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Excess conductivity in $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor

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Abstract

Synthesis and characterization of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ ($y=0$, 1.0, and 1.5) superconductor with 0%, 50%, and 75% Mg-doping at the Ca sites are reported. The samples were synthesized by solid-state reaction and characterized by X-ray diffraction (XRD), dc-resistivity (ρ) and fluctuation induced conductivity (FIC) analysis. The zero resistivity critical temperature $\{T_c(R=0)\}$ was decreased with the increase of Mg-doping at Ca sites. The microscopic parameters such as the cross-over temperature (T_o), zero temperature coherence length $\{\xi_c(0)\}$ and interlayer coupling (J) were deduced from FIC analysis. According to Aslamazov Larkin equations, a distinct cross-over temperature (T_{o1}) from three-dimensional (3D) to two-dimensional (2D) fluctuation induced conductivity regions was observed in all samples. Another cross-over temperature (T_{o2}) from 2D to zero-dimensional (0D) fluctuations was also witnessed. FIC analysis revealed the deterioration of superconductivity with increased Mg-content.

Keywords: $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor; Mg-doping; Fluctuation induced conductivity (FIC)

1. Introduction

In superconducting materials, electron pairing (Cooper Pairs) starts well above the superconductivity onset temperature (T_c^{onset}) due to thermal fluctuations, which contributes to the conductivity of the materials. Thermal fluctuations play an important role in the explanation of normal-state properties of the superconducting materials. Almost all the high T_c superconductors due to their layered structure possess the anisotropic character for their transport properties [1–4]. The anisotropic nature of the materials promotes fluctuations in the order parameters due to competing effects of different coherence lengths (along the *c*-axis and in the *ab*-plane) during transport processes. In the transport process the charge carriers have to tunnel across insulating/partially insulating barriers along the c-axis and across the grain boundaries, which promotes fluctuations in the order parameters and in turn to the conductivity of the carriers. The studies of fluctuation induced conductivity (FIC) may help in understanding the intrinsic mechanism of superconductivity. The microscopic parameters calculated from this analysis help us to study the dimensionality of the fluctuations associated with the order parameters of the superconductivity. Fluctuation induced conductivity (FIC) is one of the experimentally accessible methods just shedding light on the transport properties of high T_c oxides in normal state. Just above T_c^{onset}, the resistivity $\rho(T)$ is affected by thermal fluctuations resulting in noticeable deviation of $\rho(T)$ down from its linear dependence at higher temperatures. Thus, the fluctuation induced conductivity (FIC) occurs [5,6]. The understanding of the normal state properties of high T_c cuprates can provide useful informations about the superconductivity mechanism and the microscopic parameters i.e. coherence length, penetration depth, phase relaxation time, etc. It is observed in high T_c cuprates that a large excess conductivity above the transition temperature appears due to thermodynamic fluctuations and various models have been proposed to explain such type of large excess conductivity (or fluctuation induced conductivity). The most popular theories to explain the FIC phenomenon in superconductors are the Aslamazov–Larkin (AL) Model, Lawrence and Donaich (LD) Model, and Maki–Thompson (MT) Model [7–9].

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Therefore, these theories can be used to deduce the microscopic parameters of superconductors. Various groups have studied the different oxide high T_c cuprates using LD, AL, and MT theories. Freites et al. [10] have studied the dimensionality of the electronic system in Y-123 using the AL theory and found 3D fluctuation. Patapis et al. [11] have observed 2D MT mechanism, which shows a pair-breaking mechanism in Y-123 thin films and transferred to the 3D AL region close to T_c. Obolenskil et al. [12] used the AL theory to study the effect of pressure on the superconductivity of Y-123 single crystals and they observed a decrease in coherence length up to 10 Kbar. Sato et al. [13] have calculated the *c*-axis coherence length $\{\xi_c(0)\}$ of Ag-doped melt textured Y-123 superconductor and was found a decrease in $\xi_c(0)$ with the increase of Ag concentration. The Bi-based high T_c superconductors have been studied in the light of the FIC theory. The dimensionality of fluctuation has been studied in Bi-2212 superconductor by using AL theory and found 2D fluctuation in zero field as well as under the influence of applied magnetic field [14,15]. Ibrahim et al. [16] observed a transition from the AL contribution to FIC at low temperature in the Bi-2212 superconductor to short wavelength fluctuations at higher temperature, which has been attributed to the possibility of change in Fermi surface. The effect of sintering temperature on FIC of the Bi-2223 superconductor was studied and it was found that with the increase of sintering temperature, the critical regions become narrow and all the cross-over temperatures increase. The AL theory was used in Hg-1223 superconductor to study the dimensionality of fluctuations and $\xi_c(0)$ under high pressure [17]. The results have shown that the coupling strength of CuO_2 planes and the thermodynamic critical field increase with the increase of pressure. The dimensionality in the electronic system of highly oriented Tl-1223, Tl-2212 and Tl-2223 superconductor thin films have been studied, and found only 2D fluctuations and the cross-over to 3D fluctuation region was completely absent [18]. Passos et al. [19] have studied the HgRe-1223 granular superconductor in the light of AL and LD models by taking grain morphology into account, They observed 2D–3D transition and correlated $\xi_c(0)$ with the grain morphology. Han et al. [20] have observed a cross-over of FIC from 2D to a low dimensional region, which they called 1D region in HgTl-1223 superconductor samples and attributed this cross-over to the presence of stripes in these samples.

