

EFFECT OF NANO-SIZED Al_2O_3 ADDITION ON THE TRANSPORT CRITICAL CURRENT DENSITY OF BULK $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}$ SUPERCONDUCTOR

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ABSTRACT

The effect of nano-sized Al_2O_3 addition on the transport critical current density of $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}$ (Ti-1212) superconductor was investigated. The $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ superconductor for $x = 0.0$ to 0.05 wt.% were prepared using high purity oxide powders via solid state reaction method. Samples were studied by powder X-ray diffraction method, electrical resistance measurements, scanning electron microscopy (SEM) and Dispersive X-Ray Analysis (EDX). The zero-resistance temperature, $T_{c\text{-zero}}$ was found to decrease from 95 K to 87 K with increasing nano-sized Al_2O_3 addition. The temperature dependence of J_c of the non-added and Al_2O_3 added bulk samples were investigated. The J_c of the non-added bulk sample was 1320 mA/cm^2 at 30 K while J_c of the $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_{0.02}$ bulk sample was 4090 mA/cm^2 at 30 K. Nano-sized Al_2O_3 added bulk samples showed a higher J_c (more than 3 times) compared with the non-added sample. This study showed that nano-sized Al_2O_3 could act as effective flux pinning centers and lead to the enhancement of J_c in Ti-1212 superconductors.

Keywords: nano-sized Al_2O_3 ; transport critical current density; Ti-1212;

INTRODUCTION

The superconductor $\text{TiSr}_2\text{CaCu}_2\text{O}_7$ (Ti-1212) was reported with transition temperature (T_c) at 80 K [1]. It is not easy to prepare superconductors Ti-1212 because of the high valence of Cu [2]. Substitution of elements with higher valences improves the superconducting properties and stabilized the Ti-1212 phase [3]. Partial substitution of

Cr, Pb and Bi at Tl site can stabilize the Tl-1212 phase [4-6]. The substitution of Cr at 10 - 20% can increase the T_c to 110 K. This is because of the substitution of elements with higher valence can reduce the formal valence of Cu, optimize the holes carrier concentrations and improve the superconducting properties [7]. Substitution of rare-earth elements into Ca site and Sr site can increase the T_c to 100 K and improve the formation of Tl-1212 phase [8-10].

The critical current density (J_c) is a crucial parameter of high temperature superconductor for a variety of possible applications [11]. Transport critical current density J_c is the maximum current density that can flow before the material turns normal. The temperature dependencies of the critical current density may provide important information for identifying the flux pinning mechanism. The behavior of the superconductor critical current density in applied magnetic field was found to be increased when nanoparticles were added in the samples [12-15], which can be attributed to the presence of the flux pinning centers. By pinning the flux line effectively, vortex movement can be prevented. Hence, the critical current density is increased. To overcome this problem, one of the solutions is by adding nano-sized particles as pinning centers [16].

Artificial impurities likes γ -Fe₂O₃, Cr₂O₃, Fe₃O₄ and NiFe₂O₄ have been employed to superconductors YBa₂Cu₃O_{7- δ} , Bi-Sr-Ca-Cu-O and MgB₂ to enhance its transport critical current density [17-22]. For thallium-based superconductors, most of the studies focused on the transport current enhancement of by element substitutions [4-10]. Not many works have been done on the effects of artificial impurities addition on thallium-based superconductors. It was found that addition of nano-sized CaO and MgO have improved the phase formation and enhanced the critical current density of thallium-based superconductors [23-24].

It is interesting to investigate the effect of nano-sized Al₂O₃ addition on the transport critical current density of the Tl-1212 superconductor. In this study, we report the effect of nano-sized Al₂O₃ addition on bulk (Tl_{0.85}Cr_{0.15})Sr₂CaCu₂O_{7- δ} (Al₂O₃)_x superconductor for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt. %. Results from powder X-ray diffraction method, electrical resistance measurements, critical current density measurements, scanning electron microscopy (SEM) and Dispersive X-Ray Analysis (EDX) are reported.

MATERIALS AND METHODS

Samples with nominal starting composition (Tl_{0.85}Cr_{0.15})Sr₂CaCu₂O_{7- δ} (Al₂O₃)_x for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt.%. was prepared using the solid-state reaction method. High purity oxide powders ($\geq 99.99\%$) SrO, CaO and CuO were mixed and ground in appropriate amount. The mixed powders were sintered at 900 °C for 48 hours with an intermediate grinding. The appropriate amount of Tl₂O₃, Cr₂O₃ and Al₂O₃ were added to the precursor and ground thoroughly. The mixed powders were then pressed into pellets 13 mm diameter and 2 mm thickness. Pellets were heated at 1000 °C for 4

minutes in flowing oxygen and followed by furnace cooling. Pure $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}$ pellet was prepared for comparison.

