Effect of pointer-laser radiation on the structure of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ superconducting compound

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Samples of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ with x =0.0, 0.05, 0.1 and 0.15 were prepared using the standard solid-state reaction technique. The study used X-ray diffraction XRD analysis and a scanning electron microscope to examine how the partial substitution of silver in superconductors, along with 90 seconds of laser irradiation, affected their structures. The XRD analysis exposed a tetragonal structure for all samples, increasing the lattice constant *a* by the increasing of x compared to the sample with no silver substance. Also, it was found that changing the concentrations of silver in the samples leads to a change in density ρ_m and HTP (high-temperature phase). After exposure to laser radiation, there were variances in lattice parameters and the peak intensities, as well as a large shift in the samples with x= 0.0 and 0.05. Laser irradiation caused expansion along the c-axis and thus substantial structural distortions. On the other hand, the SEM images show that laser radiation caused notable structural changes.

(Received March 17, 2025; Accepted July 1, 2025)

Keywords: Laser irradiation, Superconducting, X-ray diffraction, HBCCO system, Pointer-laser

1. Introduction

Superconductivity is a physical phenomenon that arises in certain substances at very low temperatures. It is characterized by the expulsion of internal magnetic fields and the absence of electrical resistance, known as the Meissner effect [1]. When a material is cooled below its critical temperature, its electrical resistance drops to zero, allowing an electric current to flow indefinitely within a superconducting wire loop without the need for an external power source [2]. Superconductivity is a quantum mechanical phenomenon, like ferromagnetism and atomic spectral lines. It cannot be explained solely within the framework of classical physics as a mere idealization of "perfect conductivity." This phenomenon has been observed in a variety of materials, including elemental substances such as tin and aluminum, various metallic alloys, and heavily doped semiconductors. Additionally, a class of copper-based perovskite ceramics, known as high-temperature superconductors, also exhibits this property. Interestingly, noble metals such as gold and silver do not show superconductivity [3]. The significance of superconductivity lies in its unique properties and broad applications [4]. From an electrical perspective, the absence of resistance means no energy loss, which helps reduce electricity consumption and extend the lifespan of electrical devices by minimizing heat generation [2]. From a magnetic perspective, the superconducting material's rejection of magnetic fields prevents their penetration, opening possibilities for innovative applications based on this property [4]. Hg-based superconductors are generally represented by the formula $HgBa_2Ca_{n-1}Cu_nO_{2n+3n}$-δ, where n denotes the number of consecutive layers Cu-O. Three well-known phases exist within this system: $HgBa_2CuO_{5+}\delta$ (1201 phase, Tc = 86 K), $HgBa_2CaCu_2O_{6+}\delta$ (1212 phase, Tc = 105 K), and $HgBa_2Ca_2Cu_3O_{6+}\delta$ (1223 phase, Tc = 132 K), all synthesized through the conventional solid-state reaction method. The development

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https://doi.org/10.15251/DJNB.2025.203.701

of superconducting ceramic materials based on barium, copper, mercury, and oxygen led to the emergence of a new class of copper oxide ceramics with a greater critical temperature (Tc) of 70 K. Similarly, strontium, bismuth, copper oxides, and calcium were used to produce new superconducting ceramics, achieving Tc values ranging from 80 to 110 K. Furthermore, certain superconducting properties can be investigated through irradiation, which serves as a powerful tool for assessing defect impacts, as it enables the examination of the same sample before and after irradiation, eliminating discrepancies that arise from sample variations [5-9]. This study investigates the influence of laser treatment on the structure properties of the superconducting compound $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_xO_6+\delta$. This compound was chosen with the purpose of improving the properties of the HBCCO system, particularly its structural characteristics.

2. Experimental parts

Samples with the nominal composition ($Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_xO_{6+\delta}$) were synthesized using the standard solid-state reaction technique. The required oxides were precisely measured, softened, and thoroughly mixed over various hours (60–90 mins). The resulting powder was then reunited, mixed again, and put in an alumina crucible before being heated up to 800°C for sintering. Additionally, the mixture was dried in a furnace set to 200°C. The prepared powder was divided into four equal portions, depend on the amount of x= (0.0, 0.05, 0.1 and 0.15). A hydraulic press was used to compress each portion into pellets with a diameter of 0.25–0.30 cm and a disc shape of 1.5 cm, applying a pressure of 7 tons per square centimeter. The pellets were then thermally sintered for 120 hours at 800°C, followed by cooling to 27°C.

