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Impact of SnF_2 Addition on AC Susceptibility and Electrical Properties of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ Superconductor

Norazimah Mohd Yusof[1], Ilhamsyah Putra Abu Bakar[2], Nurul Raihan Mohd Suib[3], Madihah Mujaini[4], Roslan Abd Shukor[2], Masnita Mat Jusoh[3], Huda Abdullah[5] and Nur Jannah Azman[1]*

[1]Faculty of Applied Sciences, Universiti Teknologi MARA, Cawangan Negeri Sembilan, Kampus Kuala Pilah, 72000, Kuala Pilah, Negeri Sembilan, Malaysia
[2]Department of Applied Physics, Universiti Kebangsaan Malaysia 43600 Bangi, Selangor, Malaysia
[3]Pusat Asasi UiTM Kampus Dengkil, Universiti Teknologi MARA, 43800 Dengkil, Selangor, Malaysia
[4]Center for Nuclear Energy, College of Engineering, IKRAM-UNITEN, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
[5]Centre of Advanced Electronic and Communication Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia
*Corresponding author (e-mail: nurjannah@uitm.edu.my)

The effect of SnF_2 addition on the superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. % is reported. All samples were prepared by the solid-state reaction route. The powder X-ray diffraction (XRD) patterns revealed a single Bi-2212 phase for all samples. Scanning electron micrographs showed plate-like structure which increased in grain sizes with SnF_2 addition. The temperature-dependent resistance measurement showed the highest $T_{c\ onset}$ (91 K) was for x = 0.5 wt. % sample which belongs to the Bi-2212 phase. The susceptibility transition temperature, $T_{c\chi}$, for all samples was between 72-81 K. The lower peak temperature at the imaginary part of susceptibility χ", T_{p2} was suppressed with SnF_2 addition indicating the weakening of intergranular coupling and flux pinning force. This work showed that SnF_2 addition not only resulted in a single Bi-2212 phase but also enhanced the transition temperature and grains growth of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$. The role of internal lattice strain in improving the transition temperature of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ was also discussed.

Keywords: SnF_2; Bi-2212; internal lattice strain; AC susceptibility

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The $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$, also known as the Bi-2212 phase, is one of the interesting families of Bi-based cuprates superconductors. It superconducts at around 80 to 83 K [1, 2]. Although the critical temperature of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2$ (Bi-2223) is higher (118 K) [3] than the Bi-2212 phase superconductor, it is easier to form a single Bi-2212 phase than a Bi-2223 phase [4]. Moreover, the ability to sustain high field properties at low temperatures compared to other Bi-based families makes it advantageous for wire and tape applications [5-8]. However, the existing weak links between the grains and poor pinning capability pose significant drawbacks for this superconductor, which need to be overcome before it can be integrated into technological applications.

It is well known that adding elements and compounds to the Bi-based superconductor can enhance its superconducting properties. Additionally, introducing defects via radiation has been observed to increase the flux pinning capability of Bi-based superconductors [9, 10]. Recently, there has been an increased interest in exploring the influence of metal sulfides such as PbS [2], FeS [11], and Cr_2S_3 [12], CuS [13] on the Bi-based superconductor.

Apart from that, metal fluorides present another interesting avenue for potentially improving the cuprate-based high-temperature superconductor properties. It is also noteworthy that oxygen and fluorine share the same period (Period 2) in the periodic table. In the $YBa_2Cu_3O_7$ superconductor, the small amount of FeF_2 addition improved the transport and superconducting properties [14]. The transition temperature was enhanced for the nanosized NiF_2 added Bi-2223 superconductor [15]. NiF_2 added Bi-2223 tapes showed a significant improvement of J_c compared with the non-added tape [16].

The influence of various metal fluorides on Bi-2212 remains an interesting research area. In this study, we investigated the effect of SnF_2 addition on Bi-2212 superconductor. The SnF_2, also known as stannous fluoride, is an excellent ionic conductor due to the high polarizability of Sn^{2+} and weak coordination of F^- ion [17]. SnF_2 forms several solid electrolytes when combined with monovalent and divalent fluorides, making them highly appealing for diverse electrochemical applications and solid-state ionic devices [18, 19]. SnF_2 exhibits three polymorphic forms, with α-SnF_2 (monoclinic) stable

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at room temperature. In the temperature range of 413–453 K, it transforms γ-SnF_2 (tetragonal), maintaining stability up to the melting temperature (488 K). Upon cooling, γ-SnF_2 undergoes a second-order phase transition to β-SnF_2 (orthorhombic) [20-22].

