Article

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Effect of (Hg) on the Electrical and Structural Properties of High Temperature $Bi_2Ba_2Ca_2Cu_3O_{10+\delta}$ Superconductor

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Abstract

This work investigates how the preparation process affects the electrical characteristics of the superconducting ceramic compound ($Bi_{2-}x(Hg_X)BaCa_{1.85}(Sb_{0.15})Cu_3O_{10+\delta}$) by partially substituting (Hg) for (Bi), where x = (0, 0.1, 0.2, 0.3, 0.4). In order to achieve the highest critical transfer temperature (High-Tc) using the most efficient preparation technique, the study aims to investigate the conditions and optimal approach for achieving stability. In order to produce a conjugated material and promote an ideal progressive diffusion process among the atoms, the samples were created under ideal conditions using the solid-state reaction (SSR) method. We found the critical transition temperatures and energy gap values for the samples (x=0, 0.1, 0.2, 0.3, 0.4) by using the Four-Probe Technique to examine the resistance variation of the samples as a function of temperature. The samples showed metallic characteristics and superconducting behavior at 780° C. The SSR approach was used to create the ideal sample, which had a composition of x = 0.4 and a critical transition temperature of Tc = 122 K. In addition to outperforming other samples in terms of obtaining superconducting compounds with superior transition temperatures, this sample also showed the highest energy gap value of Eg = 0.037144 eV and a hole concentration of P(hole) = 0.16. AFM (atomic force microscopy) was also used to examine the surfaces of these systems. Through it, the average diameter (nm), average roughness (Ra), and

root mean square (Rg) were calculated. The results showed that the sample with the replacement ratio (0.4) had the bast average diameter of (608.8).

Keywords: superconductivity, Critical temperature, Energy gap, AFM, Hole concentration of P(hole)

1.Introdcation

The phenomenon of superconductivity is a discovery that has captivated solid state physics researchers. New materials have been sought for and discovered throughout history to enhance human needs and advancements save time effort, and money. Among these significant discoveries are superconducting materials since the goal of the research on these materials is not to acquire information, but rather to further the discovery of high-temperature superconductivity carriers (HTSC) [1-6] .It is important to note that learning about the procedures and methods for adding or replacing components can provide us with more opportunities in knowing the processes by which superconductivity arises in various materials and compounds, particularly as it relates to the copper oxide cuprates composition[7-10]. Even though a lot of research has been done on preparation, substitution, and addition techniques, particular techniques and mechanisms for the processes of element preparation and substitution in these kinds of materials have not yet been established[11-17] . It is from this drive and desire to accomplish the objective in this report and to enhance the research procedures through this modest endeavor, this work's objective is to give an analysis of how preparation techniques affect the bismuth-based superconductor ($Bi_{2-x}Hg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$) compound with x = 0.00, 0.1, 0.2,0.3, 0.4. It was made using a variety of technique (solid state reaction SSR) and the impact of these technique on the electrical characteristics of this chemical was also investigated.

2. Experimental

Samples of ($Bi_{2-x}Hg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$) ceramic superconductors (x = 0.0, 0.1, 0.2, 0.3, and 0.4) were synthesized using the traditional solid-state reaction method, based on their molecular weights and employing appropriate quantities of pure powders of Bi_2O_3, Sb_2O_3, Ba_2O, CaO, and Cu_3O. A precise balance was employed to ascertain the weight of each reactant. Employing an agate mortar,

amalgamate particles during the 45-minute grinding process[18]. Employing hydraulic pressure of 8 tons/cm² for a duration of two minutes, the discs possess a diameter of 1.5 cm and a thickness ranging from 0.15 to 0.25 cm. Samples were sintered utilizing the SSR process, which involves heating the air to 780 degrees Celsius for 22 hours at a rate of 10 degrees Celsius per minute. Resistance experiments employing the established methodology were utilized to examine the superconducting state of the samples. The superconducting state of the samples was evaluated by resistance measurements performed in accordance with the specified methodology. Figure (1) depicts the circuit diagram for this method.

