Be-Doped Cu_{0.5}Tl_{0.5}Ba_{2}Ca_{1}(Cu_{0.5}Zn_{1.5})O_{8} - \delta Superconductors

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Abstract We have enhanced the superconducting properties of newly discovered Cu_{0.5}Tl_{0.5}Ba_{2}Ca_{1}(Cu_{0.5}Zn_{1.5})O_{8} - \delta superconductor by doping Be at Ca sites. The superconducting properties, such as critical current density, in-field magnetic properties and quantity of diamagnetism, are enhanced by Be doping at the Ca sites. The decreased c-axis length and the volume of the unit cell have shown that the inter-ZnO_{2}-plane coupling is enhanced. We have not observed any localization of the carriers in the neighborhood of Zn atoms in Cu_{0.5}Tl_{0.5}Ba_{2}Ca_{1-y}Be_{y}(Cu_{0.5}Zn_{1.5})O_{8} - \delta (y = 0, 0.15, 0.30, 0.45, 0.6) superconductors, as proposed in the previous studies. One must expect such effects if present, through the decreased c-axis length by Be doping. The decreased c-axis length results in enhancement of coherence length and Fermi velocity of the carriers, which in turn result in enhanced superconductivity parameters. The presence of Be at the termination ends of the crystals results in enhanced inter-grain coupling and substantially improved their weak link behavior. The optimization of the carriers in CuO_{2}/ZnO_{2}-planes have been found to enhance the $T_c(R = 0)$ and the magnitude of diamagnetism in Be-doped samples. Also the softening of phonon modes with the increased Zn doping evidenced the incorporation of Zn at the CuO_{2} planar sites.

Keywords Be-doped Cu_{0.5}Tl_{0.5}Ba_{2}Ca_{1-y}Be_{y}(Cu_{0.5}Zn_{1.5})O_{8} - \delta superconductors · Enhance inter-plane coupling

1 Introduction

The existence of superconductivity in (Cu_{0.5}Tl_{0.5})Ba_{2}Ca_{n-1}Zn_{n}O_{2n+4-\delta} (n = 3, 4) superconductors with ZnO_{2} planes [1, 2] is preferred over its parent compound (Cu_{0.5}Tl_{0.5})Ba_{2}Ca_{n-1}Cu_{n}O_{2n+4-\delta} (n = 3, 4) with CuO_{2} [3, 4], due to the fixed valence state of zinc which can introduce a material with uniform carrier density in the inner and outer planes. In the later compound existence of anti-ferromagnetism is witnessed in the inner CuO_{2} planes. The anti-ferromagnetic alignment of spins of 3d^{9} Cu atoms is suggested to arising from the deficiency of the carriers there; the outer planes are over-doped whereas the inner planes are under-doped with the carriers. The existence of anti-ferromagnetism in the IP of MBa_{2}Ca_{n-1}Cu_{n}O_{2n+4-\delta} (M = Bi, Tl, Hg, Cu) superconductors has been found to suppress the critical temperature and magnitude of diamagnetism [5]. Another advantage a superconductor with ZnO_{2} planes with filled 3d^{10} shell is suppression of local spin density which was being induces by Cu 3d^{9} shell in the CuO_{2} planes and hence the interactions of spins with the free carriers in Zn-doped compounds is significantly reduced. It has also been observed from our studies that hundred percent Zn cannot replace the Cu atoms in (Cu_{0.5}Tl_{0.5})Ba_{2}Ca_{n-1}Zn_{n}O_{2n+4-\delta} (n = 3, 4) and a solubility limit appears with 90% Zn doping at the Cu sites; with the doping of Zn beyond this limit superconductivity disappears altogether. These observations lead us to a conclusion that some population of Cu 3d^{9} atoms is essential in the CuO_{2}/ZnO_{2} planes for the accomplishment of charge transfer from the charge reservoir layer. Another suggestion arising out of these observations is existence of interactions of spin density wave with the charge density wave as proposed in the charge stripe model [6]. The ideal compound for such studies is two [7–14] CuO_{2}/ZnO_{2} planes...
Cu$_{0.5}$Tl$_{0.5}$Ba$_2$Ca$_1$Cu$_{0.5}$Zn$_{1.5}$O$_8$–δ superconductor, because the under-doped inner planes would be absent altogether in this compound.

