned Tl-1223 based superconducting films with critical current densities close to 10^6 A cm^{-2} were already produced [1, 2]. Superconducting films are very convenient for application of the electric transport methods in the critical current investigations due to their small cross-section — they do not need large currents

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for such measurements. This considerably reduces problems with making good electrical contacts to the superconducting film.

Magnetic field effect on resistive transition as well as resistance and irreversibility fields of thallium films were already analysed and published [3, 4]. In this paper we compare results of ac transport measurements in magnetic fields up to 1850 Oe for three Tl-based screen printed films deposited on the single crystal $LaAlO_3$ (100) or on the polycrystalline Y_2O_3 (3 mol%) doped ZrO_2 substrates.

2. Experimental

The following superconducting films were prepared by screen printing methods:

$Tl_{0.5}Pb_{0.5}Sr_{1.6}Ba_{0.4}Ca_2Cu_3O_7/LaAlO_3$ (sample 1 — S1),
$Tl_{0.6}Pb_{0.24}Bi_{0.16}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_7/LaAlO_3$ (sample 2 — S2),
$Tl_{0.6}Pb_{0.24}Bi_{0.16}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_7(b)/ZrO_2$ (sample 3 — S3).

Samples 1 and 2 were prepared by screen printing thallium-free precursor material on monocrystalline (100) lanthanum aluminate substrates followed by *ex situ* thallination. The preparing procedures are described in earlier papers [1, 2, 5, 6]. The resulting films were quasi-monocrystalline with high *ab* alignment and *c*-axis orientation and of high purity. Sample 3 was prepared by screen printing superconducting powder on polycrystalline Y_2O_3-doped ZrO_2 substrate [7, 8]. It had granular structure of good texturing degree obtained by compaction of the layer before the final sintering step.

The thickness (below 1 μm) and the width of the films were analysed by a profilometer (Perthometer C5D Mahr, Germany) [4].

The resistance versus temperature measurements were carried out using the four-probe ac method (Fig. 1). The electrical contacts were made of silver paint burned onto Tl-1223 film. The samples were placed in the centre of copper coils, which produced the dc magnetic field. For critical current measurements, the source of ac current was used. It produced the currents with the frequency of

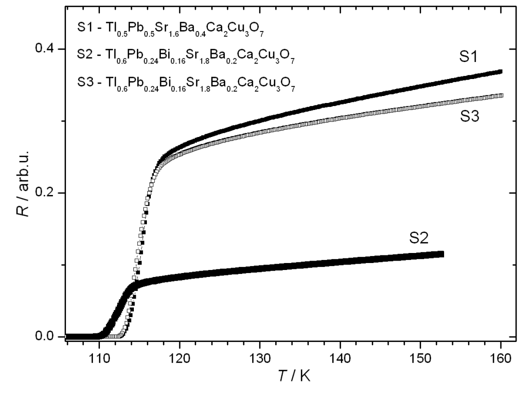

Fig. 1. Resistance versus temperature of the Tl-based films for $H_{\mathrm{dc}} = 0$.

7.23 Hz and amplitudes up to 130 mA. The source was connected to a Stanford Lock-in nanovoltmeter SR 830, which measured the voltage drop. An intersection of linear interpolation of voltage vs. current dependence with zero voltage level is our criterion of critical current (see the example — Fig. 2a and b). To obtain the current densities as high as possible, the films were scratched to the "H" shape and were about 0.35 mm wide between the voltage contacts.

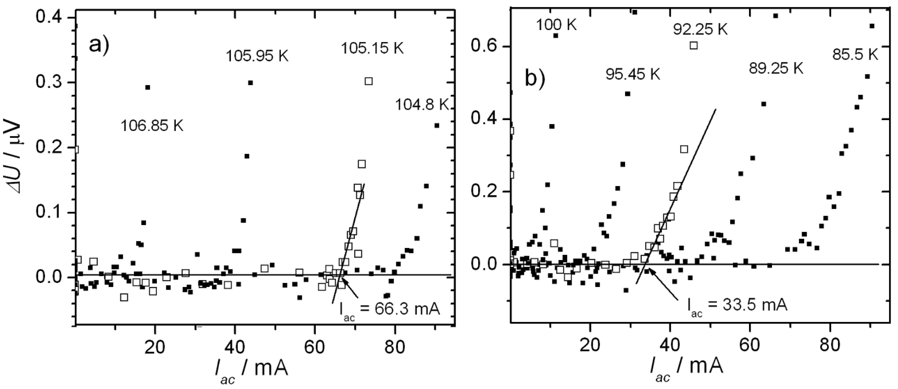

Fig. 2. The examples for criterion to determine the critical currents for $H_{\mathrm{dc}} = 0$ (a) and $H_{\mathrm{dc}} = 1850$ Oe (b) for $\mathrm{Tl_{0.6}Pb_{0.24}Bi_{0.16}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_7}$ (S2) film.