Hence, the interaction between SnF_2 and Bi-2212 is interesting to study. This work aimed to study the effects of SnF_2 addition on the superconducting properties of Bi-2212. The structure, microstructure, electrical properties, and AC Susceptibility were reported.

EXPERIMENTAL DETAILS

Powders with the starting formula of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ were synthesized via the solid-state reaction method. High purity powders (99.9 %) of Bi_2O_3, PbO, $SrCO_3$, CaO, and CuO were weighed, ground, and heated to two consecutives 24 h heating cycle at 800 °C. The mixed black powder was subsequently ground and heated for 50 h at 840 °C. Then, SnF_2 powders were added with stoichiometry of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0, 0.1, 0.2, 0.3, 0.4, 0.5 and 1.0 wt. %. The resultant powders were formed into pellets with a diameter of 13 mm and a thickness of 2 mm. The pellets were heated at 840 °C for 24 h.

A Bruker D8 Advance X-ray diffractometer, utilizing Cu Kα radiation, was employed to identify the phases. The lattice parameters were determined using the Pawley method through Xpert' Highscore software. A JEOL Model JSM6010PLUS/LA scanning electron microscope (SEM) was employed to observe the microstructure of the samples.

The temperature-dependent DC electrical resistance measurements were carried out using the four-probe method with silver paint contacts, in conjunction with a CTI Cryogenics Model 22 closed-cycle refrigerator. A constant current source from a Lake Shore Model 340 ranging between 1 and 100 mA was used for all measurements.

For AC susceptibility measurements, an AC susceptometer from Cryo Industry with model number REF-1808-ACS was utilized. The samples were cut into bar shapes with a cross-section of 2 mm × 2 mm, and an AC signal frequency of 295 Hz was applied with a constant magnetic field (5 Oe) parallel to the sample throughout the measurement.

RESULTS AND DISCUSSION

The powder X-ray diffraction pattern shown in Figure 1 revealed that a nearly single Bi-2212 (>97 %) phase was observed for all samples. This indicated that the SnF_2 did not suppress the Bi-2212 phase. Besides that, no peaks corresponding to SnF_2 were observed in all added samples. The Bi-2212 phase can be indexed based on the orthorhombic structure using ICDD database with number PDF-00-046-0781.

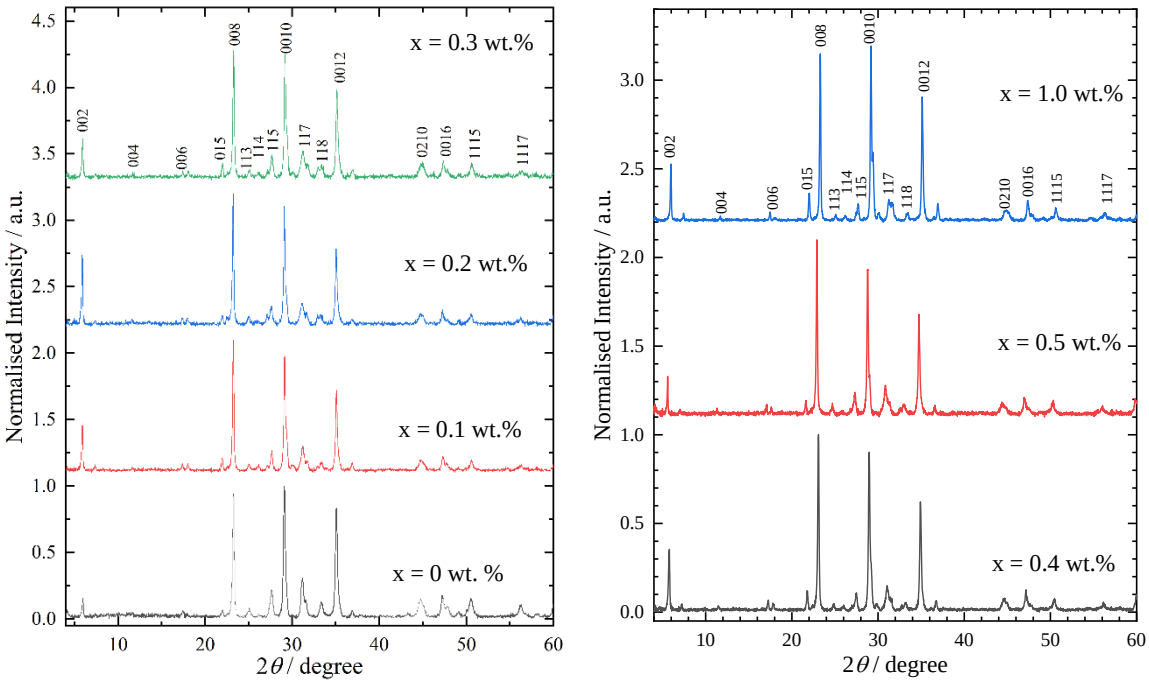

Figure 1. XRD pattern of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %.