Subsequently, the four manufactured specimens were irradiated using a laser pointer source (green laser dot module, focusable). The laser was positioned 5 mm away from the samples, and the irradiation process lasted 90 seconds. Before and after irradiation, the samples were analyzed to determine their properties of structure using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Additionally, the Rietveld refinement method [10] was employed to conclude the lattice parameters *a* and *c*, which defines the structure of the crystal.

3. Result and discussions

3.1. XRD studies

XRD pattern tests and examines crystallized phases of the prepared material and dopant traces. Figures 1 and 2 displayed the X-ray diffraction analysis before and after laser irradiation affected the structure characteristics for the $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ specimens respectively when x= (0.0, 0.05, 0.1 and 0.15). The observed diffraction peaks at 2θ values correspond to the reflection planes demonstrating the formation of a tetragonal crystal structure. Figure 1 demonstrates that all samples exhibit well-defined crystal structures and high crystallinity. Minor variations in peak positions and intensities are observed, suggesting structural alterations correlated with the increasing concentration of (x).

Table 1 illustrates the lattice parameters including the constants of lattice *a* and *c*, the unit cell volume V, the c / a ratio, the measured density ρ_m, and the high-temperature phase (HTP) percentage, which are related to the structural and physical properties of the material as a function of the amount of (x). It was found that the lattice constant of *a* increased from 5.503 Å to 5.5451 Å with increasing (x), while *c* decreased from 15.1025 Å to 15.0378 Å. This indicates a slight increase in the a-axis and a contraction in the c-axis. The unit cell volume V remains relatively constant, with only minor variations (1255.16 Å^3 to 1253.94 Å^3) and altering the amount of Ag in all the specimen causes a vary in the c / a ratio [11, 12]. The rise in the HTP (high-temperature phase) percentage suggests enhanced stability of the material in the high-temperature phase, a condition frequently linked to improved superconducting characteristics.

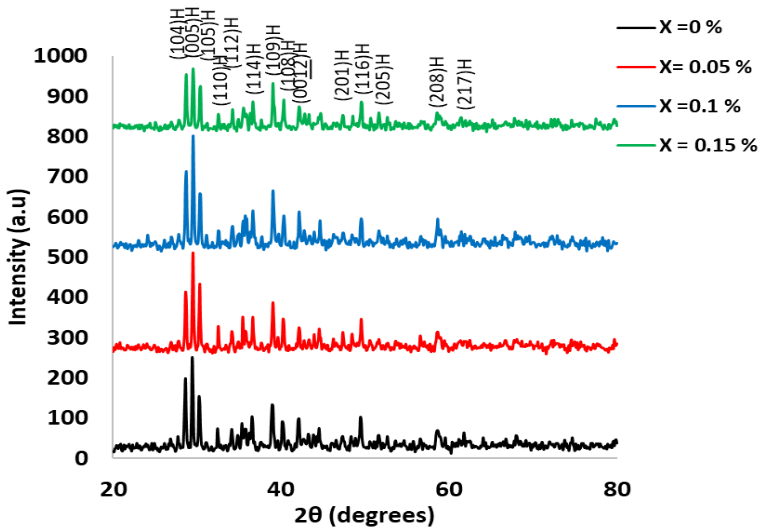


Fig. 1. XRD of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x\, O_{6+\delta}$ for x= (0.0, 0.05, 0.1 and 0.15) before irradiation with laser.