The measurements were carried out with the following procedure: at the given temperature and constant magnetic field the voltage was measured with increasing the ac current up to maximal value (Fig. 2). The critical current was determined with the criterion described above. Then the temperature was increased and the measurement was repeated in the same magnetic field and a new temperature. After the T_{C} was exceeded, the sample was cooled down and the series of measurements in a new magnetic field were carried out. It is well known that the transport measurements yield in fact the intergrain Josephson critical current density J_{cj}.

3. Results and discussion

Figures 3, 4 and 5 show the results of critical current measurements for S1, S2, and S3 samples, respectively. The H_{dc} orientation was perpendicular (a) or parallel (b) to the *ab* plane. In each case, the significant anisotropy can be observed. The J_{cj} degradation caused by magnetic field is large for the fields oriented perpendicular to the sample plane, while for parallel orientation this effect is much smaller. This difference can be observed particularly close to T_{c} (see Fig. 6) but also is large at liquid nitrogen temperature. To obtain the critical current density at 78 K, the linear extrapolation of the low temperature points in Figs. 3, 4 and 5 was used. The results are described in Fig. 7. The critical current densities are above 10^5 A cm^{-2} for the films deposited on the single crystal of $\mathrm{LaAlO_3}$ in the dc field equal to 0. Their values are over one order of magnitude higher

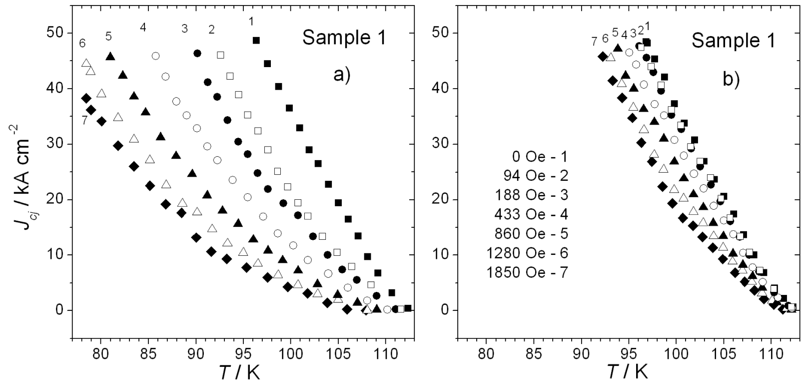

Fig. 3. Temperature dependences of critical current densities of a screen-printed $Tl_{0.5}Pb_{0.5}Sr_{1.6}Ba_{0.4}Ca_2Cu_3O_7$ (S1) film for the perpendicular (a) and parallel (b) orientation of external magnetic field for several H_{dc} values.

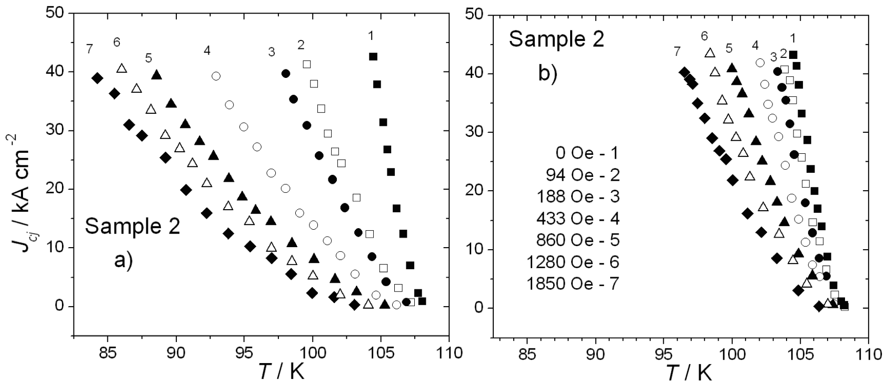

Fig. 4. As in Fig. 3, but for $Tl_{0.6}Pb_{0.24}Bi_{0.16}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_7$ (S2) film.

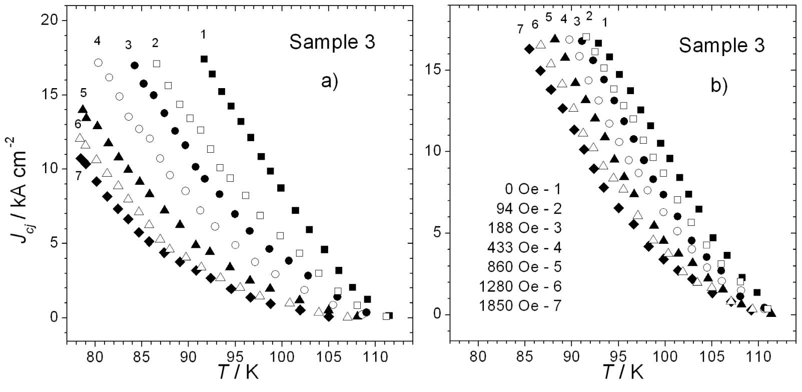

Fig. 5. As in Fig. 3, but for $Tl_{0.6}Pb_{0.24}Bi_{0.16}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_7$ (S3) film.