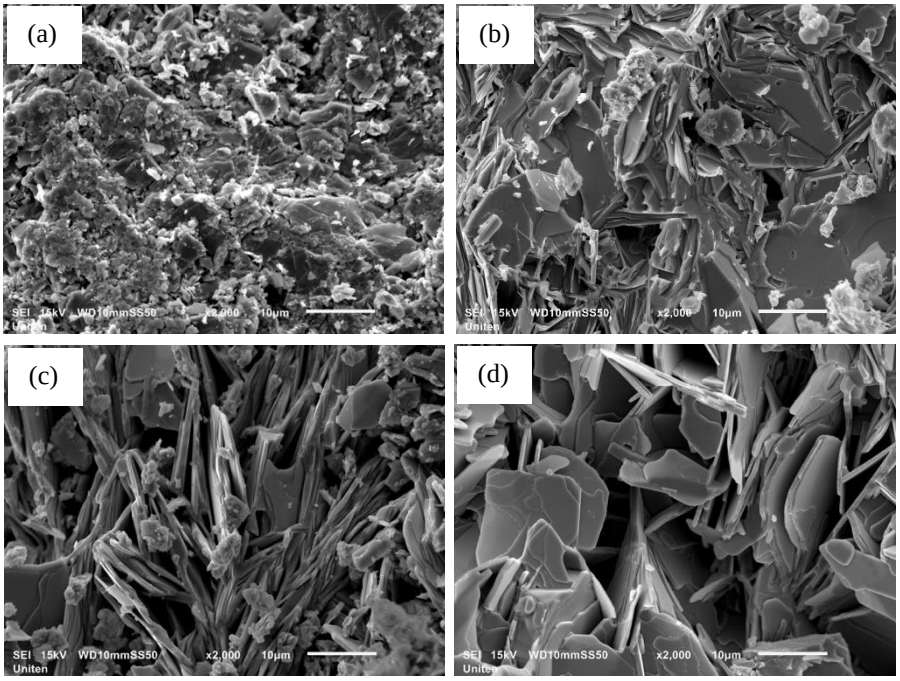

Figure 2. SEM micrograph of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with (a) x = 0, (b) x = 0.2, (c) x = 0.3 and (d) x = 0.5 wt. %.

The lattice parameters for x = 0 wt. % sample were a = 5.316 Å, b = 5.434 Å and c = 30.705 Å. All added samples showed an increase of lattice parameters a and c as well as unit cell volume compared to the non-added samples. This demonstrated that the Sn atom may be incorporated into the unit cell of the Bi-2212 phase. Nevertheless, additional direct measurements such as Rietveld refinement using neutron diffraction and XRD are essential to substantiate this claim. The internal lattice strain was calculated by the ratio c/a which is shown in Table 1. In general, the ratio c/a decreased for all added samples except for x = 1.0 wt. % sample. Typically, the elongation in c/a axes is connected to the lengthening of the Cu-O bond, which regulates the dimensions in major planes [23, 24]

Figures 2(a), 2(b), 2(c) and 2(d) show the SEM micrograph for x = 0, 0.2, 0.3 and 0.5 wt. % samples, respectively. All samples revealed a platelet-like and layered microstructure with some porosity. Partial melting was also observed for x = 0, 0.2, and 0.3 wt. % samples. Besides that, the grain sizes increased as the amount of SnF_2 increased indicating that the SnF_2 promoted the grains growth of Bi-2212 phase.

The normalized electrical resistance versus temperatures curves for $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. % are shown in Figure 3. In this work, $T_{c\ onset}$ is the temperature at which the superconducting phase begins to occur, while $T_{c\ zero}$ is the temperature at which the electrical resistance is zero. All samples exhibited normal metallic properties before onset transition temperature, $T_{c\ onset}$ except for x =1.0 wt. % sample. The x =1.0 wt. % sample showed the semi-metal like behavior above $T_{c\ onset}$. The $T_{c\ onset}$ and zero transition temperature, $T_{c\ zero}$ for x = 0 wt. % samples were 84 K and 71 K, respectively. In general, T_c onset was enhanced up until x = 0.5 wt. % but $T_{c\ zero}$ was slightly suppressed after SnF_2 addition. The highest $T_{c\ onset}$ was 91 K for the 0.5 wt. % sample. There was no systematic change in the transition width ΔT_c (11 -22 K) for all samples.

