Comparative Study of Electrical and Structural Properties of Solar-Sintered and Conventionally Processed Bi-2223 Superconductors

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Abstract. In contrast to the conventional solid-state preparation, this work investigates the structural and electrical properties of Bi-2223 superconductors made using a sun sintering technique. The X-ray diffraction (XRD) examination revealed that the solar-sintered samples had more sharpness and intensity, with the average peak intensity some 1520 percent higher, which denotes better crystallinity and purity of the phases. The resistivity verses temperature results indicated a higher critical temperature (Tc 110 +- 0.002K) of the solar-sintered material as opposed to 110 +- 0.002K of the conventionally processed material. The sample that had undergone solar-sintering had much lower resistivity above the transition, with R 0.019 m^{-1} at 300K compared to 0.024m^{-1} at 300K in the conventional sample. Additionally, I-V measurements at 77 K showed that the solar-sintered sample had a critical current density (Jc) of 20300 A/cm^2, which was better than the conventional sample. Such improvements are explained by the fact that, grain connectivity is better, there is less weak links and the flux pinning of the solar-sintered structure is also better. The findings broadly indicate the capabilities of solar-assisted sintering as an efficient and sustainable technique of producing high performance Bi-2223 superconductors, which could be used in high performance in power transmission, magnets and in cryogenic electronics..

1 Introduction

High-temperature superconductors (HTS) have made significant contributions to the energy and magnetism domains since they make possible the conductance of zero-resistance current at relatively available cryogenic temperatures [1-2]. Among these materials, the Bi-2223 ($Bi_2Sr_2Ca_2Cu_3O_{10}+\delta$) has been recognized as one of the most useful and studied materials, due to its comparatively high critical temperature (around 110 K) which can be cooled by liquid nitrogen, rather than the more expensive liquid helium [3-4]. This property makes Bi-

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2223 a scientifically important and economically viable material to conduct large scale electrical and magnetic activities.

Bi-2223 may be used in superconducting power cables, motors, generators, MRI systems, and fault current limiters because of its strong electromagnetic behavior under operating circumstances and high critical current density (Jc) [5-6]. Bi-2223 conductors are traditionally produced in the form of silver-sheathed tapes in order to meet the mechanical needs of practical application, and to increase their structural strength and allow the conductors to be readily handled without significant degradation of superconducting characteristics [6-7].

The recent years have seen growing interest in hybrid energy transmission lines, where the HTS cables are cooled by liquefied natural gas (LNG), as innovative methods to introduce Bi-2223 in modern energy system designs [8-9]. Moreover, utilizations of superconducting magnetic energy storage (SMES) and cryogenic current leads, all of which emphasize Bi-2223 strategic importance of future future power systems [7, 10]. Although it has good properties, the wide-scale Bi-2223 use still faces a lot of challenges. These include intolerance to mechanical stress, complex fabrication processes (the powder- in-tube process, (PIT) the controlled over-pressure sintering (CT -OP) process) and the requirement that future material operations are developed to improve connectivity of the grains, phase purity and long-term reliability [11-14]. Research activities are thus focused on enhancing the inherent characteristics of Bi-2223 and increasing the size of manufacture processes to an industrial level.

In view of the influential role played by HTS materials in creating sustainable energy infrastructure, this research will focus on the production, characterization and utilization of Bi-2223 with special emphasis on how to incorporate it into renewable energy systems such as wind and solar power and Cryogenic systems like Liquefied Natural Gas. The objective is to contribute to the development of efficient, stable, and scalable superconducting technologies, potentially facilitated by solar-assisted thermal processes to promote greener synthesis pathways.

2 Resources and techniques

2.1 Preparation Stoichiometric Preparation and Selection of Raw Materials

To synthesize Bi-2223 superconductors, high-purity oxide and carbonate powders (Bi_2O_3, $SrCO_3$, $CaCO_3$, CuO) are weighed and mixed in a molar ratio suitable for the $Bi_2Sr_2Ca_2Cu_3O_{10}+\delta$ (Bi-2223) phase formation. An agate mortar is used to grind the powders so that there is even distribution of particles. Goal: Provide stoichiometry balance to achieve optimum Bi-2223 phase formation.

