

THE EFFECT OF ELECTRON IRRADIATION ON TRANSITION TEMPERATURE AND MECHANICAL PROPERTIES OF NANOSIZE MgO ADDED Bi₂Sr₂CaCu₂O₈(Bi-2212) SUPERCONDUCTOR CERAMICS

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ABSTRACT

Bi₂Sr₂CaCu₂O₈ (Bi-2212) bulk samples with addition of 3% and 5% weight percentage of nanosize MgO particles were prepared by using the conventional solid-state reaction method. Oxide and carbonate powders were used in the preparation of samples. In solidification process, MgO substrate plays a major role in constructing the alignment and growth of Bi-2212 phase. The superconducting properties of the samples change significantly with different amount of MgO addition. It was found that the addition altered the transition temperature, T_C and the strength of the samples without affecting its Bi-2212 phase structure. Microstructural analysis indicates that a small amount of Bi-2212 is decomposed into Cu₂O and other impurity phases while a significant amount of un-reacted Bi-2212 particles embedded into MgO matrix, and believed to be acted as effective pinning centers for vortices. The nanosize MgO samples were also irradiated with small dose of electron irradiation 40 kGray and 80 kGray, respectively. For the irradiated samples, the microstructure was found to be more textured and thus enhanced the strength of the samples. These enhanced properties indicate that irradiated nanosize MgO added Bi-2212 superconductor ceramics have potential for applications in robust environment.

INTRODUCTION

Bi-based (BSCCO) superconductors categorized as high-T_C superconductors (HSTC) have fascinating properties that meets the necessary requirement of materials to be used in various applications. Their structure is highly depending on the concentration of defects and alignment of its microstructure. However, there are two main factors that caused limitation in superconductor's transport properties. First is weak pinning mechanism, attributed by its intrinsic lattice structure. Another factor is its intergrain connectivity [5-7]. In this work, nanosize MgO particles that have been proven as effective flux pinning centers were added to Bi-2212 superconductor to enhance its

superconducting and mechanical properties through formation of defects and texturing of microstructure, respectively. Defects in materials such as superconductor can be induced by electron irradiation without changing the crystal structure. Nevertheless the lattice parameters a and b may decreased with higher irradiation dose [1]. Rullier-Albenque et al. had proved that defects created in the CuO_2 planes increased the resistivity and degraded the value of the critical temperature, T_C [2].

EXPERIMENTAL

Highly oriented bulk of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ superconductor were prepared via conventional solid state reaction method. Molar ratio of Bi_2O_3 , Sr_2CO_3 , CaCO_3 and CuO were mixed according to its ratio into composition of $\text{Bi}:\text{Sr}:\text{Ca}:\text{Cu} = 2:2:1:2$. The mixture was ground and heated in a tube furnace with free air flow at temperature of 800 K for 24 hours to remove impurities and form the Bi-2212 oxide. The resultant powder was added with nanosize MgO of 3% and 5% weight percentage, before ground and pressed at room temperature with pressure of 7 tonnes. Bulk samples of 13 mm in diameter and 3 mm in thickness were formed and synthesized under the same condition at 840 K for 48 hours, then furnace-cooled to room temperature.

Electron irradiation on the samples was carried out using a beam of 3 MeV, current measurement of 10 mA and radiation doses of 40 kGray and 80 kGray, respectively. The irradiation was conducted using the EPS-3000 electron-beam accelerator at the Malaysian Nuclear Agency. Structural investigations of non-irradiated and irradiated samples were conducted using the Bruker D8 Advanced X-Ray Diffractometer (XRD) to confirm their phase formation. Unit cell parameters were determined by using XRD data that was obtained. Superconducting properties, such as transition temperature, T_C and transport current density, J_C of the samples were measured using Cryogenic four point probe. Compression test on the samples were done at room temperature in order to study the mechanical property of the superconductor ceramics.

RESULTS AND DISCUSSION

Samples were analysed by XRD to detect any phase changes caused by the presence of nanosize MgO . The XRD patterns illustrated from the samples are shown in Figure 1 and Figure 2. All the peaks of the samples indicate that none of them are having any other phases. According to the data, characteristic of Bi-2212 phase can be determined by the existing of (002) peak located at $2\theta \approx 5.39^\circ$. MgO peak of (111) can be spotted at $2\theta \approx 38^\circ$ but the peak is not clearly visible due to low concentration of MgO . Somehow, the existence of this element was confirmed by EDX as shown in Figure 3. The lattice parameters are determined according to the XRD, $a \approx b = 5.39 \text{ \AA}$ and $c = 30.64 \text{ \AA}$ and yet remain in orthorombic form for all samples even after irradiations. Sharpened peaks drawn in samples with addition of nanosize MgO are largely due to increment of background scatterings and grain boundaries, since it may destroyed Bi-2212 crystallinity and deteriorated their superconducting properties [3].