The improvement of $T_{c\ onset}$ particularly with a low amount of addition can be ascribed to the increase in chemical pressure induced by the presence of Sn which was signified by the changes in internal lattice strains and the increase in unit cell volume [25]. Moreover, it was suggested that $T_{c\ onset}$ = 91 K for x = 0.5 % sample belonged to the Bi-2212 phase. This was supported by the XRD results, which indicated that no peaks belonging to the Bi-2223 phase were observed in any of the samples.

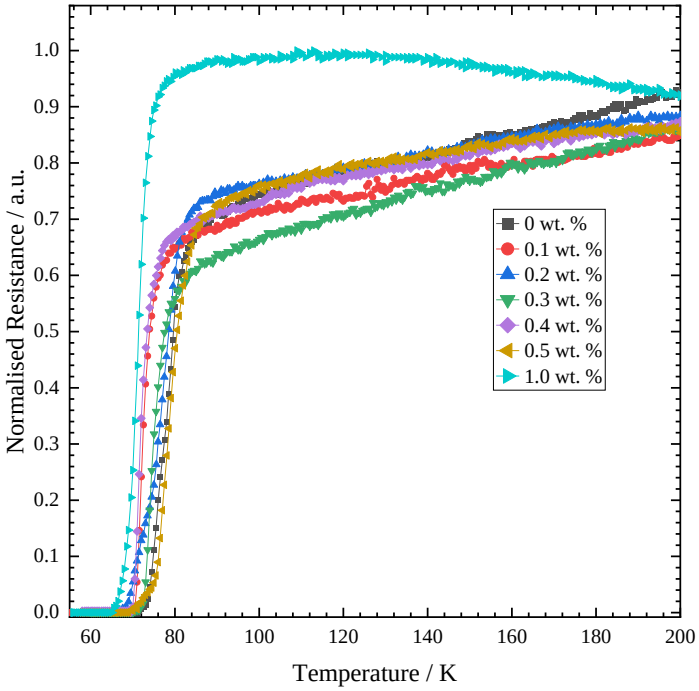

Figure 3. Normalized resistance versus temperature of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %.

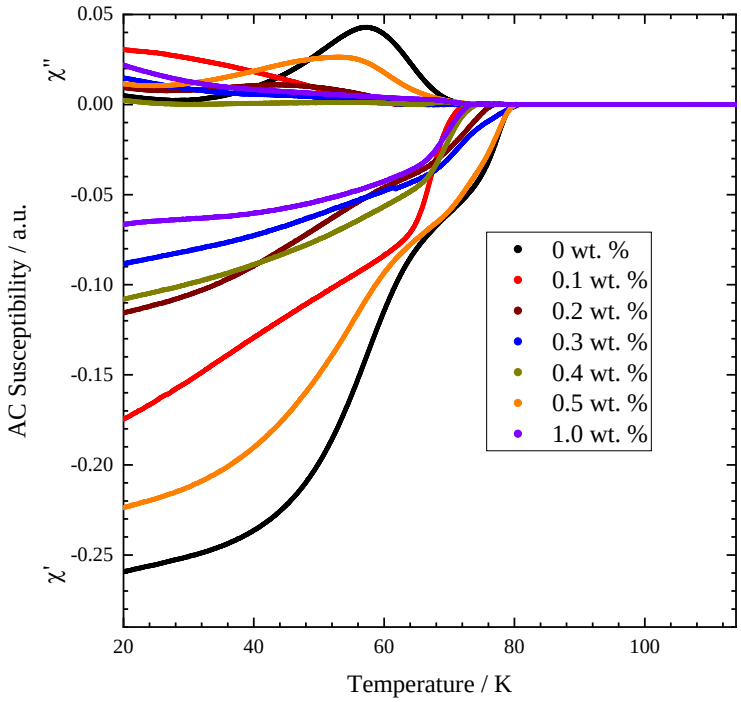

Figure 4. AC susceptibility of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %.

Figure 4 shows the AC susceptibility versus temperature of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %. The occurrence of diamagnetic shielding is denoted by the sudden drop in the real part, χ' of complex susceptibility ($\chi = \chi' + i\chi''$). This sudden drop is also known as susceptibility transition temperature, $T_{c\chi'}$. $T_{c\chi'}$ for the non-added sample is 80 K. For added samples, $T_{c\chi'}$ was between 72 and 81 K.

