



Effect of Ge^{4+} and Mg^{2+} doping on superconductivity, fluctuation induced conductivity and interplanar coupling of $\text{TlSr}_2\text{CaCu}_2\text{O}_{7-\delta}$ superconductors

A. Ali Yusuf^a, A.K. Yahya^{a,*}, Nawazish A. Khan^b, F. Md. Salleh^a, E. Marsom^c, N. Huda^a

^a Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

^b Materials Science Laboratory, Department of Physics, Quaid-i- Azam University, Islamabad 45320, Pakistan

^c College of Engineering, University Tenaga Nasional, 43009 Kajang, Malaysia

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ABSTRACT

Substitution of Ge^{4+} in place of Cu in $\text{Tl}_{0.85}\text{Cr}_{0.15}\text{Sr}_2\text{CaCu}_{2-x}\text{Ge}_x\text{O}_{7-\delta}$ ($x = 0-0.6$) showed initial increase in zero critical temperature value, $T_{c\text{ zero}}$ from 98 K ($x = 0$) to 100 K ($x = 0.1$) and in the range of 85–86 K for $x = 0.2-0.3$. The slow decrease in $T_{c\text{ zero}}$ is unexpected as tetravalent Ge^{4+} substitution is expected to strongly reduce hole concentration in the samples and suppress $T_{c\text{ zero}}$. Excess conductivity analyses of resistance versus temperature data based on Aslamazov–Larkin (AL) theory revealed that the substitution induced 2D-to-3D transition of fluctuation induced conductivity with the highest transition temperature, T_{2D-3D} observed at $x = 0.1$. FTIR spectroscopy analysis indicates Ge^{4+} substitution cause reduction in $\text{CuO}_2/\text{GeO}_2$ interplanar distance while our calculation based on Lawrence–Doniach model revealed highest superconducting coherence length, $\xi_c(0)$ and interplanar coupling, J at $x = 0.3$. On the other hand, substitution of divalent Mg^{2+} for Ca^{2+} in $(\text{Tl}_{0.5}\text{Pb}_{0.5})(\text{Sr}_{1.8}\text{Yb}_{0.2})(\text{Ca}_{1-y}\text{Mg}_y)\text{Cu}_2\text{O}_7$ ($y = 0-1.0$), which is not expected to directly vary hole concentration, surprisingly caused $T_{c\text{ zero}}$ to increase from 89.6 K ($y = 0$) to an optimum value of 95.9 K ($y = 0.6$) before decreasing with further increase in y . Excess conductivity analyses showed 2D-to-3D transition of fluctuation induced conductivity for all samples where the highest T_{2D-3D} was at $y = 0.4$. Similar calculation revealed highest values of $\xi_c(0)$ and J also at $y = 0.4$. FTIR analysis of the samples indicates inequivalent $\text{Cu}(1)-\text{O}(2)-\text{Pb/Tl}$ lengths and possible tilting of CuO_2 plane as a result of Mg^{2+} substitution. The increased $\xi_c(0)$ and J as a result of the Ge^{4+} and Mg^{2+} substitutions are suggested to contributed to sustenance of superconductivity above 80 K in the samples.

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1. Introduction

Since the discovery of high temperature superconductivity in La–Ba–Cu–O by Bednorz and Muller in 1986 [1] various other high temperature superconductor (HTSC) compounds have been successfully synthesized. In contrast to conventional superconductors, HTSC has eccentric features such as short coherence length, low carrier density and critical temperature, T_c well above 30 K [2]. The breaking of the 30 K limit set by the BCS theory signals inapplicability of the theory in explaining the phenomena of high-temperature superconductivity. The search for an acceptable theoretical explanation of HTCS has triggered intense research focusing on both the superconducting state below T_c and the normal state above T_c [3–7].

One of the properties of HTSC extensively studied in the normal state region is its electrical resistivity which was generally observed to start to deviate away from metallic normal state behavior curve at temperatures well above zero-resistance critical

temperature, $T_{c\text{ zero}}$. The deviation is represented by a gradual reduction in resistivity below the projected metallic resistivity curve upon cooling indicating emergence of excess conductivity [3]. The excess conductivity region was suggested to be dominated by superconducting fluctuation behavior (SFB) which arises from formation of Cooper pairs at the very initial stage which interacted with already existing normal-state electrons [3,8]. The study of fluctuation induced conductivity behavior provides intrinsic information on high temperature superconductivity such as the dimensionality of the superconducting fluctuation and coherence length at its commencement stage [9].

Fluctuation induced conductivity analysis has been reported for different HTSC compounds over the years. (Hg, Tl) 1223 [10] showed one dimensional (1D) fluctuation behavior whereas most of Bi–Sr–Ca–Cu–O [5,6], La–Ba–Ca–Cu–O [11,12] and HBCO [13] essentially showed two dimensional (2D) fluctuation behavior. On the other hand Y123 [8,14] and (Cu, Tl)-based [15–17] revealed cross over from 2D to 3D fluctuation behavior with decreasing temperature. For Tl-based superconductors, excess conductivity of $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_{8+\delta}$ (Tl-2212) [18,19], Tl–Sr–Ca–Cu–O (Tl-1212) [7,20,21], (Tl, Hg)-1223 [22] and also $\text{TlCa}_3\text{BaCuO}_x$ [23]

* Corresponding author. Tel.: +60 3 55444613; fax: +60 3 55444562.