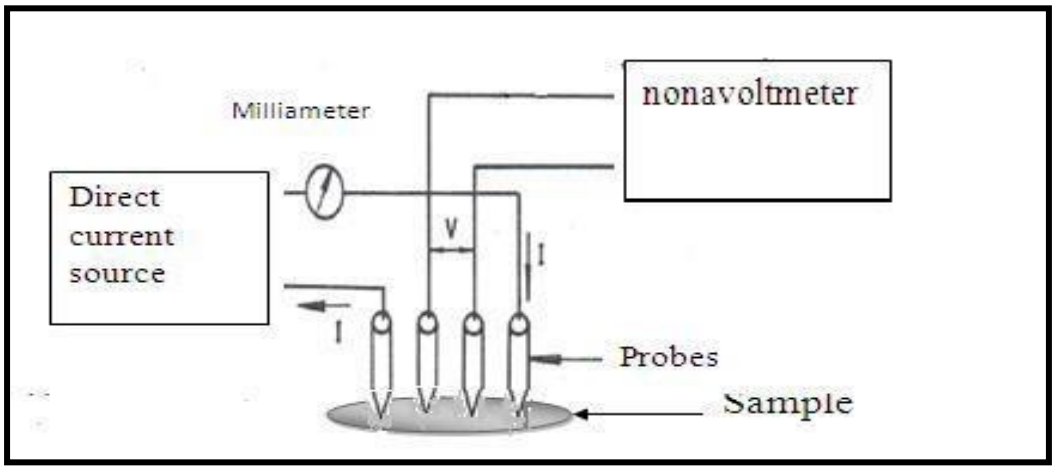


Figure (1) a diagram showing the four-sensor technique for measuring electrical resistivity as a function of temperature.

There will be a voltage drop across the electrodes when a current flows through the sample of (I). The following formula can therefore be used to determine the sample's resistivity: [15, 18]

$$\rho = \frac{V}{I}\frac{Wt}{L} \qquad (Four\ points\ probe) \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The current flowing through the specimen is represented by (I), the voltage drop between the electrodes by (V), the specimen thickness by (t), the effective length between the electrodes by (L), and the specimen width by (ω). The relationship shown below is utilized.:[19]

$$\rho = \mathbf{4.5324}\ \mathbf{V / I}\ \ (Linear - foure\ points\ probe) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The following equation can be used to calculate the critical transition temperature from the electrical resistivity curve plotted versus temperature:[4, 19]

$$\mathbf{Tc(mid)} = \frac{\mathbf{T_{c_1} + T_{c_2}}}{\mathbf{2}} \quad \text{……..(3)}$$

Tc (Onset) denotes the initial transition temperature, Tc (Offset) represents the final transition temperature at (ρ = 0), and Tc (Mid) indicates the temperature at the midpoint between Tc (Onset) and Tc (Offset) [20] .

$$Eg = 3.53KBTc \quad \text{… … … … … … … … … … … … (4)}$$

Then, the energy gap of the superconducting samples was calculated through the following relationship:[21]

$$P= (0.16) –[(1- T_C /T_{Cmax}) / (82.6)]^(1/2) \text{……..(5)}$$

In this instance, p represents the gap concentration, whereas Tc (max) indicates the system's maximum critical transition temperature (BBCCO). The architecture of the superconducting ceramic system (BBCCO), denoted by the chemical formula ($Bi_{2-x}Hg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$), operates as an electrically active structure, characterized by a sequence of copper oxide layers composed of copper and oxygen. The integration of these layers into the crystal lattice enables the entry and exit of oxygen inside the mixture. The crystalline structure enables the exact creation of cavities, crucial for the manifestation of superconductivity.

3. Results and discussion

3.1 : The results are displayed electrical resistance an effect in temperature, employed to ascertain the critical transition temperature (Tc), this property provides significant insights on the interactions among the material's particles electron coupling and pairing (Cooper pairs) are essential to achieve the crucial temperature (Tc), or the superconducting transition. The solid-state reaction technique (SSR) was employed to synthesize samples with compositions X=0, 0.1, 0.2, 0.3, and 0.4. Figure (2) illustrates the relationship between electrical resistance and temperature for the compound ($Bi_{2-x}Hg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$). At 780 degrees Celsius, all samples exhibit metallic behavior in the region preceding the superconducting transition temperature (Tc(onset)), where superconducting behavior emerges according on the preparation procedure.