In this manuscript we have reported the effects of Mg-doping at the Ca sites in $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ samples on superconductivity and fluctuation induced conductivity (FIC). The microscopic parameters such as the cross-over temperatures (T_{o1} and T_{o2}), zero temperature coherence length along the *c*-axis $\{\xi_c(0)\}$, interlayer coupling (J) and dimensionality of conduction have also been determined in Mg-doped samples.

The substitution of Mg^{+2} at the Ca^{+2} site in $Cu_{0.5}Tl_{0.5}Ba_2Ca_2Cu_3O_{10-\delta}$ superconductors improves the inter-plane coupling, which is most likely accomplished due to smaller ionic size and higher electronegativity of Mg atoms [21]. The increased inter-plane coupling may enhance the interactions between charge carriers in various conducting CuO_2 planes. Also the inter-plane coupling among ZnO_2/CuO_2 planes was enhanced and critical current density was improved by substituting Mg at the Ca sites in $Cu_{0.5}Tl_{0.5}Ba_2Ca_2(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor [22,23]. In order to investigate the correlation between different superconductivity microscopic parameters, fluctuation induced conductivity (FIC) analysis is carried out on the resistivity verses temperature data of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor samples. These Mg substituted $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ samples are extremely useful for device fabrication and wire application due their higher J_c values.

2. Fluctuation induced conductivity (FIC) analysis

In high T_c superconductors, during the transport processes well above T_c^{onset}, the probability of Cooper pairs formation is always there due to thermal fluctuations. These thermal fluctuations contribute to excess conductivity $\{\Delta\sigma(T)\}$ usually by two different ways:

(i) The direct Aslamazov–Larkin (AL) contribution [7].
(ii) The indirect Maki–Thompson (MT) contribution [8].

The AL term described by Lawrence and Donaich (LD) model predicts a cross-over temperature from 3D to 2D with increasing temperature [9]. Through the FIC analysis of resistivity versus temperature data the cross-over temperature (T_o) may be predicted. At this temperature, there is a competition between 2D and 3D conductivity processes. The system transforms from more isotropic three dimensional (3D) conducting region to a two-dimensional (2D) anisotropic conducting region with the increase of temperature. In oxide superconductors with conducting CuO_2, the AL term dominates close to T_c^{onset}. The effect of thermal fluctuations on the conductivity of normal electrons was explained by the Maki–Thompson (MT) term [8]. The MT part depends on the phase-relaxation time and becomes significant in 2D fluctuations regime accompanied by moderate pair-breaking [24,25].

We have used AL and LD theories [7] to study the fluctuation induced conductivity (FIC) of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor samples. According to the AL theory, the excess conductivity ($\Delta\sigma$) is given as

$$\Delta\sigma_{AL} = C\varepsilon^{-\lambda} \tag{1}$$

$$\Delta[\sigma_{AL}]^{3D} = C^{3D}\varepsilon^{-0.5} \tag{2}$$

$$\Delta[\sigma_{AL}]^{2D} = C^{2D}\varepsilon^{-1.0} \tag{3}$$

where λ is the critical exponent, whose value is 0.5 for three-dimensional (3D) fluctuations, 1.0 for two-dimensional (2D) fluctuations and 2.0 for zero-dimensional (0D) fluctuations [16,20,26]. The 0D fluctuations refer to the temperature region, where Cooper pairs are formed and broken down instantly and their formation is not supported in any preferred direction due to which these fluctuations are known as 0D fluctuations.