The electrical resistance-temperature measurements were carried out on pellets by the four-point probe technique in conjunction with a CTI Cryogenics Close-cycle Refrigerator Model 22 and Lakeshore Temperature Controller Model 325. The temperature at which the transition to superconductivity occurs is known as the critical temperature (T_c). Pellets were then cut into bar-shaped for the transport critical current density (J_c) measurement. The measurement was carried out in the bar-shaped samples from 30 – 77 K. The transport critical current (I_c) was identified using 1 $\mu\text{V}/\text{cm}$ criterion. The J_c was calculated using the equation below. A is cross sectional area of the bar-shaped samples.

$$J_c = \frac{I_c}{A} \quad (1)$$

Powder X-ray Diffraction (XRD) measurement was carried out by using a Siemens D5000 diffractometer with $\text{CuK}\alpha$ radiation source to identify the resultant phase. Lattice parameters a and c for the tetragonal, were calculated by using software X'pert HighScore. The volume fraction of the 1212 and 1201 phase was estimated by assuming the amounts of 1212 and 1201 phase are proportional to the strongest diffraction line of each phase. The ratio of 1212:1201 phase was calculated from the diffraction intensities of each phase using the equations below:

$$Tl-1212(\%) = \frac{\sum I_{1212}}{\sum I_{1212} + \sum I_{1201}} \times 100\% \quad (2)$$

$$Tl-1201(\%) = \frac{\sum I_{1201}}{\sum I_{1212} + \sum I_{1201}} \times 100\% \quad (3)$$

Scanning electron microscopy (SEM) was used to identify the grain size of the samples. The distribution of nano-sized Al_2O_3 in the sample was determined by Dispersive X-Ray Analysis (EDX).

RESULTS AND DISCUSSION

The powder X-ray Diffraction (XRD) patterns of $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ superconductor for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt. % are shown in Figure 1. All of the samples indicate a dominant phase of Tl-1212 with a minor phase of Tl-1201. All samples show the tetragonal lattice structure which belongs to the $P4/\text{mmm}$ space group. Table 1 shows the $T_{c-\text{onset}}$, $T_{c-\text{zero}}$, J_c at 77 K, lattice parameters and volume fraction of 1212 and 1201 phase for $(\text{Ti}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$. The highest volume fraction of the Tl-1212 phase was observed in samples $x = 0.03$ wt.% and $x =$

0.04 wt.%, which is 84%. The volume fraction has been increased with the increase of nano-sized Al_2O_3 . The results are similar to the previous findings which show the nano particles addition favors the formation of Tl-1212 phase [23-24].

Table 1: $T_{c\text{-onset}}$, $T_{c\text{-zero}}$, J_c at 77 K, lattice parameters and volume fraction of 1212 and 1201 phase in $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$

x (wt.%)	$T_{c\text{-onset}}$ (K)	$T_{c\text{-zero}}$ (K)	J_c at 77 K (mA/cm ²)	a (Å)	c (Å)	Volume Fraction 1212:1201 (%)
0.0	102	95	820	3.822	12.021	74:26
0.01	95	88	1713	3.821	12.035	76:24
0.02	95	88	2656	3.824	12.033	80:20
0.03	95	87	2302	3.818	12.029	84:16
0.04	94	87	1585	3.819	12.031	84:16
0.05	94	87	1093	3.819	12.029	83:17