In our previous studies we have developed a better correlation among the carriers in ZnO$_2$ planes, by doping Mg at the Ca sites in (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$Ca$_{n-1}$Zn$_n$O$_{2n+4}$–δ ($n = 3, 4$) superconductors, consequently enhanced superconductivity is achieved. It was observed from the studies of the cell parameters of Mg doped compounds that volume of the unit cell decreases resulting in increase in the Fermi vector $[K_F = (3\pi^2 N/V)^{1/3}]$, their coherence length $[\xi_c = h^2 K_F/2m\Delta]$ along c-axis and hence the Fermi velocity $[V_F = \frac{2\xi_c}{\hbar}]$ [15] of the carriers. In the present experiments we have doped Be at the Ca sites in (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$–(Ca$_{1-y}$Be$_y$)(Cu$_{0.5}$Zn$_{1.5}$)O$_8$–δ ($y = 0, 0.15, 0.3, 0.45, 0.6, 0.75$) superconductors. The main objective of this to enhance the inter-plane coupling and increase the interactions of remaining Cu atoms spins with the carriers in the conducting ZnO$_2$/CuO$_2$ planes. These experiments would help in understanding charge density wave and spin density wave and the role of their interaction in the mechanism of high temperature superconductivity.

2 Experimental

The (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$(Ca$_{1-y}$Be$_y$)(Cu$_{0.5}$Zn$_{1.5}$)O$_8$–δ ($y = 0, 0.15, 0.3, 0.45, 0.6$) superconductors samples are prepared by solid-state reaction method accomplished in two stages. At the first stage (Cu$_{0.5}$)Ba$_2$(Ca$_{1-y}$Be$_y$)(Cu$_{0.5}$Zn$_{1.5}$)O$_8$–δ ($y = 0, 0.15, 0.3, 0.45, 0.6$) superconductors precursor materials were synthesized by using Ba(NO$_3$)$_2$ (99%, Merck), Ca(NO$_3$)$_2$ (99%, Merck), BeO (99%, BDH Chemical Ltd. Poole England), Cu$_2$(CN)$_2$ (99%, BDH Chemical Ltd. Poole England) and ZnO (99.7%, BDH Chemical Ltd. Poole England) as starting room temperature. Rectangular bar shaped samples of dimensions 2 mm × 2.5 mm × 10 mm are used for dc-resistivity and ac-susceptibility measurements. The structure of the material is determined by using x-ray diffraction scan (D/Max IIC Rigaku with a CuK$_{\alpha}$ source of wavelength 1.54056 Å) and cell parameters by using a computer program. The phonon modes related to the vibrations of various oxygen atoms in (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$(Ca$_{1-y}$Be$_y$)-(Cu$_{0.5}$Zn$_{1.5}$)O$_8$–δ ($y = 0, 0.15, 0.3, 0.45, 0.6, 0.75$) superconductors unit cell were observed by Nicolet 5700 Fourier transform infrared (compounds). These compounds are mixed in appropriate ratios and grinded in a quartz mortar and pestle for about an hour. After grinding, the material is loaded in a quartz boat for firing in a furnace at 825 °C. The material is fired twice following one-hour intermediate grinding. The precursor material is then mixed with Tl$_2$O$_3$ (99%, Merck) to give (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$(Ca$_{1-y}$Be$_y$)-(Cu$_{0.5}$Zn$_{1.5}$)O$_8$–δ ($y = 0, 0.15, 0.3, 0.45, 0.6, 0.75$) superconductors as final reactant composition. Thallium oxide mixed precursor material is pelletized under 3.8 tons/cm$^2$ pressure. The pellets are wrapped in a thin gold foil and sintered at respective temperatures for 10 minutes, followed by quenching to FTIR spectrometer in the 400–700 cm$^{-1}$ wave number range. The dc-resistivity and IV characteristics of the samples are measured by four-probe technique. The ac-susceptibility measurements are carried out by mutual inductance method using SR530 Lock-in Amplifier at a frequency of 270 Hz with $H_{AC} = 0.7$ Oe of primary coil.

Fig. 1 X-ray diffraction of (Cu$_{0.5}$Tl$_{0.5}$)Ba$_2$(Ca$_{1-y}$Be$_y$)Cu$_{0.5}$Zn$_{1.5}$–O$_8$–δ ($y = 0.0, 0.15, 0.30$) superconductors.