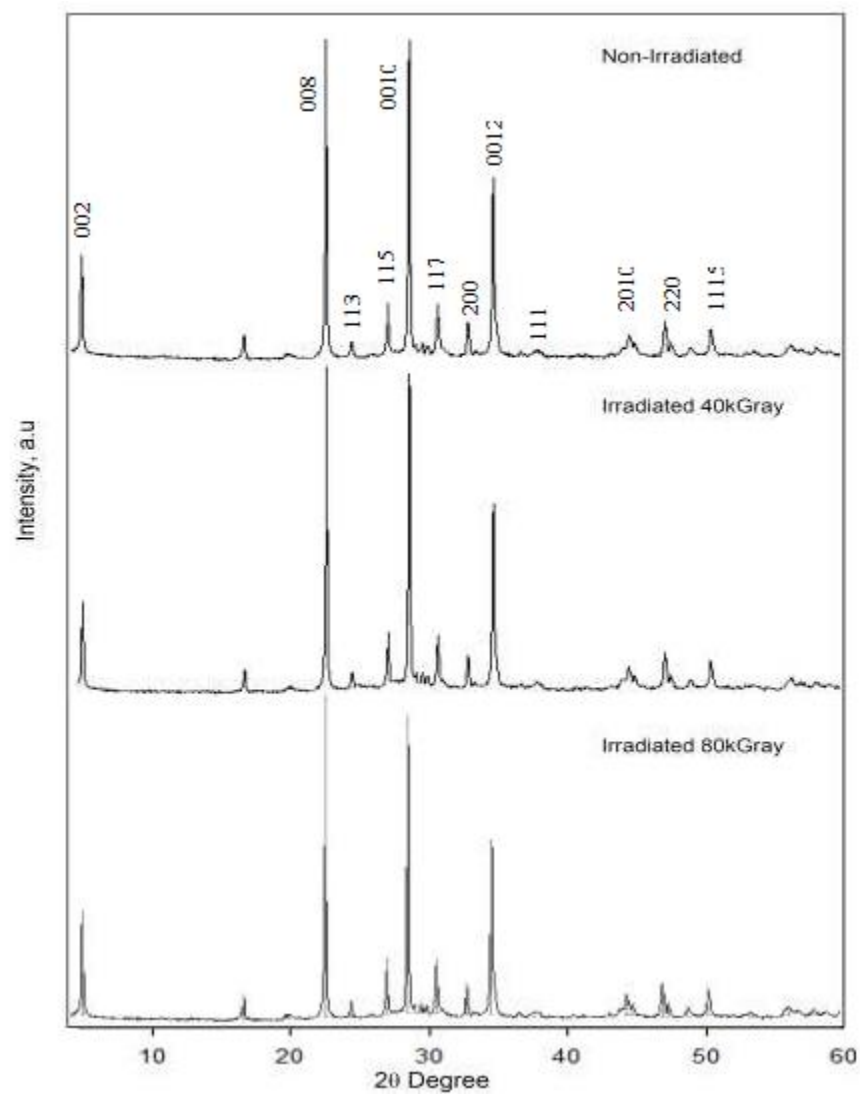


Figure 1: XRD patterns of Bi-2212 with 3% MgO for non-irradiated and irradiated with 40 kGray and 80 kGray, respectively