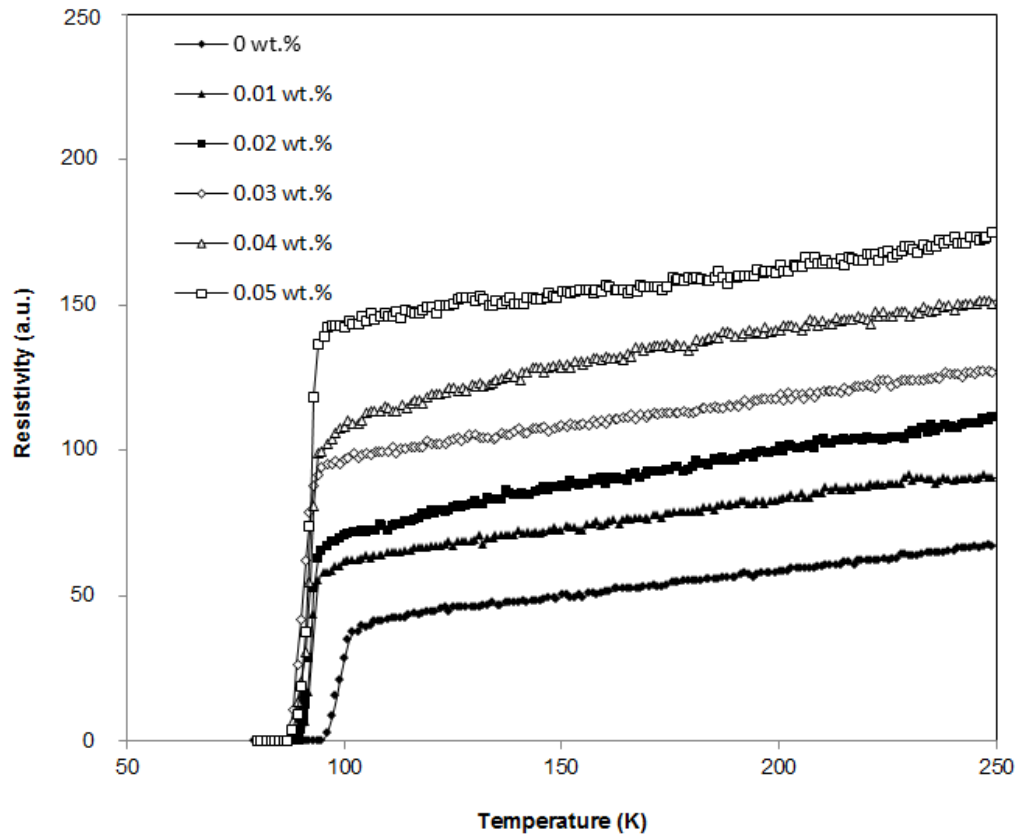


Figure 1: Powder X-ray Diffraction (XRD) patterns of $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ superconductor for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt.% showing a major 1212 phase. The 1201 phase is indicated by (*)

The electrical resistivity versus temperature curves for pure and nano-sized Al_2O_3 added samples are shown in Figure 2. All the samples showed a metallic normal state behavior before the transition temperature (T_c). The sample without addition of nano Al_2O_3 showed the highest $T_{c\text{-onset}}$ and $T_{c\text{-zero}}$ at 102 K and 95 K, respectively. The $T_{c\text{-zero}}$ was found to decrease from 95 K to 87 K with increasing nano-sized Al_2O_3 addition from $x = 0.01$ wt.% to $x = 0.05$ wt.%. The $T_{c\text{-zero}}$ was gradually suppressed with the addition of nano-sized particles.

