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Magnetic susceptibility and critical currents of $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$ superconductor

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The $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$ superconductor has been fabricated by the wet chemical gel technique. The structure of the superconductor was determined as a Tl-1212 tetragonal structure by X-ray diffraction technique. Magnetic properties of the specimen were characterized by measurements of the real and imaginary parts of ac susceptibility in function of the temperature and of the ac applied magnetic field. The peaks of imaginary part of ac susceptibility shifted to lower temperatures upon increasing magnetic field. Taking advantage of the Bean model, the critical current densities of the samples were calculated. The temperature dependences of the critical current were successfully fitted using the power-law from thermally activated magnetic flux creep model.

Key words: *Tl Gd doped 1212 superconductor; magnetic measurements; critical current*

1. Introduction

Thallium based superconductors, especially in the form of thin films, are good candidates for power as well as microwave applications. Thallium (Tl-2212) thin films were already used in the fabrication of microwave filters for wireless telecommunication. Tl-1223 films on $LaAlO_3$ substrate have good pinning properties and are suitable for high current applications [1] and for preparation of coated conductors. The Tl-1212 phase has the structure similar to that of YBCO 123 superconductor. Substitution of rare earth cations into Ca^{2+} sites and partial replacement of Tl^{3+} with Pb^{4+} [2] considerably facilitates the synthesis of Tl-1212. The preparative conditions for doped Tl-1212 phases are less stringent than for other cuprate superconductors and optimum

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oxygen stoichiometry is achieved rather easily. Compared to the Tl-1223 phase, the Tl-1212 phase exhibits a wider processing window and extended phase stability. This makes the material an interesting superconducting compound for both bulk phase application and for superconducting films [3] justifying further research on this class of superconductors.

In this paper, real and imaginary parts of ac susceptibility have been measured in function of both the temperature and amplitude of ac magnetic field, and critical current densities have been determined based on Bean's model.

2. Experimental

Sample preparation. Respective amounts of nitrates of Sr, Ca and Cu were dissolved in water. The solution was evaporated to dryness and post-dried at 130 °C under the pressure of 1 mbar. Calcination was carried out in a chamber furnace at 900°C in air for 50 h. Appropriate amounts of PbO, Tl_2O_3 and Gd_2O_3 were added in a milling step in a Retsch micro-mill with a zirconium pestle and mortar for 30 min. The resulting powders were uniaxially compacted with the pressure of 1 GPa into cylinders of 10 mm in diameter and about 1 mm thick. The discs were wrapped in silver foil. After detailed studies on the heat treatment procedure, the following sintering technique was applied. The samples were heated to 1168 K at the rate of 3 K/min and kept at this temperature for 10 h. The cooling rate was 3 K/min [4, 5]. The overall composition of the bulk superconducting material was determined by atomic absorption spectroscopy after dissolving the samples in 30% nitric acid and dilution with water [5].

Apparatus and experimental procedure. X-ray diffraction (XRD) studies with Ni-filtered CuK_α were carried on an X'Pert instrument (PANalytical, Netherlands) [4, 5]. The real and imaginary ac susceptibilities in function of ac magnetic field were measured by the standard mutual inductance bridge operating at the frequency of 189 Hz. A Stanford SR 830 lock-in nanovoltmeter served both as a source of ac current for the coil producing ac magnetic field and as a voltage meter of the bridge. The temperature from 77 K to 300 K was monitored by a Lake Shore temperature controller employing a chromel–gold–0.07 % Fe thermocouple with the accuracy of ±0.05 K.

3. Results and discussion

X-ray diffraction spectra showed that the sample was practically phase pure [4, 5]. The XRD data were analyzed based on a tetragonal unit cell with the lattice parameters $a = b = 3.809$ Å and $c = 12.117$ Å. The real and imaginary parts of the ac susceptibility of the sample $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$ are shown in Figs. 1a, b .

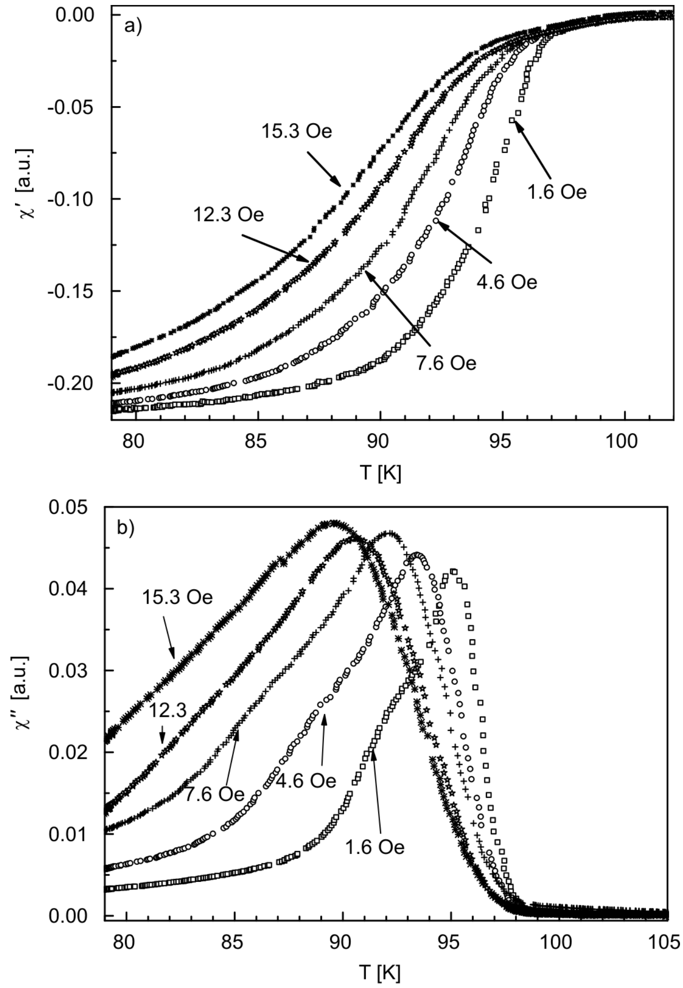

Fig. 1. The real (a) and the imaginary (b) parts of ac susceptibility in function of temperature for various amplitudes of ac magnetic fields for $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$

From the measurements of the real part (χ') of ac susceptibility we have estimated the critical temperatures for the lowest ac magnetic field of both inter- and intra-grain regions as shown on Fig. 2, which were used later in Eq. (1) as starting parameters.

