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AC susceptibility of the $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.95}Ag_{0.5})_4O_{10+\delta}$ superconductor

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ABSTRACT

In this work, the temperature, magnetic field and frequency dependence of the ac susceptibility of $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.95}Ag_{0.5})_4O_{10+\delta}$ were studied. The superconductivity still survives even at this amount of Ag. The magnetic field dependence of the irreversibility line (IL) and the flux pinning of this compound are discussed and compared with those of low Ag content. The IL exhibits thermally activated behaviour. A collective creep of the vortex bundle also occurs for this level of doping. A crossover from a two- to a three-dimensional system is suggested at $T/T_c = 0.75$ and a magnetic field, $H_{dc} = 0.04$ T. Based on vortex glass phase transition theory, the effective pinning energy, u_{eff}, was calculated. The change in the characteristic temperature of the studied compound and that of low Ag content samples are summarised. Comparisons with similar materials are discussed.

1. Introduction

The study of the ac susceptibility of high-T_c superconductors (HTSCs) provides us information about their characteristic properties, such as the superconducting transition temperature, T_c, the inter-grain and intra-grain effects. By changing the applied dc magnetic field, H_{dc}, frequency, and temperature, one obtains useful information for understanding the mechanisms of HTSCs. In addition, the frequency dependence of the ac susceptibility is a suitable technique to throw light on vortex dynamics, and to give information about vortex mobility, flux diffusion, and relaxation mechanism using dynamic critical exponents [1–4].

Similar to our previous report on $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{1-x}Ag_x)_4O_{10+\delta}$, $0.10 \le x \le 0.30$ [5], a trail has been done to study the irreversibility line, IL when $x =$ 0.50 by the evaluation of the peak values of the imaginary parts of the ac susceptibility (χ''_{ac}). It was found that T_c of the compounds with x=0.1, 0.2 and 0.3 are 121.7 K, 126.7 K and 126.8 K, respectively. While T_c decreased with an increasing applied field, H_{dc}, two peaks were observed for field below 1.0 T. This behaviour was explained based on different pinning mechanisms. Moreover, the irreversibility temperature, T_{irr} and irreversible magnetic field (H_{irr}) which depend on x, show a crossover from two- to three-dimensional (2D–3D) as the temperature varies. Matsushita's formula, is well verified for the compounds of $0.10 \le x \le 0.30$, indicating thermally activated flux creep behaviour.

In this article, we attempted to extend our previous work for higher Ag content $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{1-x}Ag_x)_4O_{10+\delta}$, ($x$=0.50) to determine whether superconductivity still exists and provide important superconducting parameters. Motivated by the ac magnetic susceptibility, which was measured for different applied dc fields, we investigated how this high level of nonmagnetic Ag impurities influenced the irreversibility line and flux pinning of the bulk properties of the Hg-1234 system. The temperature dependent of χ''_{ac} at different frequencies are analysed by thermally activation mode.

2. Experimental methodology

A mercury-based compound, $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$, was prepared using the conventional solid state reaction technique in a non-evacuated sealed quartz tube, as reported previously [6]. The ac susceptibility as a function of both temperature ($5\,K < T < 130\,K$) and magnetic field ($0\,Oe \le H_{dc} \le 3600\,Oe$) was carried out using a quantum design PPMS model 6000 magnetometer. At different values of the dc magnetic field, a set of measurements was taken of the sample when the temperature was cooled down to 5 K either in zero field cooling (ZFC) or field cooling (FC). The ac susceptibility was also measured with varying temperatures and frequencies.

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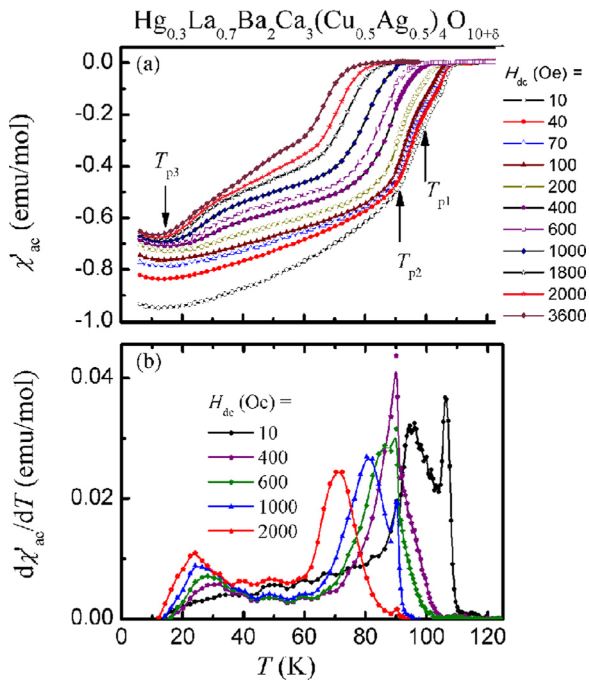

Fig. 1. (a) The real part of ac susceptibility, χ'_{ac}, in the temperature range 5-130 K at different dc fields and ac field amplitude of 1.0 Oe for $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$. (b) The change of $d\chi'_{ac}/dT$ with temperature at some selected applied fields.

Table 1
The estimated transition peaks of the $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$ compound at different applied fields based on the $d\chi'_{ac}/dT$ curves.