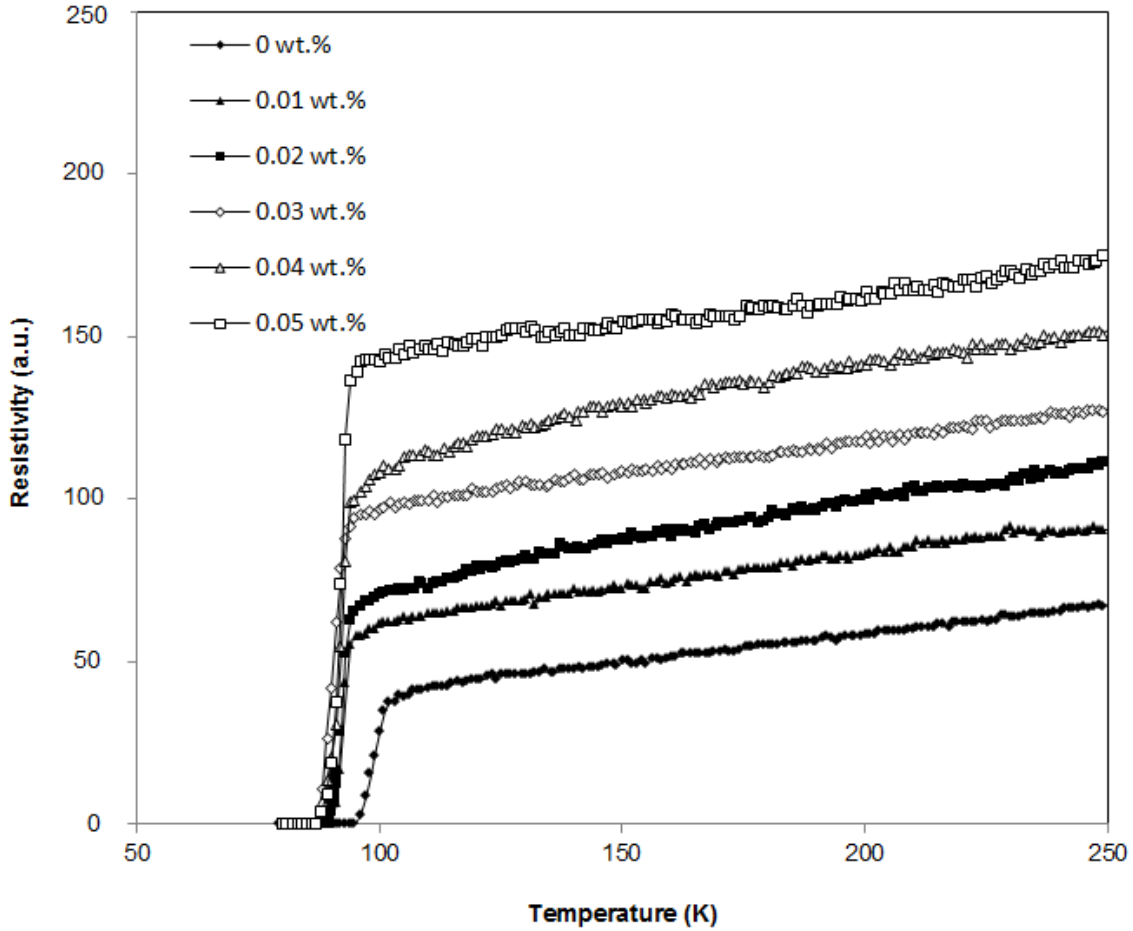


Figure 2: Electrical resistivity versus temperature curves for pure and nano-sized Al_2O_3 added samples

The transport critical current density (J_c) of $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt. % are shown in Figure 3. The inset shows transport critical current density at 77 K versus amount of nano-sized Al_2O_3 . Transport critical current density for all samples decreased linearly with increasing temperature (30 – 77 K) as a consequence of thermally activated flux creep. Sample with 0.02 wt.% nano-sized Al_2O_3 showed the highest J_c , which was found to be 4090 mAcm^{-2} at 30 K and 2656 mAcm^{-2} at 77 K. Transport critical current density (J_c) at 30 K for the sample with 0.02 wt.% Al_2O_3 was 3 times higher than the J_c for the sample without Al_2O_3 . The

J_c was found to decrease rapidly with the higher amount of nano-sized Al_2O_3 . The results is similar to the previous report which nano MgO was added to Tl-1212 phase [25].

Overall, the nano-sized Al_2O_3 addition has caused the enhancement in current carrying capacity of Tl-1212. Nano-sized Al_2O_3 which was used in this work has the average grain size $l = 13$ nm. This l is smaller than the penetration depth ($\lambda \approx 100$ nm) but much larger than the coherence length ($\xi = 5\text{\AA}$) of Tl-1212 superconductor [26]. If characteristic length l falls in the range of $\xi < l < \lambda$, a strong interaction between flux line network and impurities can be expected resulting in a frozen flux superconductor [16]. As such, the J_c enhancement in Tl-1212 phase superconductors is basically originated from the increased flux pinning with the addition of nano-sized Al_2O_3 .

The SEM micrographs for $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ for $x = 0.0, 0.02$ and 0.04 wt. % samples with nano-sized Al_2O_3 are shown in Figure 4(a), (b) and (c). Most of the samples showed the dense microstructure with low porosity. All of the samples have the similar average grain size of $8\text{ }\mu\text{m}$. The porosity level was improved with 0.02 wt.% nano Al_2O_3 addition. This improvement has led to J_c enhancement for the same sample. The red dots shown in Fig. 4(b) and (c) indicated the distribution of nano-sized Al_2O_3 . The nano particles are well distributed in the Tl-1212 samples.