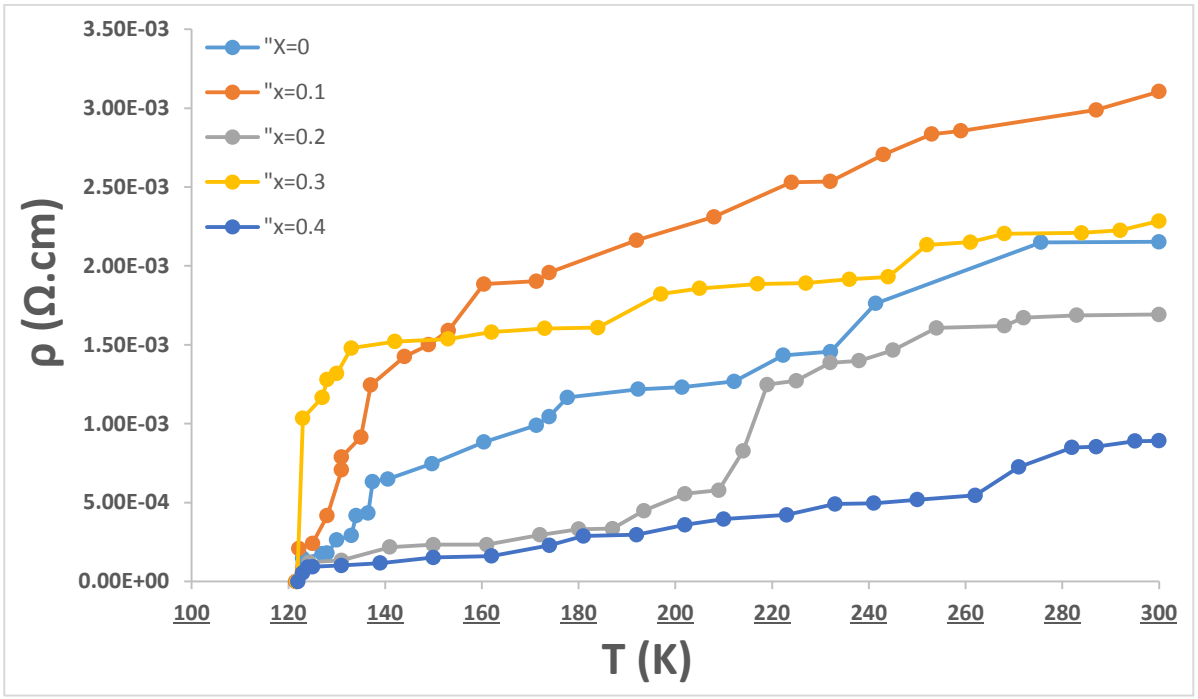


Figure (2) illustrates how electrical resistance changes with temperature for the compound ($Bi_{2-x}Hg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$)

The critical temperatures of the dyed samples exceeded that of the pure sample in the region preceding (Tconset), where superconducting activity was seen, as depicted in Figure 2, first Table. This indicates that with time, the electrical resistance of the superconducting samples diminished. In the lead-substituted samples, we noted that the transition width exhibited reduced values, which were lower than those of the pure sample, suggesting that the critical temperature was elevated due to an enhancement in the crystal structure. This indicates the uniformity of the samples. The varying quantities of low-level phases and contaminants in the samples are the cause of this phenomenon.

Table 1 presents a comparison of the critical temperature, the energy gap, and gaps concentrations for the samples.

X	Tc(of) (K)	Tc(on) (K)	ΔT (K)	Tc(mid) (K)	Eg (eV)	P(Hole)
0	121.7	123	1.3	122.23	0.037053	0.159985
0.1	120.5	123	2.5	122.25	0.036992	0.159926
0.2	121.8	127	5.2	124.4	0.037084	0.15999
0.3	121.8	123	1.2	122.4	0.037084	0.15999
0.4	122	123	1	122.5	0.037144	0.16

We see the variation in critical temperatures for the samples obtained for the chemical. The primary cause of the variance in the critical degree of the generated samples is attributed to the disparity in both the oxygen content and the concentration of voids in the high phase of the compound synthesized by these methods.

