Study of the Effect of partial substitution on the structural and electrical properties of (YBCO) Superconducting System

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Abstract

The purpose of this study is to find out the optimal substitution ratio for Indium with yttrium through the structural and electrical properties of the prepared compounds. The superconductor compound (Y1−xInxBa2Cu2.85La0.15O6+δ) was prepared by the solid state reaction (SSR) method. The effect of partial substitution for the Indium on the compound's structural characteristics has been studied The variation of (x) is (0, 0.05, 0.1, 0.15, 0.20, 0.25). With a pressure of 7 tons per square centimeter, the combined powder was formed into a disc with a thickness of (about 0.2 cm). The samples were sintered for a while (24 hours)at a rate that changed from room temperature to (820°C). Based on (XRD) study All samples were discovered to contain an orthorhombic structure. It was established that variations in the lead concentrations in each of our samples result in variations in parameters for a lattice (a,b,c),(c/a), dm, Tc, and energy gap. Where its best values were recorded at a concentration (x = 0.05), where the values of the lattice constants in angstrom units (a, b, c) were (3.883388, 3.877665, and 11.65027) respectively, the highest value for (Tc) was (116.2). The density value (dm) is (6.34631683), Vph(H) was (90.91), the highest percentage was (c/a =3.000029) and the highest energy gap was (Eg = 0.035077875 eV), so we can consider it the optimal replacement ratio under the conditions of this work. (FESEM and AFM) were used to analyze microscopic pictures of the compounds prepared with different substitution ratios in addition to the pure sample at very high magnifications at a degree of magnification (5μm,200nm).

Keywords: *Partial substitution, Field Emitting Scanning electron microscope (FESEM), Solid state reaction (SSR) method, Superconductor, X-ray diffraction (XRD).*

Introduction

Materials in terms of their electrical conductivity, in general, are classified depending on the structural nature of the material and the strength of the bonding of the electrons of its atoms to the nucleus, into conductive materials, semiconductors, and insulating materials, in addition to superconductors, which is a special case that occurs for a large number of metals and alloys when cooled to temperatures below a degree Its critical temperatures (which vary from one superconductor to another), in addition to transmitting current without resistance, is characterized by perfect magnetism (magnetic flux inside the conductor -Meissner effect) (1).

A material is said to be a perfect superconductor when it exhibits zero electrical resistance and perfect magnetic permeability, for example, lead(Pb), tantalum(Ta), and

tin(Sn) become superconductors, while copper(Cu), silver(Ag), and gold(Au), which are much better conductors, do not super-conduct. In the normal state, some super-conducting metals are weakly diamagnetic and some are paramagnetic. Below Tc, they exhibit perfect electrical conductivity and also perfect or quite pronounced diamagnetism(2).

Since the discovery of the phenomenon of superconductivity, it has been found that, if magnetic elements are excluded, about half of all primary metals and thousands of alloys and intermetallic compounds, including metal oxidesو borides, and nitrides as well as some semiconductors, polymers, and even, given the right circumstances, C60 and DNA molecules, display superconductivity at low enough temperatures(3). As the progress of the cooling technique gave access to lower and lower temperatures, superconductivity was established as common low-temperature instability of most, possibly all metallic systems (4). directional effective electrical conductivity is a result of the unique properties of the chemical interaction between copper and oxygen. The presence(of Cu-O) chains and (CuO2)planes in cuprate superconductors demonstrate the significance of Cu atoms in these materials. Thus, a key factor in defining the properties of novel superconductors, which include both the dopant element's valence number and ionic radius. Doping Y123 with different substances is done primarily for two reasons. The first one is modifying the microstructure to get fundamental knowledge about potential processes, while the second involves enhancing its physical attributes, To enhance Y-123's capacity for superconductivity(5). These materials' physical characteristics might be modifiable by partial or whole atomic replacements(6).

Perovskite compound $YBa_2Cu_3O_{6+\delta}$ is regarded as a ceramic substance(7). CuO_2 mediates the layering of the perovskite structure of (YBCO), in addition to that the (CuO) levels are mediated by yttrium along the crystal's c-axis in the stacking order (BaO-CuO2-Y-CuO2-BaO) (8).

In the current work, The study aims to Preparation of the high-temperature superconducting compound ($YBa_2Cu_{2.85}La_{0.15}O_{6+\delta}$)By using pure oxides and by solid-state reaction method (SSR), studying The impact of partial In replacement for the Y site on the superconducting characteristics of Y123 superconductor was examined. ($Y_{1-x}In_xBa_2Cu_{2.85}La_{0.15}O_{6+\delta}$) where (x =0,0.05,0.1,0.15,0.2,0.25), search the structure characteristics of superconducting compounds as well as determine the coefficients of the lattice (a,b,c) and the density of the unit cell. and to try to obtain the highest critical transfer temperature (High-Tc), investigate the optimal substitution ratio for the formation of the high phase (Y-123) and its stability by using (XRD) diffraction and images from (SEM and AFM).

Experimental

Using the (SSR) method, the superconducting compound () with (x=0, 0.05, 0.1, 0.15, 0.20, 0.25), was prepared by using suitable weights of powders of (Y_2O_3, BaO, CaO, CuO, La_2O_3, In_2O_3) (with a purity of more than 99.9%). With sensitivity order (10-4) g, a sensitive balance was used to estimate the reactants. To homogenize the reactants, isopropanol ($C_2H_3O_5$) was added and the reactants were mixed in a gate mortar for two hours to obtain fineness and optimal homogeneity of the powders, then the resulting powders were dried at a temperature of 200 oC for a period of (1hr) in a drying

oven. The samples were compressed into discs with a thickness of (0.2cm) and a diameter of (1.5 cm) using a hydraulic press under pressure (7 tons/cm2) for one minute. To produce a coherent material and to assure the process, the samples were sintered inside a sintering furnace for 24 hours at a temperature of 820 degrees Celsius. The temperature was progressively raised (i.e. at the rate of 10 oC/min). The samples were gradually cooled within the furnace(i.e. at the rate of 5 oC/min) after optimal atoms diffusion.