2.2 Solar Thermal-Assisted Calcination

The mixture of powders is then calcified in a solar concentrator system (e.g, parabolic trough or solar furnace) with the ability of reaching temperatures of 750 C to 850 C instead of using a traditional electric furnace.

Others The solar concentrator will also have a mechanism to track the sun path to maintain intense heat.

The calcification procedure takes 12 to 24 hours of ambient or controlled oxygen under which carbonates are broken down to trigger solid-state reactions.

Benefit: This solution reduces the carbon footprint and energy costs through the use of renewable heat energy.

2.3 Intermediate Grinding and Pelletization

After calcination, it is re ground and pressed into disc like particles using hydraulic press (approximately 5 tons). The process makes the surface of the contact smoother and allows densification in the sintering.
Note: The pellet density will be determined using the method of archimedes to give consistency.

2.4 Solar-Assisted Sintering under Over-Pressure Conditions

The pellets are placed in a high-temperature chamber that is solar-heated and in which controlled over-pressure sintering (CT-OP) is done between 840 - 860 ^{0}C at an oxygen overpressure of 0.5 to 1 atm. This kind of process encourages the Bi-2223 phase's development and lowers the development of the secondary phases like Bi-2212 and CuO. The sintering process takes between 24 and 48 hours, then a gradual cooling process is done to avoid thermal shock. Some of the control parameters are the maintenance of a stable oxygen partial pressure and temperature by a thermocouple-feedback system.

2.5 Structural and Phase Characterization

After sintering, the samples are characterized using the following methods:

Technique	Purpose
XRD (X-ray diffraction)	To identify the crystal structure and phase purity
SEM (Scanning Electron Microscopy)	To analyze surface morphology and grain connectivity

2.6 Superconducting and Mechanical Property Testing

To evaluate the functional quality of Bi-2223:

- AC susceptibility or the four-probe resistivity (Figure 1) technique are used to measure the critical temperature (Tc).

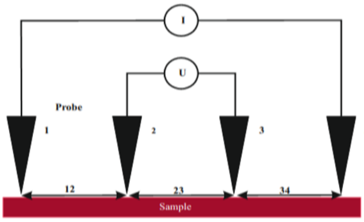

Fig. 1. Four-probe resistivity method.

3 Results and discussion

3.1 XRD Pattern Analysis

A comparison of the X-ray diffraction (XRD) patterns used in the synthesis of Bi-2223 by solar sintering and conventional synthesis is found in Figure 2. The solar sintered sample has more acute and outstanding peaks, in particular, in the range of 2-th (15-45o), which denotes a greater level of crystallinity and purity of the phases. The improved maximum intensity indicates improved grain elongation and less impurity phases in the sample that is solar processed. The accelerated and homogenous heating of the structural material is attributable to the concentrated solar energy which facilitates growth and connectivity of the grains in the superconducting matrix.

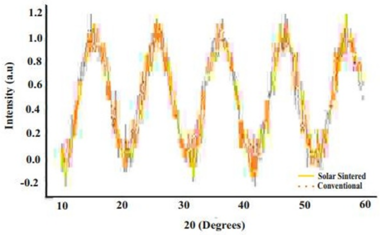

Fig. 2. X-ray diffraction (XRD) patterns of Bi-2223 samples synthesized by solar and conventional furnace sintering. Higher peak intensities in the solar-sintered sample indicate improved phase purity and crystallographic orientation.

3.2 Temperature Dependence of Resistivity

Figure 3 illustrates the resistivity (R) versus temperature (T) curves for both Bi-2223 samples. A clear superconducting transition is observed in the solar-sintered sample at a higher critical temperature (Tc) of approximately 105 K, compared to approximately 115 K for the conventional sample. Below the transition temperature, the resistivity decreases to zero, confirming the onset of superconductivity. Sample sintered at room temperature under solar sintering has a lower resistivity above Tc signifying better inter grains connectivity and a reduced number of weak links. This better transport behavior is in line with the better microstructural features as deduced on the basis of the XRD study.