Also, where $\varepsilon=(T/T_{mf}-1)$ is the reduced temperature, T_{mf} is the mean field critical temperature at which $d\rho/dT$ is maximum [27,28] and C is the fluctuation amplitude that is given by

$$C^{3D} = e^2/32\xi\hbar_c(0) \quad (4)$$

$$C^{2D} = e^2/16\hbar d \quad (5)$$

In these equations, e, d and $\xi_c(0)$ are electronic charge, effective interlayer thickness and zero temperature coherence length along the c-axis. Lawrence–Doniach modified the Aslamasov–Larkin theory and predicted a dimensional cross-over from 2D to 3D fluctuation regimes, where the excess conductivity is given by the following relation:

$$\Delta\sigma_{LD} = (A)^x\varepsilon^{-1}[1+(2\xi_c(0)/d)^2] \quad (6)$$

The temperature at which 3D–2D cross-over takes place is given by the following relation:

$$T_{LD} = T_{mf}[1+(2\xi_c(0)/d)^2] \quad (7)$$

The second term in Eq. (7) is the interlayer coupling strength (J), which is related to the reduced cross-over temperature ε^* by $J=\varepsilon^*/4$ [29–31]. These theories help us to study the dimensionality of the fluctuations associated with the order parameters of the superconductivity [29–31]. The excess conductivity induced by thermal fluctuations is given by

$$\Delta\sigma_{AL} = 1/\rho - 1/\rho_n \quad (8)$$

where ρ represents the experimentally measured resistivity, while ρ_n is the extrapolated normal state resistivity and can be calculated by using the following equation:

$$\rho_n = \alpha+\beta T \quad (9)$$

where α is a intercept, i.e., $\alpha=\rho_n\rho(0\ K)$ and β is a slope of the straight line.

3. Sample preparation techniques and experiments

The polycrystalline ceramic $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ (y=0.0, 1.0, and 1.5) superconductor samples were synthesized by a solid-state reaction method accomplished in two stages. At the first stage, the $Cu_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ precursor material was synthesized by using $Ba(NO_3)_2$, $Ca(NO_3)_2$, MgO, $Cu_2(CN)_2$ and ZnO as starting compounds. These compounds were mixed in appropriate ratios and ground in a quartz mortar and pestle for about 1 h. The material after grinding was loaded in a quartz boat for firing in a chamber furnace at 860 °C for 24 h. The material was fired second time following 1 h intermediate grinding. The precursor material after firing was mixed with Tl_2O_3 and again ground for about 1 h. The pellets of Tl_2O_3 mixed $Cu_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ precursor material were prepared under 3.8 t/cm^2 pressure. The sintering of pellets wrapped in thin gold foils was carried out at 860 °C for 10 minutes followed by quenching to room temperature to get $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor as final reactant composition. The firing and sintering of the samples were carried out at ambient pressure. The diameter and thickness of the final pellet are 1.5 cm and 1–1.5 mm respectively. This synthesis method is convenient and samples synthesized are highly reproducible. The structure of the material was determined by using x-ray diffraction (XRD) scan (D/Max IIIC Rigaku with a CuK$_\alpha$ source of wavelength 1.54056 Å) and cell parameters were calculated by using a computer program. Resistivity of the superconducting materials was measured by using the conventional four-probe method and the current value during dc-resistivity measurements was kept 1 mA. The rectangular bar shaped samples of dimensions 1.2 mm × 2 mm × 8 mm were used for resistivity.

4. Results and discussion

The X-ray diffraction scans of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ (y=0, 1.5) superconductor are shown in Fig. 1. The diffraction lines are indexed using a computer program (crystal), which shows that the material has grown in tetragonal CuTl-1223 structure with P4/mmm symmetry. Few un-indexed diffraction peaks in the XRD pattern of very small intensity represent the presence of CuTl-1234 phase in the material. Most of the diffraction lines are indexed according to tetragonal structure with cell parameters a=3.35 Å and c=14.40 Å for y=0 and a=3.34 Å and c=14.37 Å for y=1.5, respectively. It is observed that cell parameters lengths were decreased with the increase of Mg-content in the final compound. The decrease of axes lengths reduces the volume 'V' of the unit cell which is an evidence of improved inter-plane coupling.