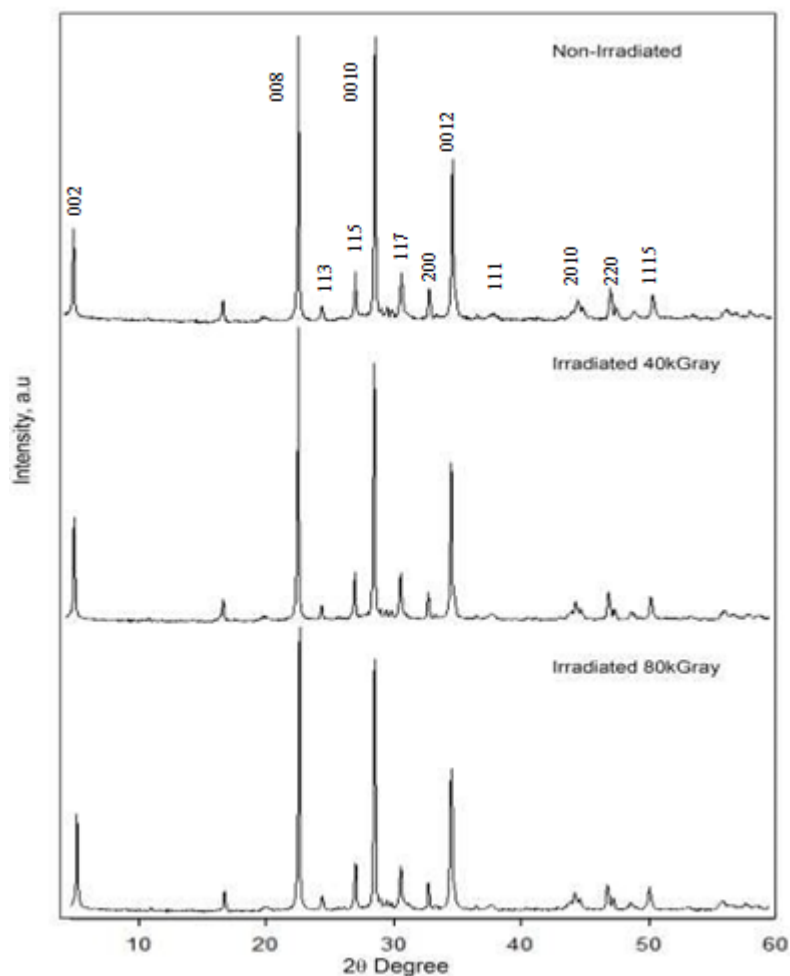


Figure 2: XRD patterns of Bi-2212 with 5% MgO for non-irradiated and irradiated with 40 kGray and 80 kGray, respectively

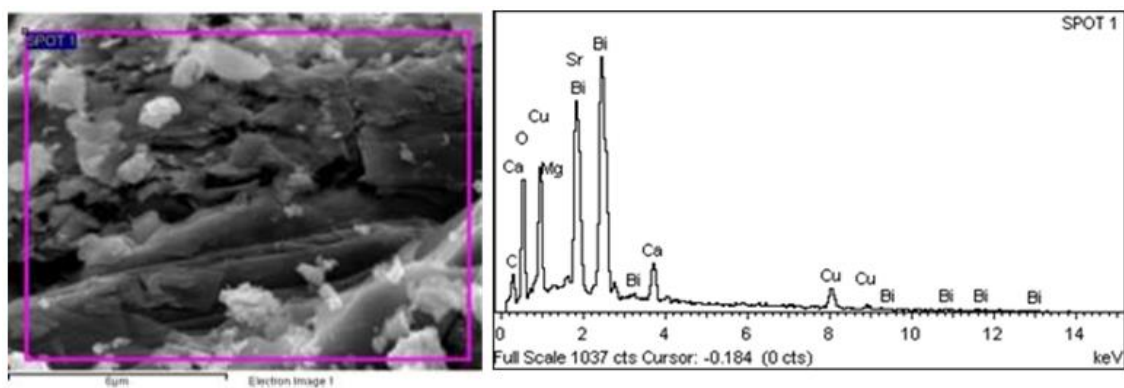


Figure 3: EDX result of Bi-2212 with 5% MgO for non-irradiated sample

From Figure 4, it demonstrates that the transition temperature, T_C decreases dramatically from 80K to 65K but increases to 75K as amount of MgO addition in the samples are increased to 3% and 5%, respectively. There is sign of increasing gap between T_C at onset and zero temperature. The increased in ΔT_C is mainly contributed by the existance of collisions between interstitial atoms and particles that promote destruction of weak links coupling between grains. Overall reduction of transition temperature with increasing concentration of MgO is a reflection of lattice defects existed in the crystal. Buckel and Kleiner [8] explained that the electrons will be scattered at this imperfections and its momentum covers all favorable spatial directions. Thus, the most favorable directions will not become fully active and interaction leading to superconductivity will be averaged.