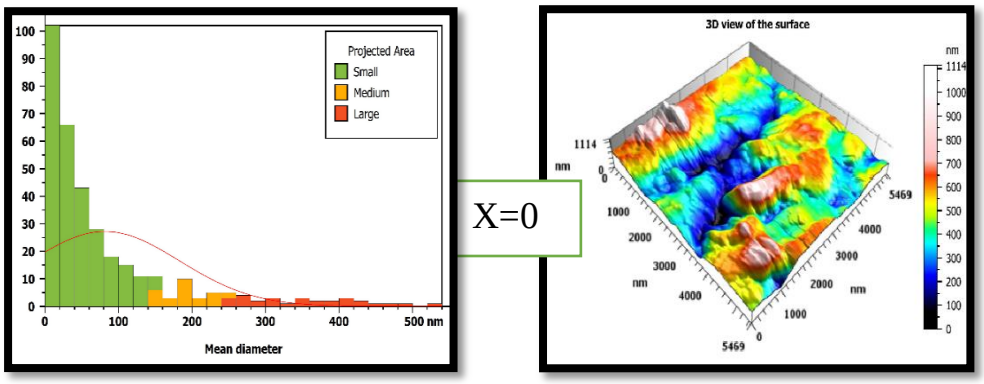
Table (1) indicates that the transition width ΔT (K) = Tc(on) - Tc(off) diminishes, implying an enhancement in the crystal structure. Furthermore, Table (1) indicates that the critical temperature (Tc) may grow with higher gap concentrations. Oxygen atoms bond with copper atoms to generate copper oxide, which is responsible for the stability of the superconducting state and the increase in the critical temperature of these conductors[22]Analysis of the four probes revealed that samples prepared using the SSR technique with optimal substitution at a concentration of x = 0.4 yielded the most favorable findings. This occurred because the sample exhibiting the best critical temperature possessed the highest concentration of gaps and the greatest value of the energy gap. The attainment of compatible substitution ratios (SSR) that corresponded with the preparation and shaping parameters may be the underlying reason for this. The sample's tight crystalline structure, substantial grain size, and decreased pore count all enhance its superconducting properties. These attributes ensure elevated conductivity among the grains, regulated by the state of the (CuO) layers. This suggests that the conditions and preparation procedure positively influenced the enhanced production of the upper phase, hence elevating the critical temperature[23].

3.2 AFM (atomic force microscopy): is a great way to look at the shape and texture of different surfaces. Nanometric accuracy in understanding surface topography has made it easier to study things like mechanical manufacturing, tribological properties, dynamic biological processes, and mostly thin film surfaces. Compared to other microscopic methods, this approach stands out. Because this technique is flexible, it can be used to look into and judge the films' shape and texture in great detail. The roughness parameters (Rq) and (Ra) were used to find the surface's roughness. The average roughness (Ra) over the whole measured length or area is equal to the mean height. The square root of the surface height distribution is referred to as root mean square (RMS) roughness (Rq), and it is considered more responsive to substantial deviations from the mean line or plane than average roughness[24].

Table (2) : average roughness (Ra) , root mean square (RMS) roughness (Rq), Mean dimeter(nm) for x=0 , 0.1, 0.2, 0.3 , 0.4

x	Ra(nm)	Rq(nm)	Mean dimeter(nm)
0	220.3	283.8	597.7
0.1	1251	92.24	74.74
0.2	399.4	101.1	75.95
0.3	149.9	190.2	1613
0.4	37.70	51.25	608.8

Table (2) indicates that the values of average diameter (nm), average roughness (Ra), and root mean square (Rq) are influenced by variations in the substitution ratio of mercury to bismuth. The big drop in Rq at 0.4 substitutions compared to the pure sample suggests that changes have happened inside the structure, resulting in less surface heterogeneity. The big difference in the average diameter between the different substitutions shows how the substitutions change the material's particle distribution or microstructure. Elevated results, such as 1613 at 0.3, may signify agglomeration or heterogeneous particle development. The very low diameters seen at 0.1 and 0.2 substitutions may mean that these levels of substitution cause structural fragmentation and different grain dispersion.The sample with a substitution ratio of 0.4 exhibited the bast average diameter of 608.8 compared to other parameters. The Ra value was 37.70 nm, and the Rq value was 51.25 nm. It was noticed that an increase in the substitution ratio between mercury and bismuth elements resulted in an average diameter of 608.8 nm.