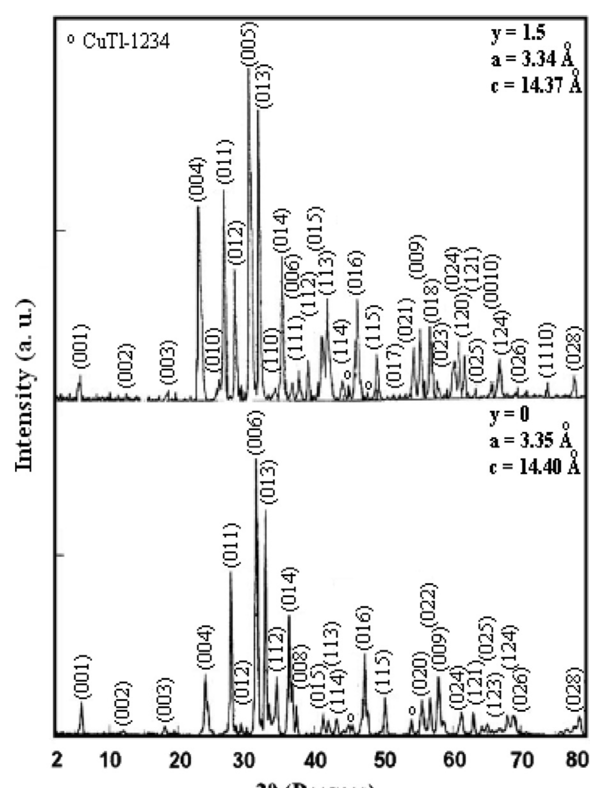

Fig. 1. X-ray diffraction (XRD) patterns of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ (y=0, and 1.5) superconductor samples.

The electrical resistivity measurements of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ (y=0.0, 1.0, and 1.5) superconductor samples are shown in Fig. 2. All the samples have shown a metallic variation of resistivity from room temperature down to the onset of superconductivity. The temperature at which the electrical resistivity deviates from linearity towards zero resistivity critical temperature is known as superconductivity onset temperature (T_c^{onset}). It can be observed from these measurements that T_c^{onset} and zero resistivity critical temperature {$T_c(R=0)$} of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ samples are 135 K, 120 K for y=0, 130 K, 113 K for y=1. 0 and 127 K, 115 K for y=1.5. The increased Mg-content in the final compound deteriorates the quality of samples i.e. increase in the normal state resistivity, T_c^{onset}, $T_c(R=0)$, etc.

The microscopic parameters such as the cross-over temperature (T_o), zero temperature coherence length along c-axis {$\xi_c(0)$}, interlayer coupling (J), mean field critical temperature (T_{mf}) and dimensionality of conduction etc, are also calculated by FIC analysis and observed to be suppressed with Mg-doping. Also the parameter 'α' represents the inter-grain coupling, whose lower values are responsible for better inter-grain connectivity and the increase in the values of 'α' is also in agreement with the increased experimental normal state resistivity of the material. The value of 'α' has been increased with the increase of Mg-content in $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ samples and normal state resistivity $\rho(T)$ has also been increased, which may be due to deterioration of inter-grain connectivity.

The plots of $\ln(\Delta\sigma_{AL})$ versus $\ln(\varepsilon)$ of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ samples are shown in Fig. 3(a) for y=0, Fig. 3(b) for y=1.0 and Fig. 3(c) for y=1.5. The fitting of experimental data curves using the AL theory shows the existence of three different regions of fluctuations in all these samples. The values of the critical exponent (λ) deduced from the slops of the three regions are found to be 0.53, 1.3 and 2.3, which correspond to 3D, 2D and 0D fluctuations respectively, for the un-doped (y=0) sample (Fig. 3(a)). On the other hand,

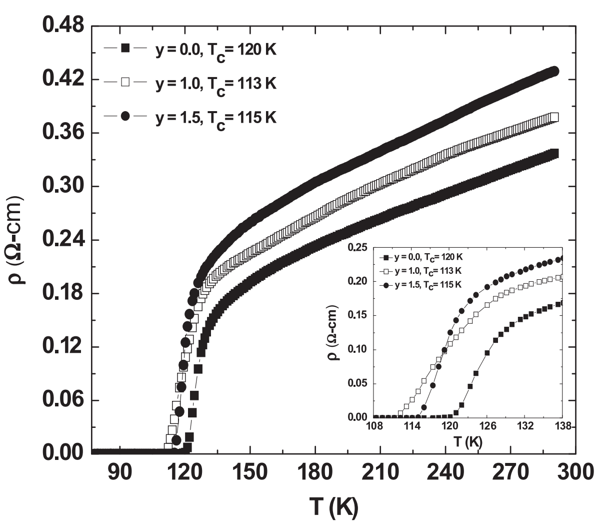

Fig. 2. Resistivity versus temperature measurements of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ (y=0, 1.0, and 1.5) superconductor samples.

