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Flux pinning in $Tl_{1-x}C_xBa_2Ca_3Cu_4O_{12-\delta}$ superconductor

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ABSTRACT

The dissipation mechanism in $Tl_{1-x}C_xBa_2Ca_3Cu_4O_{12-\delta}$ ($x = 0$, 0.25, 0.5 and 0.75) superconductor under the influence of external magnetic fields have been studied. The sample with $x = 0.25$ have shown strong flux pinning characteristic as compared to the $Tl_{1-x}C_x$-1234 ($x = 0$, 0.5 and 0.75) samples. The scanning electron micrographs of $Tl_{1-x}C_x$-1234 shows well connected grains in $x = 0$ and 0.25 samples. Whereas, $x = 0.5$ and 0.75 samples have relatively poor grain morphology, which shows that the source of pinning in $Tl_{0.75}C_{0.25}$-1234 sample is intrinsic one. The transition width data was also fitted to the thermally activated flux flow model. The apical phonon modes of vibrations were studied through FTIR absorption measurements.

1. Introduction

The transport properties i.e. electrical conductivity and electrical current density of high T_c superconductors are largely affected by the application of external magnetic fields [1–3]. The effect of magnetic field is to produces vortices which form rectangular flux line lattice inside a superconductor. When an electrical current is applied perpendicular to the axis of the vortices a Lorentz force $\boldsymbol{f}_L = \mathbf{J} \times \mathbf{B}$ acts on the vortices which moves these flux lines. The motion of the flux lines results in resistive transition (also called flux flow resistivity), which is manifested in the broadening of the resistivity curve in the transition region just above the critical temperature [4,5]. One way to stop the motion of the vortices is to create potential barriers in their way. These barriers are called pinning centers because they have the ability to pin the magnetic flux lines at certain points in the material. Therefore, the superconducting materials with weak flux pinning can loose its superconductivity with the application of small magnetic fields. The pinning centers exert a pinning force f_P opposite to $\boldsymbol{f}_L$, which will oppose the motion of the flux lines in the superconductor; in other words the vortices has to overcome the pinning barriers having a barrier height U. In sintered superconductors the crystal defects can act as efficient pinning centers, however, they could also be artificially grown using the energetic ion beams [6–10].

In the present article we have studied the flux pinning characteristics of $Tl_{1-x}C_xBa_2Ca_3Cu_4O_{12-\delta}$ ($x = 0$, 0.25, 0.5, 0.75) superconductor. The $Tl_1Ba_2Ca_3Cu_4O_{12-\delta}$ (Tl-1234) superconductor is one of the members of single Tl–O layer superconductors, which has high irreversibility field and critical current density [11–13]. The demerit associated with these compounds is the issue of phase purity. We prepared phase pure Tl-1234 superconductor at ambient pressure and substituted carbon in the charge reservoir layer [14].

2. Experimental

The $(Tl_{1-x}C_x)Ba_2Ca_3Cu_4O_{12-\delta}$ ($x = 0$, 0.25, 0.5 and 0.75) superconductor samples were prepared by two stage solid-state reaction method. At the first stage $C_xBa_2Ca_3Cu_4O_{12-\delta}$ ($y = 0$, 0.25, 0.5 and 0.75) precursor material was prepared by using $Ba(NO_3)_2$, $Ca(NO_3)_2$, $Cu_2(CN)_2$ and carbon powder as starting compounds. These compounds were thoroughly mixed in appropriate ratios in a quartz mortar and pestle for about 1 h and fired in a quartz boat at 860 °C for 24 h in air, followed by furnace cooling to room temperature. At the second stage Tl_2O_3, was mixed with precursor material in appropriate ratio to get $(Tl_{1-x}C_x)Ba_2Ca_3Cu_4O_{12-\delta}$ as a final composition. The pellets of thallium mixed precursor material were prepared under 3.8 tons/cm^2 pressure. The pellets were wrapped in a gold capsule and heat treated at 880 °C for 10 min followed by quenching to room temperature after the heat treatment. The four-probe technique was used to measure the resistivity of these samples under the influence of DC magnetic field. The crystal structure of the material and its lattice parameters were determined by X-ray diffraction (XRD) measurements using STOE, Germany diffractometer. The grain morphology of the sample was studied from the scanning electron micrographs. The FTIR (Fourier Transform Infrared Spectroscopy) absorption measurements were performed using the spectrometer from Thermoelectron Corporation.