In the imaginary part of susceptibility, two peaks representing AC losses should be observed in the samples. One small peak near the $T_{c\chi'}$ represents

the intrinsic loss and corresponds to intragranular properties, while a larger peak at lower temperatures denotes the intergranular behavior. In our work, the x = 0, 0.1, 0.2, 0.4, 0.5 and 1.0 wt. % samples (Figure 5) exhibited a peak corresponding to the intrinsic loss. The higher peak temperature, T_{p1} for x = 0, 0.1, 0.2, 0.4, 0.5 and 1.0 wt. % samples were 77, 67 K, 73 K, 70 K, 77 and 69 K, respectively. The lower peak temperature, T_{p2} is related to the intergranular couplings and the strength of the flux pinning. If T_{p2} shifts to higher temperatures, it indicates an enhancement of intergranular coupling and flux pinning force [2]. T_{p2} for the non-added sample was 57 K. T_{p2} for all added samples were decreased (between 47 and 56 K) and further addition (1.0 wt. %) severely suppressed T_{p2} to the lower temperatures (< 20 K). This suggested that the addition of SnF_2 decreased the intergranular coupling and weakened the flux pinning force.

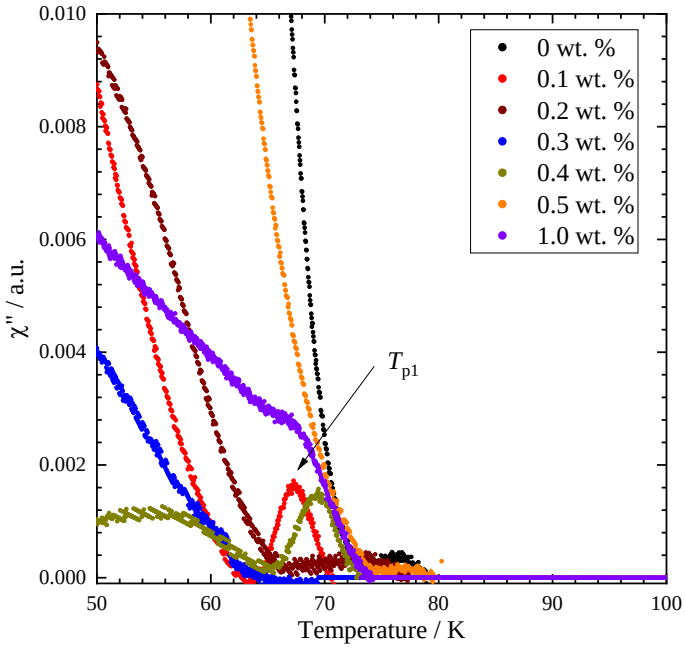

Figure 5. Imaginary part of susceptibility, χ" of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %.

Table 1. $T_{c\ onset}$, $T_{c\ zero}$, ΔT_c, lattice parameter, V, c/a, $T_{c\chi'}$, T_{p1} and T_{p2} of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ $(SnF_2)_x$ with x = 0-1.0 wt. %.

Sample / wt. %	0	0.1	0.2	0.3	0.4	0.5	1.0
$T_{c\ onset}$ / K	84	80	88	87	80	91	79
$T_{c\ zero}$ / K	71	69	66	70	69	69	65
ΔT_c / K	13	11	22	17	11	22	14
a /Å	5.316	5.327	5.377	5.336	5.372	5.355	5.325
b /Å	5.434	5.441	5.424	5.430	5.404	5.418	5.449
c /Å	30.71	30.77	30.84	30.71	30.83	30.80	30.83
V /Å^3	887.0	891.9	899.4	889.7	895.1	893.7	894.4
c/a	5.776	5.777	5.736	5.754	5.74	5.752	5.789
$T_{c\chi'}$ / K	80	72	77	81	74	80	73
T_{p1} / K	77	67	73	-	70	77	69
T_{p2} / K	57	<20	47	50	56	54	<20

CONCLUSIONS

The effect of SnF_2 addition on $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_8$ with x = 0-1.0 wt. % has been investigated. The Bi-2212 phase was not suppressed by SnF_2 addition. The grain growth was promoted with SnF_2 addition. The addition of a small amount of SnF_2 improved $T_{c\ onset}$ of Bi-2212. The decrease in T_{p2} demonstrated that SnF_2 suppressed the intergrain coupling and flux pinning force. This work also showed that the changes in the internal lattice strains due to the SnF_2 play an important role in enhancing the transition temperature of Bi-2212 superconductor. Additional investigations involving other metal fluoride with different electrical and magnetic properties can be conducted to further explore their potential to enhance the performance of the Bi-2212 superconductor.

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