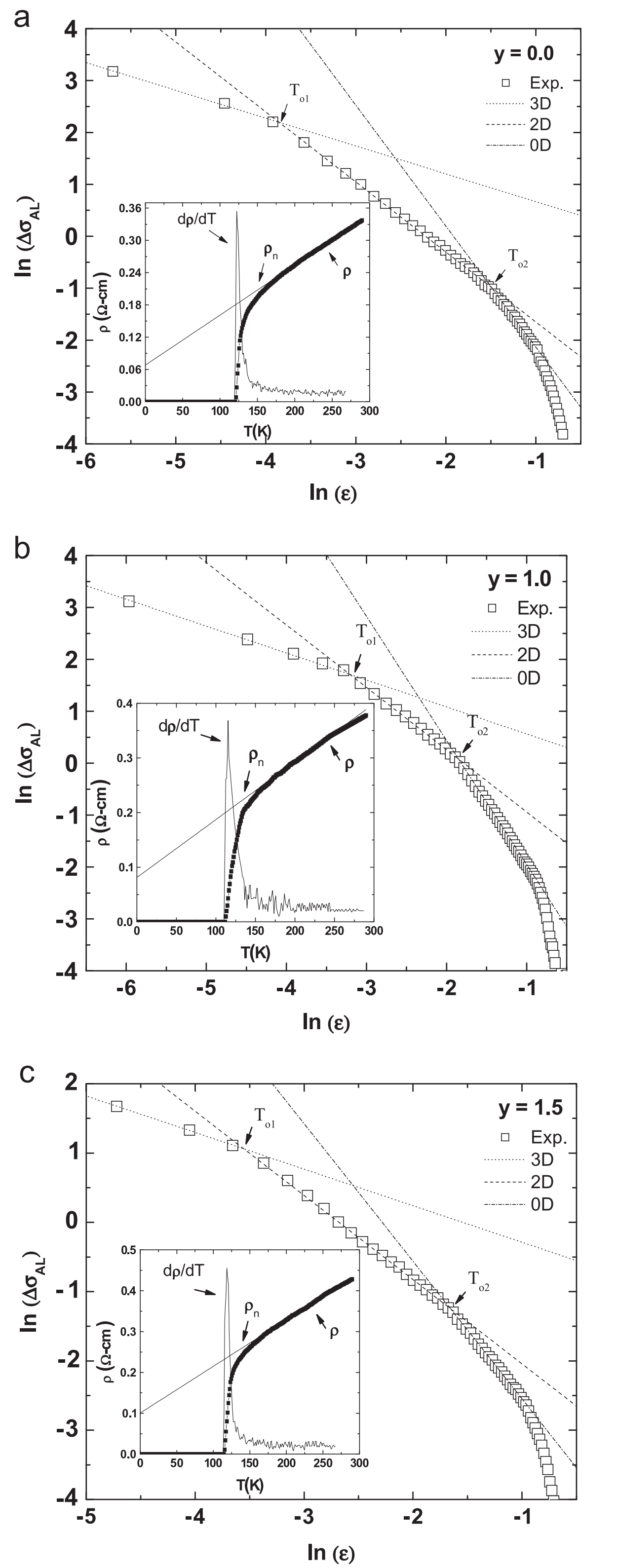

Fig. 3. (a) $\ln(\Delta\sigma)$ versus $\ln(\varepsilon)$ plot of $Cu_{0.5}Tl_{0.5}Ba_2Ca_2(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor sample. (b) $\ln(\Delta\sigma)$ versus $\ln(\varepsilon)$ plot of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor sample. (c) $\ln(\Delta\sigma)$ versus $\ln(\varepsilon)$ plot of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor sample.

the values of λ were found to be 0.51, 1.2 and 2.3 for 3D, 2D and 0D fluctuations respectively, for the sample with y=1. 0 (Fig. 3(b)) and the values of λ deduced from the slops of the

Table 1
Parameters such as the zero resistivity critical temperature ($T_c(R=0)$) cross-over temperatures (T_{o1}, T_{o2}), mean field critical temperature (T_{mf}), inter-grain coupling constant (α), critical exponents (λ), the zero temperature coherence length $\{(\xi_c(0)\}$ and inter-plane coupling (J) extracted from the FIC analysis of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ ($y=0$, 1.0, and 1.5) samples.

$Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$™	$T_c(R=0)$ (K)	T_{o1} (K)	T_{o2} (K)	T_{mf} (K)	$\alpha=\rho_n\rangle$(290 K) (Ω cm)	$\alpha=\rho_n\rangle$(0 K) (Ω cm)	λ_{3D} slope	λ_{2D} slope	λ_{0D} slope	$\xi_c(0)$ (�)	$J\left[\frac{2\xi(0)}{d}\right]^2=$
$y=0.0$	117	125	151	122	0.337	0.06	0.53	1.3	2.3	1.961	0.068
$y=1.0$	113	120	134	115	0.378	0.08	0.51	1.2	2.3	1.867	0.062
$y=1.5$	115	122	142	118	0.428	0.1	0.52	1.2	1.9	1.85	0.06

Table 2
Widths of 3D, 2D and 0D fluctuation regions observed from the fitting of the experimental data using AL model on resistivity data of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ ($y=0$, 1.0, and 1.5) samples.

$Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$	λ_{3D} T(K)	$ln\varepsilon$ (range in 3D)	λ_{2D} T(K)	$ln\varepsilon$ (range in 2D)	λ_{0D} T(K)	$ln\varepsilon$ (range in 0D)
$y=0.0$	123–125	$-5.5 < ln\varepsilon < -3.9$	125–151	$-3.9 < ln\varepsilon < -1.5$	151–168	$-1.5 < ln\varepsilon < -0.9$
$y=1.0$	116–120	$-5.9 < ln\varepsilon < -3.3$	120–134	$-3.3 < ln\varepsilon < -1.8$	134–164	$-1.8 < ln\varepsilon < -0.9$
$y=1.5$	120–122	$-4.7 < ln\varepsilon < -3.7$	122–142	$-3.7 < ln\varepsilon < -1.6$	142–165	$-1.6 < ln\varepsilon < -0.9$

three regions found to be 0.52, 1.2 and 1.9, which correspond to 3D, 2D and 0D fluctuations respectively, for the sample with $y=1.5$ (Fig. 3(c)). There are two cross-over temperatures T_{o1} and T_{o2} in all the three samples, as shown in Fig. 3(a–c). The cross-over temperature at which fluctuation induced conductivity is changed from 3D to 2D in the low temperature region is represented by T_{o1}, while the second cross-over temperature at which the fluctuation induced conductivity is changed from 2D to 0D in the higher temperature region is represented by T_{o2} (Fig. 3(a–c)). The parameters such as cross-over temperatures (T_{o1} and T_{o2}), mean field critical temperature (T_{mf}), critical exponents (λ_{3D}, λ_{2D} and λ_{0D}), and the zero temperature coherence length along the c-axis$\{\xi_c(0)\}$ extracted from the fitting of the excess conductivity data of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor samples are given in Table 1, whereas the widths of three fluctuation regions are also given in Table 2. It can be seen from Table 1 that the cross-over temperatures T_{o1} and T_{o2} for Mg-doped samples are lower than that of Mg-free samples. The decrease in T_{o1} and T_{o2} is more significant in Mg-doped samples compared to the Mg-free sample, which shows that there is a direct correlation between the dimensional cross-over temperatures and the carrier concentration in CuO_2 planes. These results show that dimensionality of the order parameters as observed from FIC analysis depends on the carriers concentration in CuO_2 planes. On the other hand the zero temperature coherence length along the c-axis$\{\xi_c(0)\}$ and the interlayer coupling strength (J) is 1.96 Å and 0.068 respectively in the Mg-free samples. But after Mg-doping, these values were decreased to 1.867 Å, 0.062 and 1.850 Å, 0.060 for the samples with $y=1.0$ and 1.5 respectively. The value of $\xi_c(0)$ depends on the thickness and the composition of the charge reservoir layer. The decrease in these values might be due to the higher Tl-content in the charge reservoir layer that suppresses the mobile charge carrier's density in the conducting CuO_2 planes suppressing the Fermi wave vector $K_F=(3\pi^2 n)^{1/3}$ and $\xi_c(0)=\hbar K_F/2m\Delta$ of the carriers; $n=N/V$ is the number of carriers per volume of unit cell and m is the mass of charge carrier [31,32].

5. Conclusion

The polycrystalline ceramic $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor samples were synthesized and characterized. The effects of Mg-doping at the Ca sites on superconductivity and fluctuation induced conductivity (FIC) were investigated. The superconductivity onset temperature (T_c^{onset}) and the zero resistivity critical temperature $\{T_c\ (R=0)\}$ were decreased after Mg-doping. The microscopic parameters such as the cross-over temperatures (T_{o1} and T_{o2}), zero temperature coherence length along the c-axis $\{\xi_c(0)\}$, inter-layer coupling (J) and dimensionality of conduction have also been suppressed by Mg-doping. The suppression of these parameters is most likely caused by the degradation of quality of the samples by the Mg-doping, which has suppressed 3D conductivity in this material. This may be due to increased scattering cross section of the carriers and breaking of Cooper pairs, which is evident from increased normal state resistivity after Mg-doping.