E-mail address: ahmad191@salam.uitm.edu.my (A.K. Yahya).

have been investigated. $Tl_{1-x}Cu_xSr_{1.2}Yb_{0.8}CaCu_2O_{7-\delta}$ [20], $Tl_{1-x}Cu_xSr_{1.6}Yb_{0.4}CaCu_2O_{7-\delta}$ [21] and $Tl_{0.5}Pb_{0.5}Sr_{2-x}Yb_xCaCu_2O_{7-\delta}$ [7] showed strong influence of the substitutions on fluctuation behavior with transition from 2D to 3D behavior. Interestingly, $Tl_{0.5}Pb_{0.5}Sr_{2-y}Mg_yCa_{0.8}Yb_{0.2}Cu_2O_{7-\delta}$ showed 1D fluctuation behavior before transition to 2D behavior [21] and $Tl_{0.8}Hg_{0.2}Ba_{2-}$

$Ca_{2-x}R_xCu_3O_{9-\delta}$ ($R = Sm$ and Yb) revealed the transitions from 1D to 2D and 2D to 3D as temperature is lowered [22].

There are several methods for analysis of fluctuation induced behavior such as Aslamazov–Larkin (AL), Maki–Thompson (MT), Lawrence–Doniach (LD), and Hikami–Larkin (HL) methods [24–27]. Excess conductivity $\Delta\sigma$ [5] is defined by:

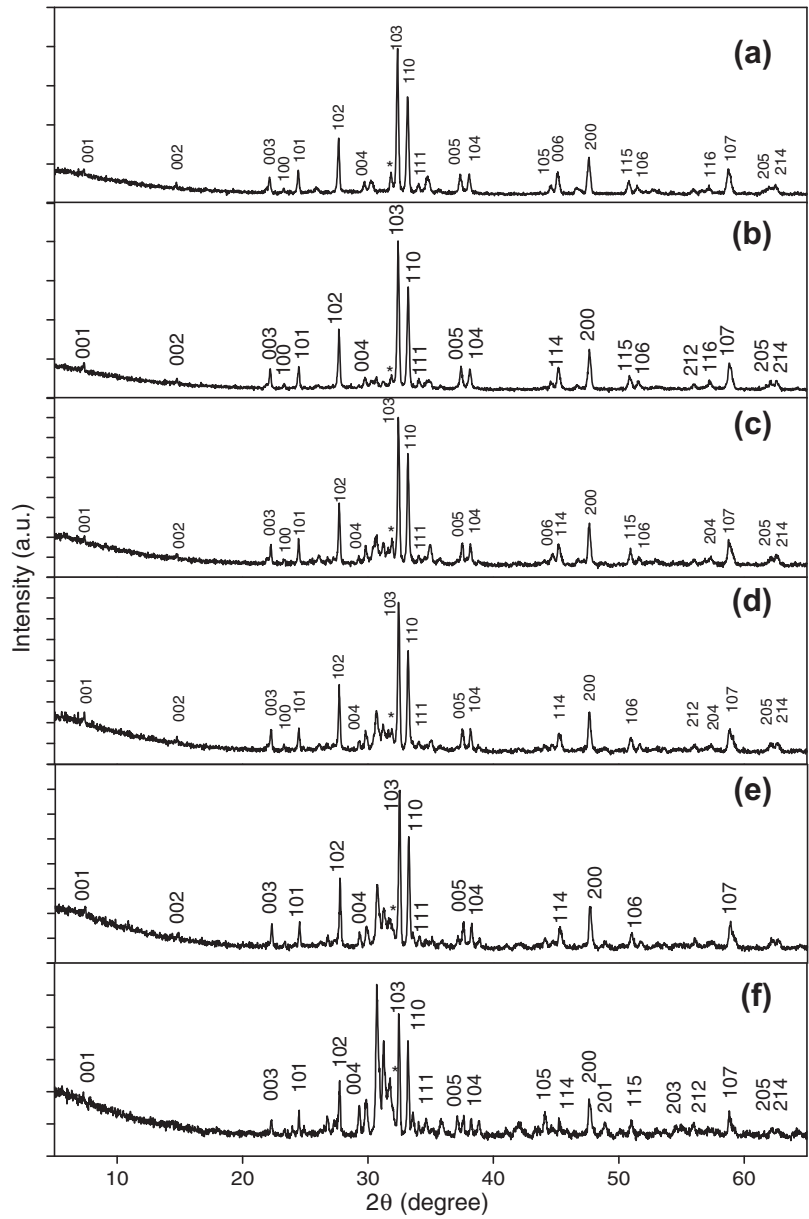


Fig. 1. Powder X-ray diffraction patterns for $Tl_{0.85}Cr_{0.15}Sr_2CaCu_{2-x}Ge_xO_{7-\delta}$ for (a) $x = 0$, (b) $x = 0.1$, (c) $x = 0.2$, (d) $x = 0.3$, (e) $x = 0.4$, (f) $x = 0.6$, showing major 1212 phase. 1201 phase is indicated by *.

Table 1
 T_c onset, T_c zero, 1212:1201 phase ratio, lattice parameters of $Tl_{0.85}Cr_{0.15}Sr_2CaCu_{2-x}Ge_xO_{7-\delta}$.

(x)	Normal state behavior	T_c onset (K) ± 0.1	T_c zero (K) ± 0.1	1212:1201 phase ratio (vol.%) ± 1	1212 lattice parameter	
					a (Å) ± 0.001	c (Å) ± 0.003
0	Metallic	102.2	98.6	86:3	3.825	12.056
0.1	Metallic	104.8	100.2	91:3	3.824	12.033
0.2	Metallic	93.4	86.2	84:9	3.827	12.008
0.3	Metallic	92.8	84.5	83:7	3.823	12.004
0.4	Metallic–Semimetallic	54.3	–	72:15	3.822	11.984
0.6	Insulating	–	–	60:25	3.827	11.980

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