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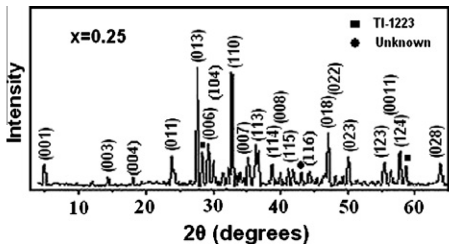

Fig. 1. XRD pattern of $Tl_{1-x}C_x$-1234 ($x = 0.25$) superconductor.

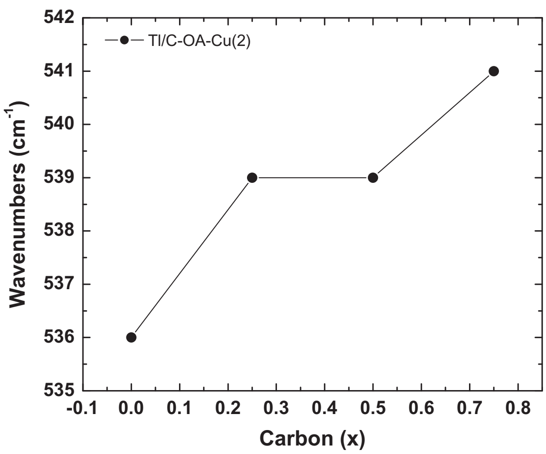

Fig. 2. FTIR apical oxygen absorption modes of $Tl_{1-x}C_x$-1234 superconductor versus carbon content.

3. Results and discussion

The X-ray diffraction pattern of one of the $Tl_{1-x}C_x$-1234 superconductor samples ($x = 0.25$) is shown in Fig. 1. The XRD pattern shows almost phase pure $Tl_{0.75}C_{0.25}$-1234 sample with small inclusion of Tl-1223 and some unknown impurity phases. The phase percentages are calculated to be 90% $Tl_{0.75}C_{0.25}$-1234, 7% Tl-1223 and 3% unknown. The samples with higher concentrations of carbon have also shown the same trend with $Tl_{1-x}C_x$-1234 as a major phase [14]. The indexing of the XRD spectra was done using the check cell program. The hardening of the apical oxygen FTIR mode with the inclusion of carbon in the charge reservoir layer is shown in Fig. 2. In thallium based superconductors the absorption modes around 500 cm^{-1} are related to vibrations of apical oxygen atoms Tl(1)–O_A–Cu(2) [15–16]. We can therefore assign 536 cm^{-1} mode to the apical oxygen atoms of $Tl_{1-x}C_x$-1234 superconductor. Since carbon is lighter than thallium ion therefore, the hardening of the Tl(1)–O_A–Cu(2) mode with the increase of carbon concentration as shown in Fig. 2 may be due to replacement of thallium with carbon in the charge reservoir layer. It could also be inferred from these results that carbon has been incorporated in the unit cell of $Tl_{1-x}C_x$-1234 superconductor. The resistivity measurements of $(Tl_{1-x}C_x)Ba_2Ca_3Cu_4O_{12-\delta}$ ($y = 0$, 0.25, 0.5 and 0.75) superconductor under zero field and $H = 750$, 1500, & 3000 G are shown in Fig. 3a–d. It can be seen from this figure that the normal state resistivity is least in $Tl_{0.75}C_{0.25}$-1234 superconductor sample. The electron micrographs of $Tl_{1-x}C_x$-1234 samples in Fig. 4a–d shows a better grain morphology of $x = 0$ and 0.25 samples as compared to the sample with $x = 0.5$ and 0.75. The poor grain morphology might be the reason of higher normal state resistivity of $Tl_{1-x}C_x$-1234