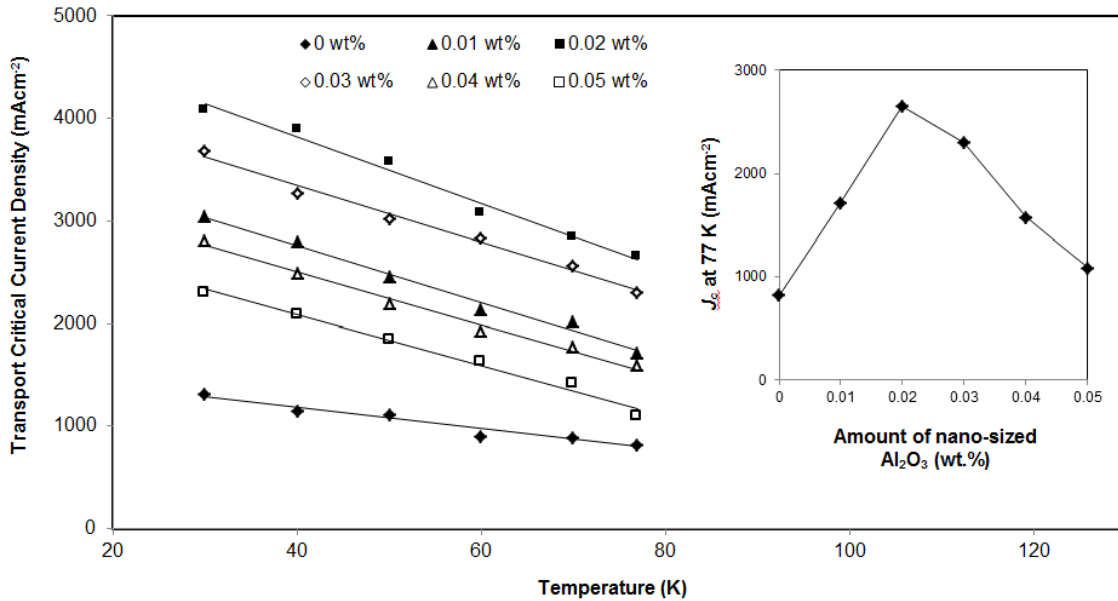


Figure 3: Transport critical current density (J_c) versus temperature curves for $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ and transport critical current density at 77 K versus amount of nano-sized Al_2O_3 addition curve (inset)

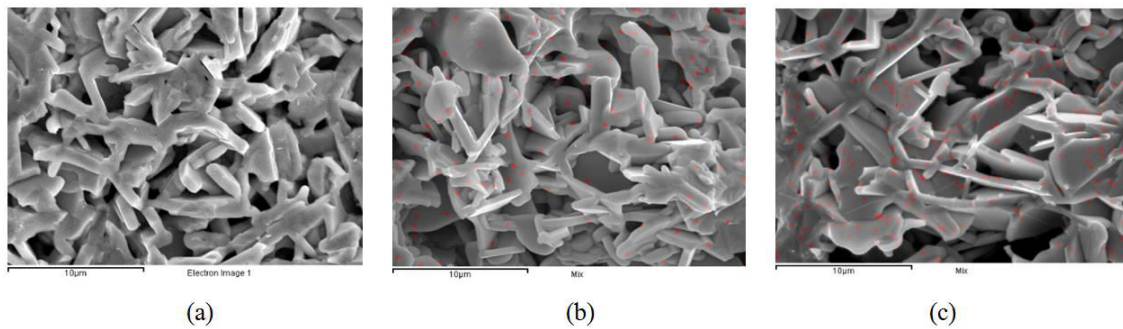


Figure 4: SEM micrographs of $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ for (a) $x = 0.0$ wt.%, (b) $x = 0.02$ wt.% and (c) $x = 0.04$ wt.%. The red dots indicated the distribution of the nano-sized Al_2O_3

CONCLUSION

In conclusion, samples with nominal starting composition $(\text{Tl}_{0.85}\text{Cr}_{0.15})\text{Sr}_2\text{CaCu}_2\text{O}_{7-\delta}(\text{Al}_2\text{O}_3)_x$ for $x = 0.0, 0.01, 0.02, 0.03, 0.04$ and 0.05 wt. % have been prepared and investigated by powder X-ray diffraction method, electrical resistance measurements, scanning electron microscopy (SEM) and Dispersive X-Ray Analysis (EDX). All of the samples showed a dominant phase of 1212 with minor phase of 1201. The addition of nano-sized Al_2O_3 has improved the formation of Tl- 1212 phase. However, the addition of nano-sized Al_2O_3 as impurities has suppressed the T_c . This study showed that nano-sized Al_2O_3 could act as effective flux pinning centers and lead to the enhancement of J_c in Tl-1212 superconductors.

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