Table 1. Lattice parameters of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x\, O_{6+\delta}$ f or x= (0.0, 0.05, 0.1 and 0.15) before irradiation with laser.

x	a (Å)	c (Å)	V (Å^3)	c/a	ρ_m (g/cm^3)	HTP %
0	5.503	15.1025	1255.16	2.7444	1.0334	40.77%
0.05	5.5147	15.0875	1255.32	2.7359	1.0333	61.52%
0.1	5.5165	15.0776	1254.09	2.7332	1.0344	71.05%
0.15	5.5451	15.0378	1253.94	2.7119	1.0346	65.93%

The X-ray diffraction analysis of the $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x\, O_{6+\delta}$ compound demonstrated the structure characteristics affected by laser irradiation (Figure 2). X-ray diffraction showed no phase transformations after laser irradiation since the samples affected by laser irradiation also have a tetragonal crystal structure. However, there were differences in the peak intensities and lattice parameters, as well as a large shift in the samples with x= 0.0 and 0.05. Table 2 shows the lattice characteristics for four samples after laser irradiation.

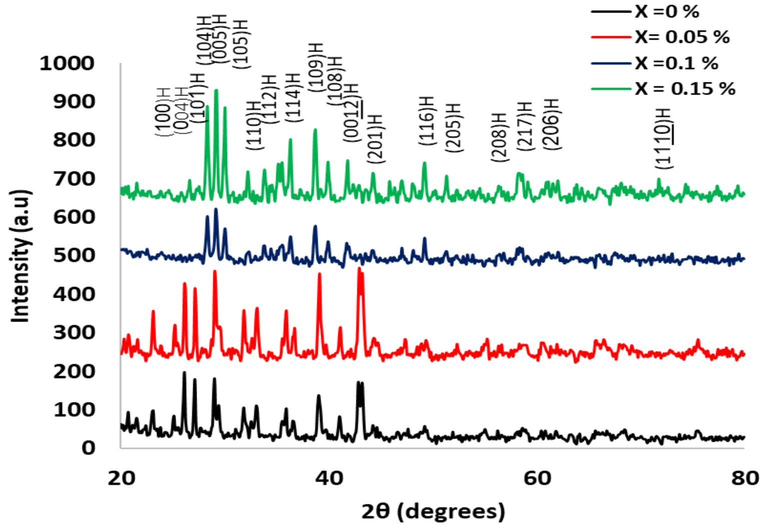


Fig. 2. XRD of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ for x= (0.0, 0.05, 0.1 and 0.15) after irradiation with laser.