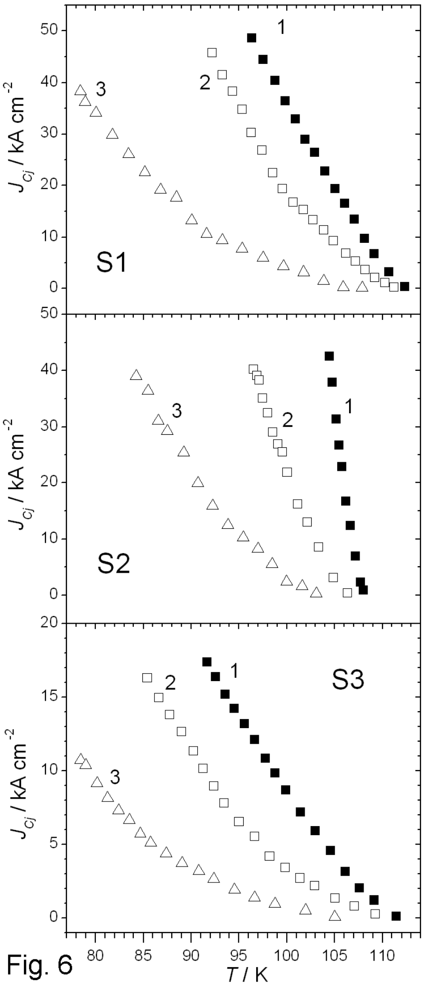

Fig. 6

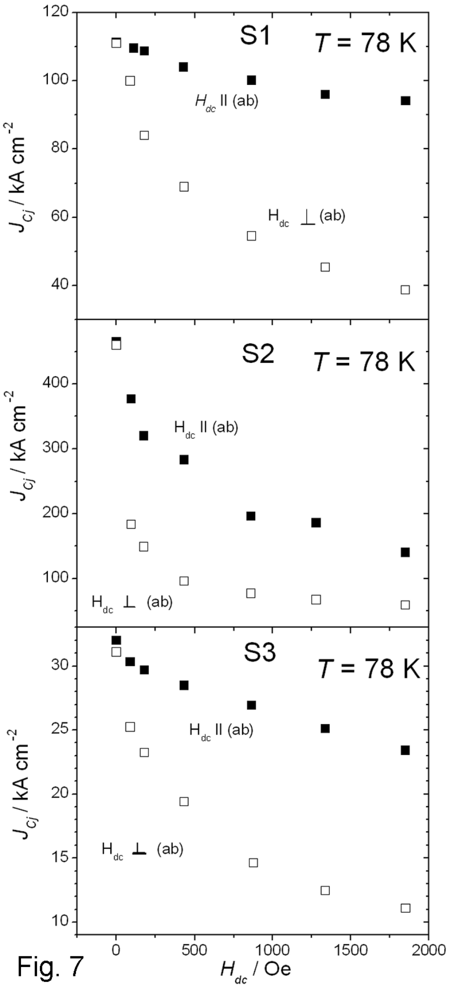

Fig. 7

Fig. 6. Critical current density $J_{cj}(T)$ of the films S1, S2, and S3 in magnetic field $H_{\rm dc} = 0$ Oe and $H_{\rm dc} = 1850$ Oe to show its anisotropy. (1) $H_{\rm dc} = 0$ Oe, (2) $H_{\rm dc} = 1850$ Oe, $H_{\rm dc} \parallel (ab)$, (3) $H_{\rm dc} = 1850$ Oe, $H_{\rm dc} \perp (ab)$.

Fig. 7. Critical current densities at 78 K as a function of the magnetic field of screen-printed thallium-based superconducting films.

in comparison to the critical current density of the film with granular structure (sample 3). This is due to their monocrystalline structure which results in excellent *ab* alignment, small porosity, and lack of intergrain junctions. The possible reason of anisotropy is that the pinning is better when the whole vortice lines lie in the superconducting *ab* planes than in the case when they cross them perpendicularly.

4. Conclusions

Our measurements confirm that the superconducting films have the highest critical current densities among the superconductors prepared by many methods except single crystals. This fact as well as the small degradation of J_{cj} in magnetic field parallel to the ab plane makes good hope for the future applications.

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