H_{dc} (Oe)	T_{p1} (K)	T_{p2} (K)	T_{p3} (K)
10	106	95	–
100	103	93	–
200	100	92	90
400	–	90	30
600	90	86	28
1000	90.5	81	25
2000	90	72	24

3. Results and discussion

Noting that the differences between the ZFC and FC measurements were very small, Fig. 1(a) depicts the field dependence of the real part of the FC susceptibility, χ'_{ac}, versus the temperature of $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$, in the temperature range 5–125 K at different dc applied fields, H_{dc}. As shown in this figure, there is an abrupt change in the diamagnetic susceptibility with temperature and H_{dc}. Different characteristic temperatures are also characterised as T_{p1}, T_{p2}, and T_{p3}. Both T_{p1} and T_{p2} shift to lower temperatures with increasing H_{dc}. While T_{p2} could no longer be identified, T_{p1} spread out with increasing applied H_{dc}. Also, an increase in χ'_{ac} at the lower temperature (T_{p3}) was noticed at $H_{dc} > 100$ Oe. This behaviour can be seen from the variation of $d\chi'_{ac}/dT$ with temperature as shown in Fig. 1(b). The estimated values of these peaks are given in Table 1. In addition, the values of χ'_{ac} at $T \approx 5$ K suggest that $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$ also exhibits Meissner state (MS), which decreases with the increase in H_{dc}. Even the applied field reaches 3600 Oe, χ'_{ac} remained negative. As seen in Fig. 1(b), T_c decreased with increasing of H_{dc}. The observed upturn in χ'_{ac} could be attributed to the relative increase in the magnetic contribution of the Cu planes.

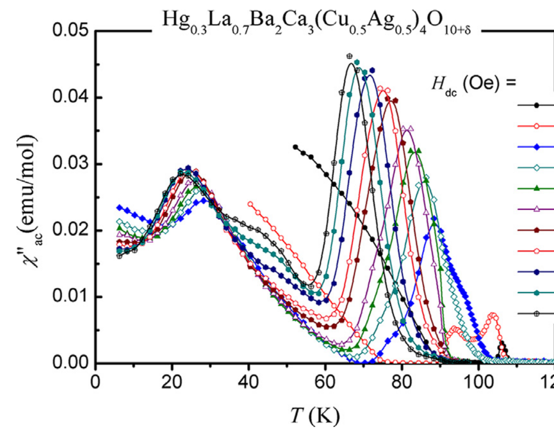

Fig. 2. The imaginary part of ac susceptibility, $\chi''_{ac}(T)$, in the temperature range 5-130 K at different dc fields and ac field amplitude of 1.0 Oe for $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$, compound.

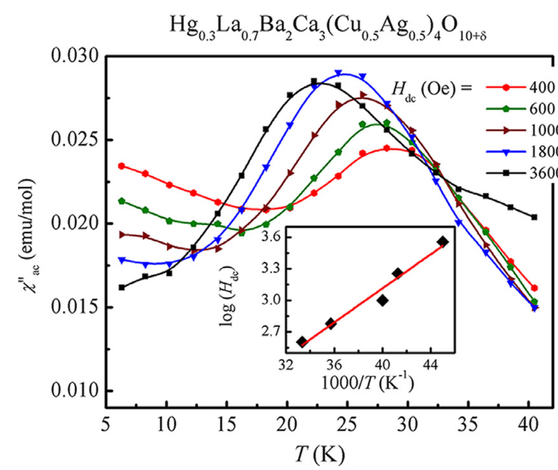

Fig. 3. The imaginary part of ac susceptibility, $\chi''_{ac}(T)$, in the temperature range 5-40 K at different dc fields and ac field amplitude of 1.0 Oe for $Hg_{0.3}La_{0.7}Ba_2Ca_3(Cu_{0.5}Ag_{0.5})_4O_{10+\delta}$, compound. The inset shows the variation of log (H_{dc}) against 1000/T, where the solid red line represents the fit according to Eq. 1.

Fig. 2 displays the temperature dependence of the imaginary part of the ac susceptibility, χ''_{ac}, measured at different H_{dc}, and ac amplitude of 1.0 Oe. Two peaks, T_{P1} (nearest T_c) and T_{P2}, were observed consistent with the inflection points in χ'_{ac}, (see Fig. 1(a)). These double peaks can be attributed to intergranular and intragranular effects [5] or different pinning mechanisms consistent with that observed for fluorine, F-doped Hg-1223 [7]. The increase in H_{dc} caused both peaks to shift to lower temperatures, with T_{P1} shifting faster than T_{P2}, until they completely merged into a single peak at $H_{dc} \geq 200$ Oe. The intensity of T_{P1} and T_{P2} initially increased up to $H_{dc} \sim 200$ Oe, and their relative intensities started to decrease and then increase in width until they completely merged at $H_{dc} \approx 400$ Oe. The resulting single peak is associated with T_{P1}, T_{P2} or both. A third broad peak T_{P3}, showing hysteresis, was found at $T \sim 30$ K. This peak was well developed at a field value $H_{dc} = 400$ Oe. Furthermore, it shifted slowly towards lower temperatures with increasing H_{dc} as seen in Fig. 3. The inset in Fig. 3 shows the thermally activated behaviour of the H_{dc} shift of T_{P3}:

$$H_{dc} \approx \exp\left(E/K_B T\right) \tag{1}$$

where K_B is Boltzmann's constant and E is the activation energy. Within the dc applied magnetic field range 400 Oe $\leq H_{dc} \leq$ 3600 Oe, the E value of the studied compound was 0.07 eV, which is higher than that of low Ag content sample [5].