The critical temperatures of the specimen are: T_{c0}^{inter} = 97.1 K, T_{c0}^{intra} =101.1 K. The ac applied magnetic field broadens significantly the transitions to the superconducting state. This means that the inter-granular junctions are not very strong for the sample. Looking at the imaginary part of ac susceptibility (Fig. 1b), one can notice that the absorption peaks are moved to lower temperatures upon increasing ac applied magnetic field. From the measurements, we can calculate the critical current density which can be derived from the position of the absorption peaks employing Bean's critical state model and its extensions [6].

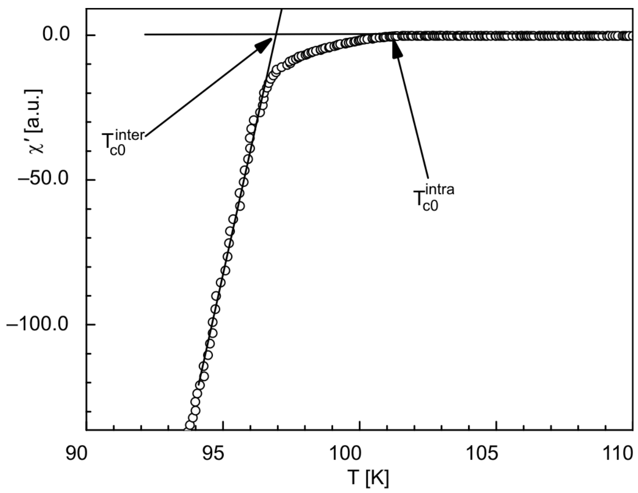

Fig. 2. The real part of ac susceptibility versus temperature with the critical temperatures of inter-grain and intra-grain regions as indicated

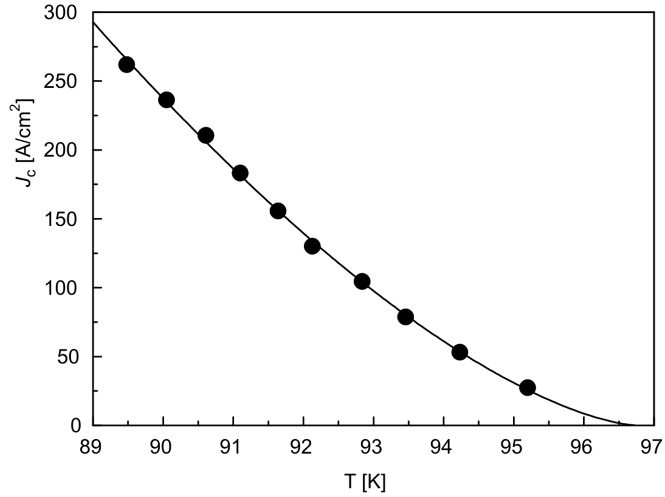

Fig. 3. Density of the critical current in function of temperature for $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$ (full circles). The solid line is the fit to Eq. (2)

At the peak at a given temperature, the ac field amplitude B_{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 [7]:

$$J_c = \frac{2\,B_{ac}}{d} \tag{1}$$

where d is the sample dimension perpendicular to the ac magnetic field. Using Eq. (1), we calculated the critical current density for various temperatures. The critical current densities in function of temperature are shown in Fig. 3.

We assumed that the absorption in superconductors is due to thermally activated flux flow [1, 9, 10] which may be described by the following equation:

$$J_c(T) = J_c(0)\left[1 - \frac{T}{T_{c0}}\right]^n \tag{2}$$

where $J_c(0)$ is the critical current density at 0 K, n is the fitting parameter which may vary between 1.3 and 2.0 for high temperature superconductors [10]. T_{c0} is the zero-field critical temperature related to inter-granular region of the sample. It has been taken as a starting parameter from real part (χ') of ac susceptibility as shown in Fig. 2. The fitting of Eq. (2) to the data obtained from experiments is shown in Fig. 3 as the solid line with T_{c0} = 96.8±0.3 K being very close to the experimental value T_{c0}^{inter} = 97.1 K. The fitting parameters were: n=1.51±0.1 and $J_c(0)$=(13.4±3)×10^3 A/cm^2. Taking advantage of the fitting parameters, we calculated the critical current density at 77 K: $J_c(77)$ = 1.22×10^3 A/cm^2. These J_c values are comparable to the critical current densities determined by dc transport measurements in [5]. The fitting exponent n of Eq. (2) is very close to 3/2 which was originally introduced in the superconductive glass state and the giant flux creep model [8, 11].

4. Conclusions

The $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.9}Gd_{0.1})Cu_2O_y$ superconductor has comparable superconducting properties to yttrium based YBCO-123 superconductor. Its inter- and intra-granular critical temperatures are 97.1 K and 101.1 K, respectively. The critical current density at 77 K is 1.22×10^3 A/cm^2. Equation (2) fits very well the temperature dependence of critical current with the exponent n equal to 3/2 proving the giant flux creep model.

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