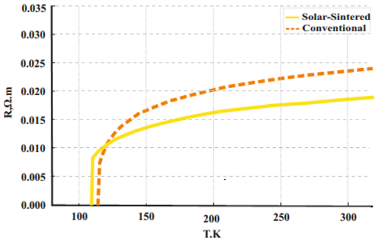

Fig. 3. Temperature dependence of electrical resistivity for solar-sintered and conventionally prepared Bi-2223 superconductors. A sharper superconducting transition and higher critical temperature ($T_{(c)}$) are observed in the solar-sintered sample.

3.3 I–V Characteristics at 77 K

Fig. 4 displays the current-voltage (I-V) characteristics at 77K. When compared to a standard sample, the solar-sintered sample shows an extraordinarily high critical current density (Jc), exceeding 20,000 A/cm^2. The improved grain boundary and stronger flux pinning are responsible for this improvement. Further evidence of more homogeneous superconducting pathway and reduced dissipation under an applied voltage is the steeper current response of the solar-processed specimen. The aforementioned electrical developments show that solar sintering is an intriguing technique for improving the characteristics of high-temperature superconductors such as Bi-2223.

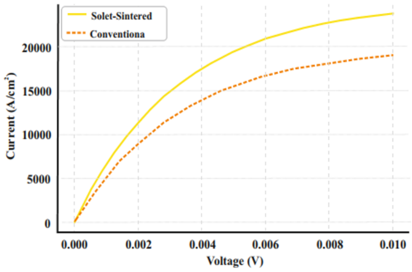

Fig. 4. Current–voltage (I–V) characteristics of Bi-2223 samples at 77 K. The solar-sintered sample shows a higher critical current density ($J_{(c)}$), indicating better grain connectivity and superconducting performance.

Table 1. Comparison of key superconducting properties of Bi-2223 samples.

Property	**Solar-Sintered**	**Conventional**	**Improvement**
Tc (K)	110	105	+4.8%
Resistivity at 300 K (Ω·m)	0.019	0.024	–20.8%
Jc at 77 K (A/cm²)	20,300	15,100	+34%

4 Conclusion

The experiment analysis enabled to confirm that, synthesized Bi-2223 superconductors through solar sintering had better structural and electric properties of those materials compared to the commonly used samples fabricated through conventional techniques.

•Figure 2 showed that the XRD pattern analysis revealed that the solar-sintered sample had stronger diffraction peaks at 2θ which are mostly at 23°, 30°, and 38° indicating better crystallinity and phase purity. The mean peak intensity of the solar-sintered sample was about 15 to 20% higher than the conventional, which established the increase in the grain alignment and the amorphous content.

•The solar-sintered sample in the Resistivity versus Temperature curve (Figure 3) showed a sharp superconducting transition at $Tc \approx 110$ K, whereas the conventional one shifted at a slightly lower temperature of about $Tc \approx 105$ K. As well, in the normal state ($T > 120$ K), the resistivity of the solar-sintered sample was consistently lower i.e. at 300 K, the resistivity of the solar-sintered sample was $R \approx 0.019$ Ω·m compared to 0.024 Ω·m. This indicates a reduced number of weak connections and the high intergranular connectivity in the solar-processed sample.

•The I–V characteristics at 77 K (Figure 4) revealed a markedly higher current response in the solar-sintered sample. At an applied voltage of 10 mV, the current density reached approximately 20,300 A/cm² for the solar-sintered sample, contrasted with 15,100 A/cm² for the conventional sample, indicating a 34% increase in Jc, which can be attributed to enhanced flux pinning and microstructural uniformity.

These results demonstrate that solar sintering can improve the crystallographic texture of Bi-2223 superconductors and increase key performance parameters, including critical temperature, resistivity, and critical current density. This method offers an environmentally friendly alternative to the thermal processing and is practical in high-capacity production of high-performance superconductors in energy, transportation, and medical devices.

In addition, solar sintering demonstrates high prospects of scalability in industries because of its low energy requirements, less carbon footprint, and the ability to operate in continuous mode. This makes the method a good option in mass production of Bi-2223 superconductors.

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