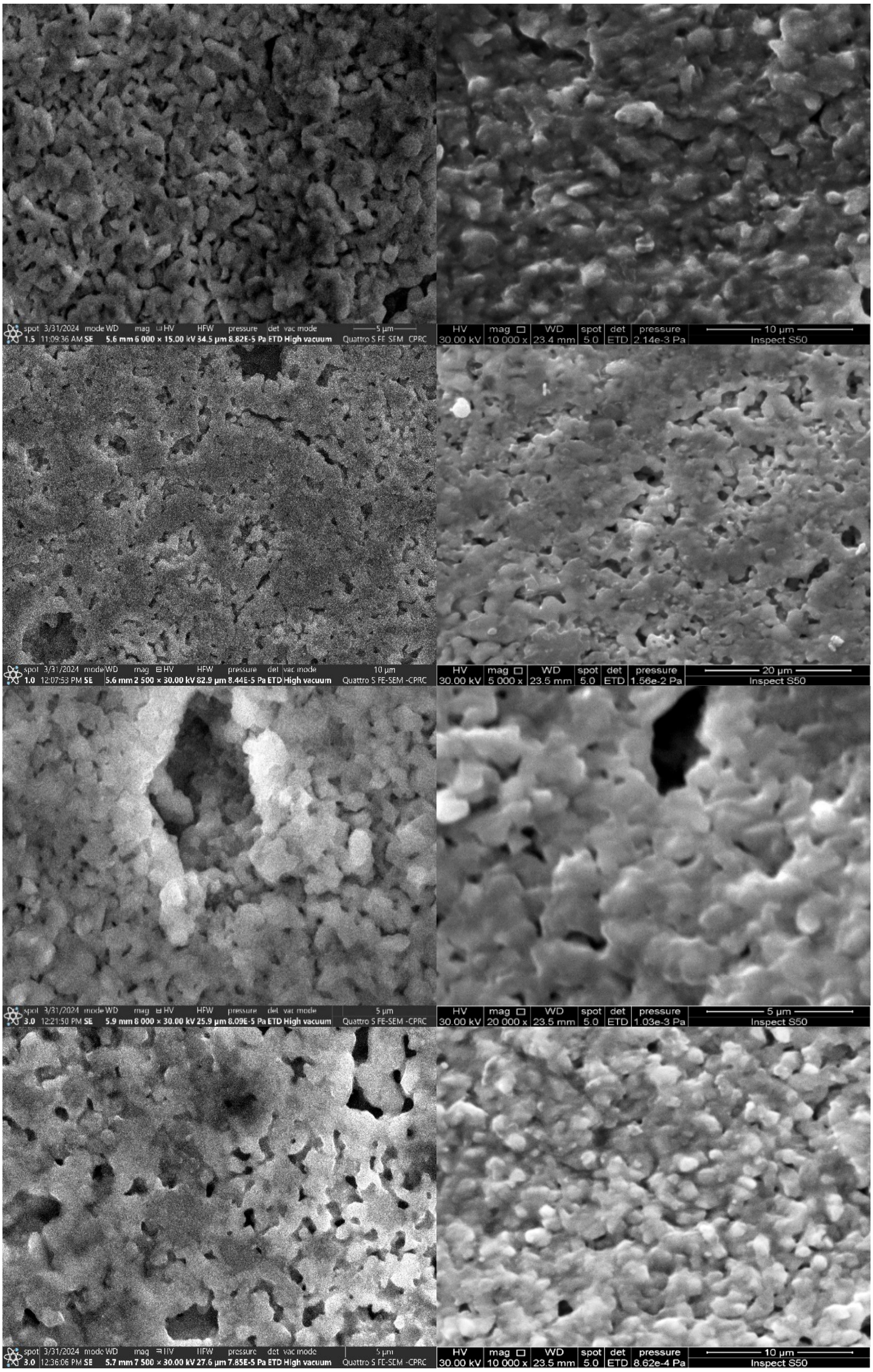
Significant changes were found in lattice constants unit cell volume in the samples after irradiation with the laser. It is indicated that laser radiation has a deep effect on the crystal structure [13]. The increase in lattice constant *c* (expansion in the c-axis) and the increase in the unit cell volume suggest that the laser radiation caused substantial structural distortions. The decrease in measured density after laser irradiation suggests that the material becomes less tightly packed. The decrease in measured density after laser irradiation suggests that the material becomes less tightly packed, while the increase in HTP percentage indicates that the material becomes more stable in the high-temperature phase.

Table 2. Lattice parameters of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$f or x= (0.0, 0.05, 0.1 and 0.15) before irradiation with laser.

x	a (Å)	c (Å)	V (Å^3)	c/a	ρ_m (g/cm^3)	HTP %
0	3.839	13.569	706.832	3.5345	1.8351	51.63%
0.05	3.1133	18.105	1020.52	5.8154	1.2711	67.11%
0.1	3.1122	18.0931	1018.82	5.8135	1.2733	76.14%
0.15	3.8582	21.053	1710.07	5.4566	0.7586	73.53%

3.2. Scanning electron microscope (SEM)

The SEM images of $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ samples are shown in Figure 3 for different values of x = (0.0, 0.05, 0.1 and 0.15) before and after laser irradiation. There are grains randomly distributed for samples before laser irradiation, While the grains tend to reduce the grain boundaries for the $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ samples after exposure to the laser. Also, the SEM images show the laser radiation caused notable structural changes. The results of the XRD analysis confirmed these results.



Before laser exposure *After laser exposure*

Fig. 3. FE-SEM for $Hg_{0.15}Ag_{0.85}Ba_2Ca_2Cu_{3-x}Ag_x O_{6+\delta}$ for x= (0.0, 0.05, 0.1 and 0.15) after irradiation with laser.

4. Conclusions

From the analysis of X-ray diffraction, which displayed a tetragonal structure, you can conclude that increasing the partial substitution of Ag in superconductors leads to a change in lattice parameters and a noticeable increase in the lattice constant *a* and HTP (high-temperature phase). Whereas, after pointer-laser irradiation, the results show the increasing value of all lattice parameters except measured density ρm, which suggests that the material becomes less tightly packed after laser irradiation. The SEM images show these changes in the structure.

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