References

[1] E.F. Talantsev, N.M. Strickland, P. Hoefakker, J.A. Xia, N.J. Long, Critical current anisotropy for second generation HTS wires, Current Applied Physics **8** (2008) 388.

[2] E. Giannini, R. Gladyshevskii, N. Clayton, N. Musolino, V. Garnier, A. Piriou, R. Flükiger, Growth, structure and physical properties of single crystals of pure and Pb-doped Bi-based high T_c superconductors, Current Applied Physics 8 (2008) 115.

[3] E. Aksu, A. Gencer, N. Calinli, H. Koralay, S. Cavdar, Investigation of odd-order harmonic susceptibilities of a bulk $Tl_2Ba_2Ca_2Cu_3O_{10}$ superconductors using critical state approach, Physica B 363 (2005) 158.

[4] P. Badica, T. Kondo, K. Togano, K. Yamada, Anisotropy of $Na_{0.35}CoO_2\cdot 1.3H_2O$ superconductor, Journal of Physics and Chemistry of Solids 67 (2006) 590.

[5] M. Irfan, Najmul Hasan, Syed Asad Manzoor, Baber Shabbir, Nawazish A. Khan, Enhanced three-dimensional excess conductivity in Be-doped $Cu_{0.5}Tl_{0.5}Ba_2Ca_{3-x}Be_xCu_4O_{12-\delta}$ (x=0,0.5,0.75,1.0,1.25,1.5) superconductors, Journal of Applied Physics **106** (2009) 113913.

[6] M. Mumtaz, Nawazish A. Khan, S.M. Hasnain, Adnan Younis, Role of mobile charge carriers and fluctuation induced conductivity in $(Cu_{0.5}Tl_{0.5-x}K_x)Ba_2Ca_3Cu_1Zn_3O_{12-\delta}$ superconductor, Journal of Superconductivity and Novel Magnetism 24 (2011) 1939.

[7] L.G. Aslamazov, A.L. Larkin, The influence of fluctuation pairing of electrons on the conductivity of normal metal, Physics Letters A **26** (1968) 238.

[8] K. Maki, The critical fluctuation of the order parameter in type-II superconductors, Progress of Theoretical Physics 39 (1968) 897.

[9] W.E. Lawrence, S. Doniach, in: Eizo Kanda (Ed.). Proceedings of the 12th International Conference on Low Temperature Physics, Keigaku, Tokyo (1971), 361.

[10] P.P. Freites, C.C. Tsuei, T.S. Plaskett, Thermodynamic fluctuations in the superconductor $Y_1Ba_2Cu_3O_{9-\delta}$: evidence for three-dimensional superconductivity, Physical Review B 36 (1987) 833.

[11] S.K. Patapis, E.C. Jones, Julia M. Phillips, D.P. Norton, D.H. Lowndes, Fluctuation conductivity of YBaCuO epitaxial thin films grown on various substrates, Physica C 244 (1995) 198.

[12] M.A. Obolenskil, R.V. Vovk, A, V. Bondarenko, Influence of high pressure on the fluctuation conductivity of $YBa_2Cu_3O_{7-\delta}$ single crystals with an oxygen deficiency, Low Temperature Physics 32 (2006) 614.

[13] T. Sato, H. Nakane, S. Yamazaki, N. Mori, Analysis of fluctuation conductivity in melt-textured $YBa_2Cu_3O_{7-y}$ superconductors with Ag-doping, Physica C 372 (2002) 1208.

[14] A.K. Pradhan, S.B. Roy, P. Chaddah, C. Chen, B.M. Wanklyn, Fluctuation phenomena in excess conductivity and magnetization of single-crystal $Bi_2Sr_2CaCu_2O_{8+y}$, Physical Review B 50 (1994) 7180.

[15] G. Balestrino, A. Nigro, R. Vaglio, M. Marinelli, Thermodynamic fluctuations in the 110-K Bi–Sr–Ca–Cu–O superconductor: evidence for two-dimensional behavior, Physical Review B **39** (1989) 12264.

[16] E.M.M. Ibrahim, S.A. Saleh, Influence of sintering temperature on excess conductivity in Bi-2223 superconductors, Superconductor Science and Technology **20** (2007) 672.