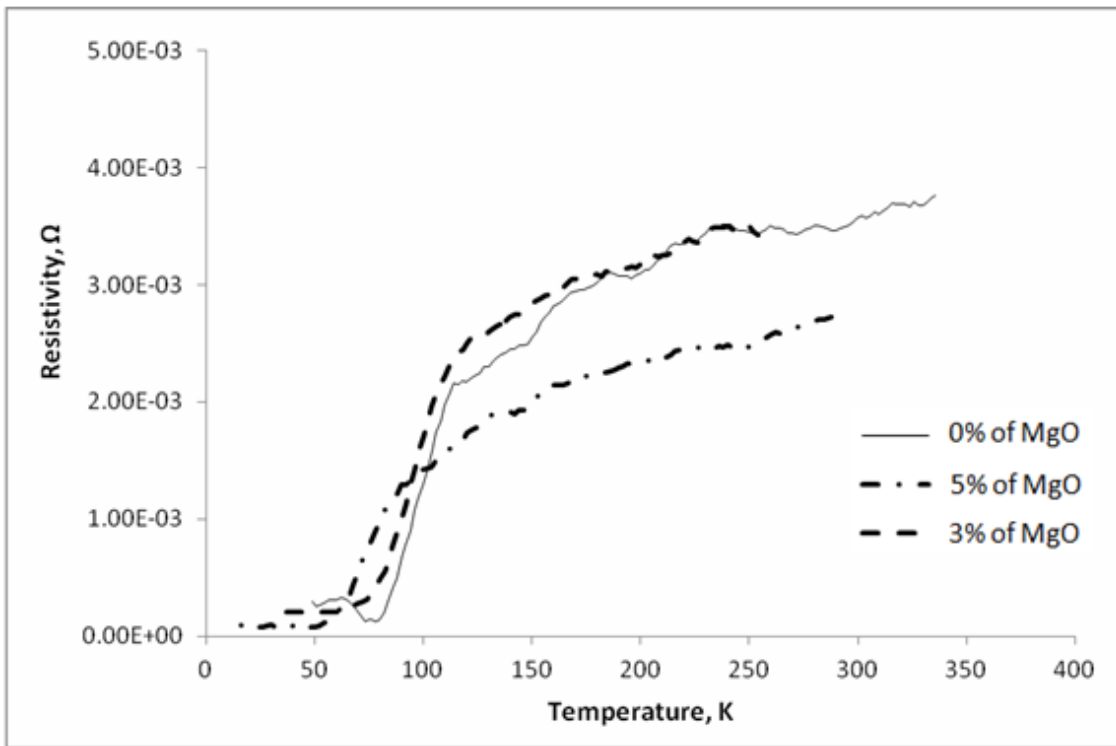


Figure 4: Transition temperature, T_C for 40kGray irradiated samples with addition of 0%, 3% and 5% of MgO respectively

Table 1 shows the results of I_C and J_C for Bi-2212/MgO compound with addition of 0% (non- irradiated), 3% and 5% (both are irradiated with dose of 40k Gray). There is an increment of J_C value as the amount of addition increases from 3% to 5%.

Table 1: Critical current and transport current density for non-irradiated and irradiated samples

Nano-size MgO Addition	Dose of Irradiation	Critical Current, I_c (A)	Transport Current Density, J_c (A/cm ²)
0%	Non	0.546	1.400
3%	40kGray	0.550	1.410
5%	40kGray	1.115	2.859

The formation of textured microstructure altered the strength of the material since this characteristic depends on the grain layers on the *a-b* plane and concentration of pores between the superconducting grains. Fibson and Ashby [4] stated that the strength of porous ceramics increases with decreasing porosity. MgO addition in the sample has ability to enhance superconducting properties by creating defects that might weaken interface bonding between grains, and thus reducing strength and stiffness of the material. Information in Table 2, Figure 5 and Figure 6 are very crucial to determine the optimum amount of addition and dose of irradiation needed to produce finest quality of superconductor. The 5% of MgO addition with 40 kGray irradiation sample seems to be the most preferable option with the highest record in compressive strength. Non-irradiated sample is the most fragile, and on the other hand small amount of MgO addition has proven to improve degree of texturing and strength of the samples.

Previous research has reported that MgO promotes texturing of microstructure during annealing process where fractured crystal are reconnected during the process [9]. In short, bonding between adjacent grains and existence of pores are the main features in microstructure that was reflected through the overall performance of the samples.