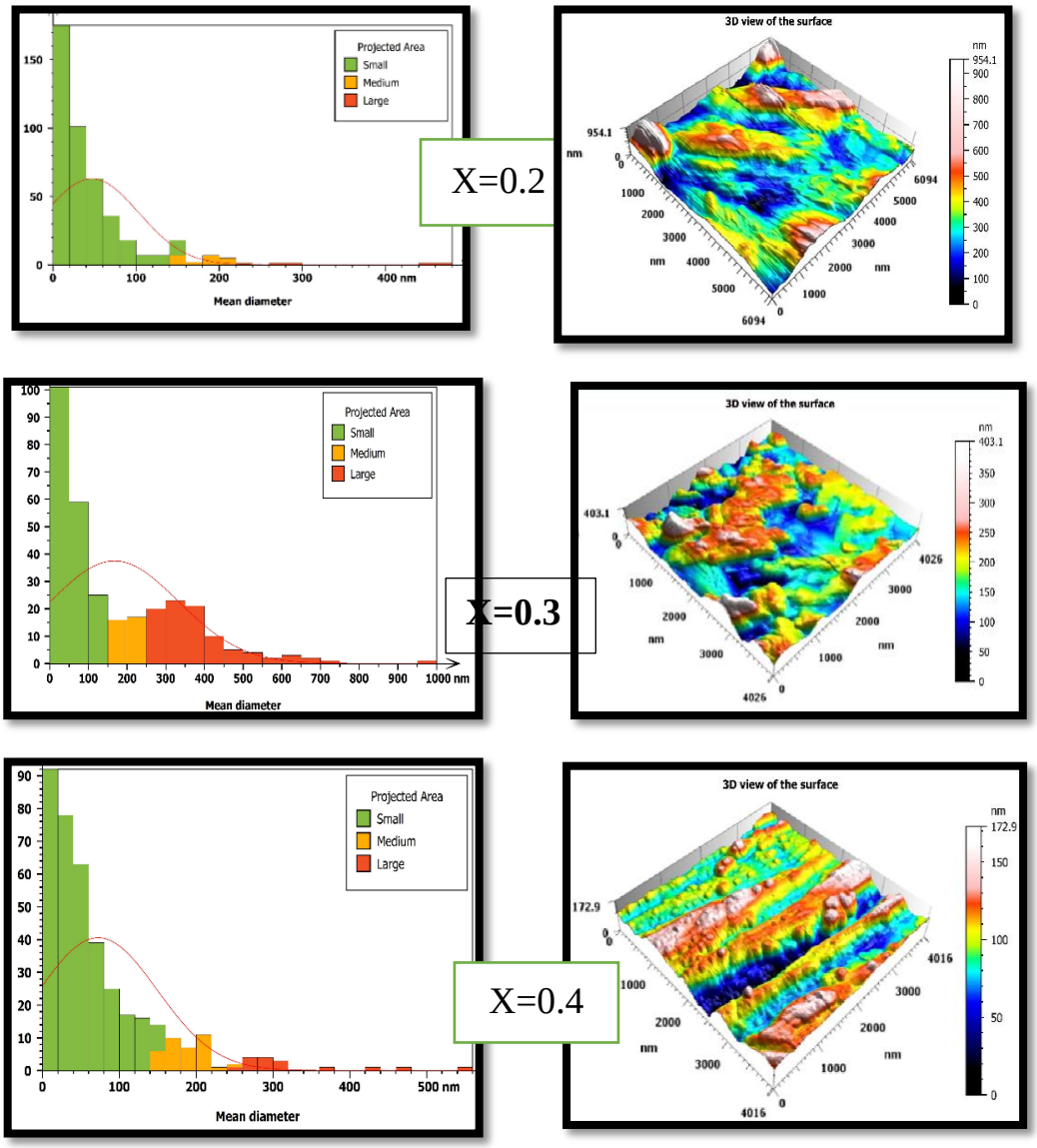


Fig (3): reveals the chart distribution and three-dimensional AFM pictures of (Bi_2-$xHg_XBaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$)

4. Conclusions

The impact of substituting mercury for bismuth in the molecular substitution ratios for thes uperconducting ceramic compound**(Bi_2-x$Hg_X$$BaCa_{1.85}Sb_{0.15}Cu_3O_{10+\delta}$)** on the BBCCO system was examined at ratios samples (X=0, 0.1, 0.2, 0.3, and 0.4). It was discovered that all samples exhibited metallic behavior, with sample x=0.4 being the best in terms of critical temperature (Tc(of)=122K), energy gap(Eg= 0.037144ev), (ΔT (K)=1) and gap concentration(P(Hole)= 0.16), all of which are linked to the high phase that offers thermodynamic stability. AFM techniques were used to examine the picture composition of the and used to examine the structure of the image. The reduced Ra and Rq values at the 0.4 substitution suggest enhanced surface smoothness relative to certain other replacements, potentially indicating an improvement in structural composition. The results showed that the best average diameters (nm) were found at (x=0.4).

5. References

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