[17] L.J. Shen, C.C. Lam, J.Q. Li, J. Feng, Y.S. Chen, H.M. Shao, Thermodynamic fluctuation under high pressure in Hg-1223 superconductors, Superconductor Science and Technology **11** (1998) 1277.

[18] D.H. Kim, A.M. Goldman, J.H. Kang, K.E. Gray, R.T. Kampwirth, Fluctuation conductivity of Tl–Ba–Ca–Cu–O thin films, Physical Review B 39 (1989) 12275.

[19] C.A.C. Passos, M.T.D. Orlando, J.L. Passamai Jr, E.V.L. de Mello, H.P. S. Correa, L.G. Martinez, Resistivity study of the pseudogap phase for (Hg,Re)-1223 superconductors, Physical Review B 74 (2006) 094514.

[20] S.H. Han, J. Axnäs, B.R. Zhao, Ö. Rapp, Fluctuation conductivity at high temperatures in polycrystalline Hg, Tl-1223: is there 1D fluctuation behavior?, Physica C 408–410 (2004) 679

[21] Nawazish A. Khan, A.A. Khurram, Enhanced superconducting properties of $Cu_{0.5}Tl_{0.5}Ba_2(Ca_{2-y}Mg_y)Cu_3O_{10-\delta}$; y=0, 0.5, 1.0, and1.5, Applied Physics Letters 86 (2005) 152502.

[22] Nawazish A. Khan, M. Mumtaz, Enhanced superconductivity by Mg doping in $Cu_{1-x}Tl_xBa_2Ca_{2-y}Mg_y$ $Cu_{0.5}Zn_{2.5}O_{10-\delta}$, Materials Letters 62 (2008) 659.

[23] M. Mumtaz, Nawazish A. Khan, Improved interplane and intergranular coupling by Mg doping at Ca site in $Cu_{0.5}Tl_{0.5}Ba_2Ca_2(Cu_{0.5}Zn_{2.5})O_{10-\delta}$ superconductor, Journal of Applied Physics 103 (2008) 083913.

[24] S. Hikami, A.I. Larkin, Magnetoresistance of high temperature superconductor, Modern Physics Letters B 2 (1988) 693.

[25] B. Oh, K. Char, A.D. Kent, M. Naito, M.R. Beasley, T.H. Geballe, R. H. Hammond, A. Kapitulnik, J.M. Graybeal, Upper critical field, fluctuation conductivity, and dimensionality of $YBa_2Cu_3O_{7-x}$, Physical Review B 37 (1988) 7861.

[26] M. Mumtaz, S.M. Hasnain, A.A. Khurram, Nawazish A. Khan, Fluctuation induced conductivity in $(Cu_{0.5}Tl_{0.5-x}K_x)Ba_2Ca_3Cu_4O_{12-\delta}$ superconductor, Journal of Applied Physics 109 (2011) 023906.

[27] P. Shun-Hui Han, Lundqvist, Ö. Rapp, Excess conductivity in $Y_{1-2x}Ca_xTb_xBa_2Cu_3O_{7-\delta}$, Physica C 282 (1997) 1571.

[28] T. Sato, H. Nakane, S. Yamazaki, N. Mori, S. Hirano, S. Yoshizawa, T. Yamaguchi, Analysis of fluctuation conductivity in melt-textured $D_yBa_2Cu_3O_y$ superconductors, Physica C 392 (2003) 643.

[29] F. Vidal, J.A. Veira, J. Maza, D. Garcia-Alvarado, E. Moran, M. A. Alario, Excess electrical conductivity above T_c in high-temperature superconductors, and thermal fluctuations, Journal of Physics C: Solid State Physics 21 (1999) L599.

[30] Yu. Shun-Hui Han, Eltsev, Ö. Rapp, Three-dimensional XY critical fluctuations of the dc electrical conductivity in $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals, Physical Review B 61 (2000) 11776.

[31] S.B. Azzouz, M. Zouaoui, M. Annabi, M.B. Salem, Fluctuation conductivity analysis on the Bi-based superconductors processed under same conditions, Physica Status Solidi 3 (2006) 3048.

[32] H. Ihara, Y. Sekita, H. Tateai, N.A. Khan, K. Ishida, E. Harashima, T. Kojima, H. Yamamoto, K. Tanaka, Y. Tanaka, N. Terada, H. Obara, Superconducting properties of $Cu_{1-x}Tl_x$-1223 $[Cu_{1-x}Tl_x(Ba,Sr)_2Ca_2Cu_3\ O_{10-y}]$ thin films, IEEE Transactions on Applied Superconductivity 9 (1999) 155.