Table 2: Maximum load and compressive strength for non-irradiated and irradiated samples

Nano-size MgO Addition	Dose of Irradiation	Maximum Load, kN	Compressive Strength, MPa
0%	Non	21.72	163.64
3%	40 kGray	27.85	209.80
3%	80 kGray	27.78	208.52
5%	40 kGray	39.14	294.87
5%	80 kGray	32.54	245.16

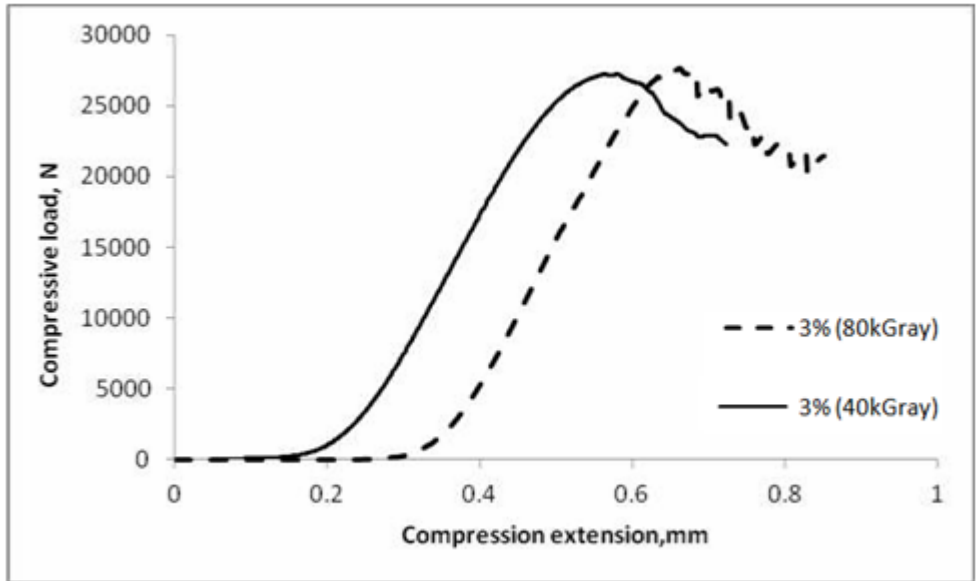


Figure 5: Comparison of strength between different dose of irradiation

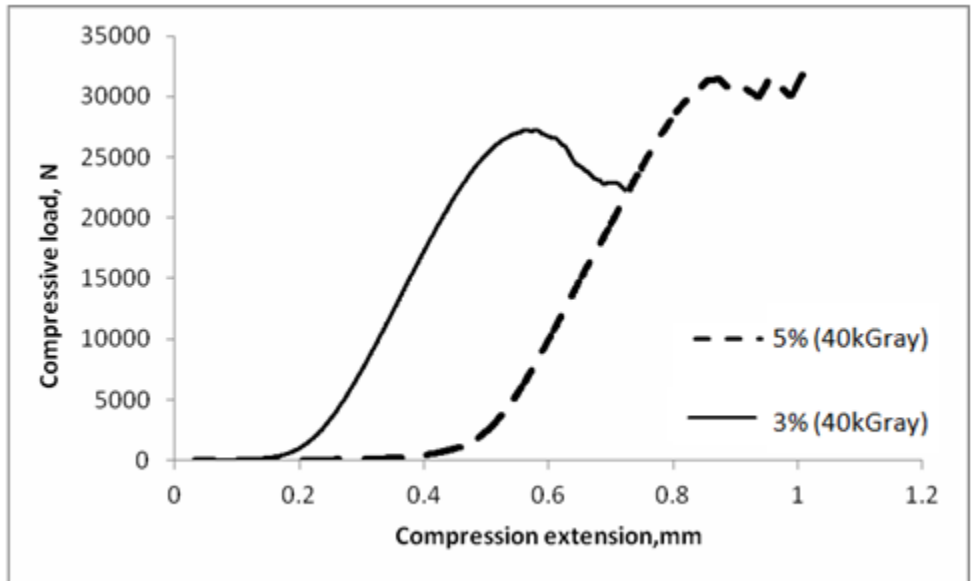


Figure 6: Comparison of strength between different amount of MgO addition

CONCLUSION

Bulk samples of Bi-2212 with addition of nanosize MgO were successfully prepared and the properties of the samples before and after irradiation were investigated. The superconducting properties of these samples improved with MgO addition up to 5%. The crystal structures remain unchanged, and other properties such as critical temperature and strength of the material were improved. On the other hand, increasing

in porosity and disorientation of grains in samples with higher dosage of electron irradiation leads to reduction in their electrical and mechanical properties.

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