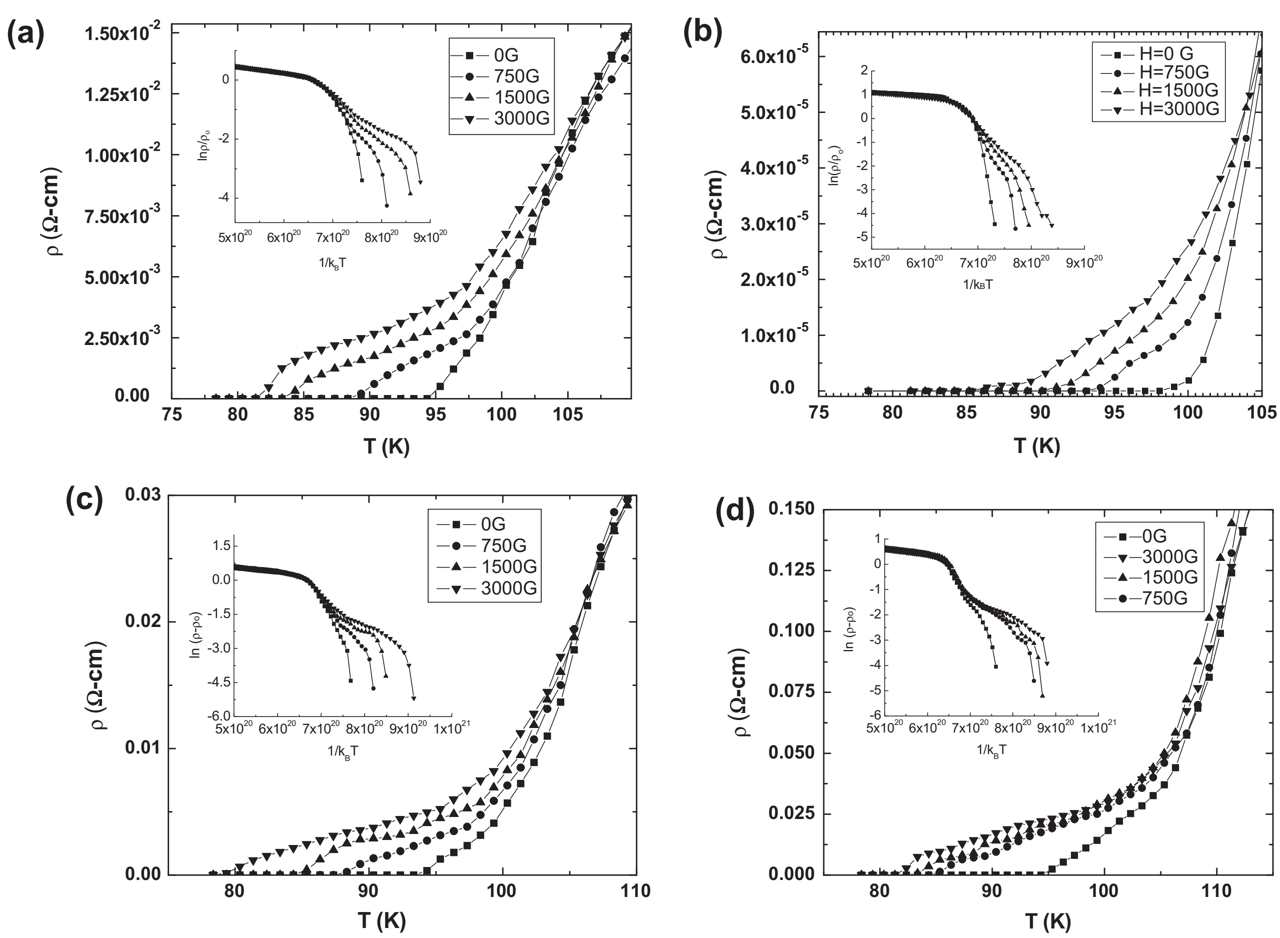

Fig. 3. Resistivity measurements of $Tl_{1-x}C_x$-1234 (a) $x = 0$ (b) $x = 0.25$ (c) $x = 0.5$ (d) $x = 0.75$ superconductor; Inset (Arrhenius plots).