An (X-ray diffraction) test was performed, through which the structural properties of the compound were studied. Mathematically, the sample's lattice constants were computed by finding the (2θ) and Miller's coefficients (hkl) for each vertex and applying Eq.1(9):

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2} \dots\dots\dots\dots 1$$

The formula below was used Eq.2 to get the volume fraction of phase(10):

$$(V_{Ph})\% = \frac{\sum I_0}{\sum I_1 + \sum I_2 + \sum I_{other(peaks)}} \times 100\% \dots\dots\dots 2$$

Where I represent the intensity of each phase's peaks. The density of a unit cell was determined using the Eq.3 shown below(11):

$$D_m = \frac{W_m}{N_A V} \dots\dots\dots\dots\dots\dots\dots 3$$

Where Wm: the molecular weight (amu), NA: Avocado's number (particles/gm.mol)), and V: the volume of a unit cell (cm3). TC critical transition temperature. then used the four probes technique with the presence of liquid nitrogen to determine the critical temperature of the transition as a function of temperature

Following that, There determined a gap in the samples' energy (Eg) using Eq.4(8):

$$Eg = 3.53 K_B T_c \dots\dots\dots 4$$

Where KB represents the Boltzmann constant. and the concentrations of hole per Cu ion(P) was calculated by means of (12) :

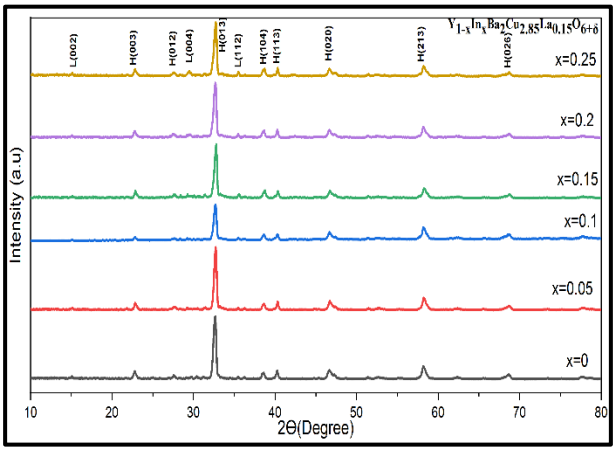
$$P = (0.16) - [(1 - T_C/T_{C\,max})/(82.6)]^{1/2} \dots\dots 5$$

SEM and AFM were used to view microscopic pictures of the materials at extremely high magnifications (SEM).

Result and Discussions

Through X-ray diffraction analysis to find out the crystal structure of the samples and the high phase ratio, and to make a comparison between the samples with different concentrations of indium, as in the fig.(1), which shows the X-ray diffraction patterns, was found that all the samples are polycrystalline.

Figure 1. X-ray diffraction pattern of (Y1-xIn xBa2Cu2.85 La0.15 O6+δ) compound.



By substitution of In concentration. The substitution process will lead to a very small shift in the (XRD) chart angle and peak intensities as shown in Table 1. Note The lengths of the lattice constants can expand or contract with the change of electrons in the orbitals, and the behavior of the samples prepared by different concentrations affected structural attributes; This is demonstrated by the variation of density, the ratio (c/a), and

constants. These samples' altered lattice constants may be an indication that oxygen has been added. which might be brought about by the environment's impact on the preparation's circumstances, and can have a substantial affect on the oxygen concentration, Additionally, it could be caused by the ionic radius difference, which changes the phases and lattice coefficients of superconducting compounds(13).

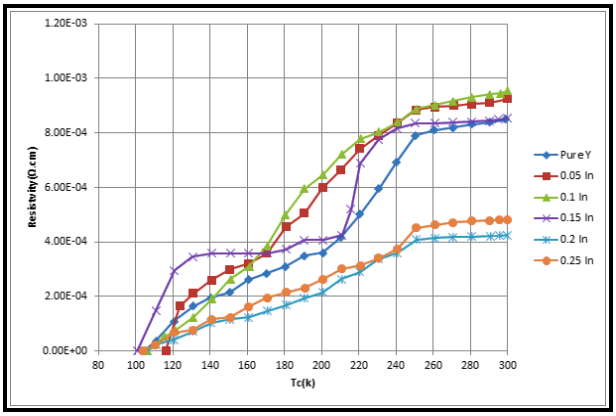
Table 1. Values of the parameters a,b, and c with different substitutions.

X	a (Aº)	b (Aº)	c (Aº)	c/a	V $(Aº)^3$	dm (gm/cm^3)	Vph(H) (1223)%	Vph(L) + Impurity%
0	3.873335	3.881677	11.61	2.997417	174.5567	6.37826207	85.7	14.3
0.05	**3.883388**	**3.877665**	**11.65027**	**3.000029**	**175.4354**	**6.34631683**	**90.91**	**9.09**
0.1	3.892634	3.87989	11.62856	2.987324	175.626	6.33943008	83.3	16.7
0.15	3.849186	3.875653	11.40423	2.962765	170.1296	6.544238	83.3	16.7
0.2	3.846969	3.882246	11.475	2.982867	171.3778	6.49657588	80	20
0.25	3.867214	3.880711	11.43293	2.956374	171.5801	6.48891442	76.9	23.1

When compared to alternative substitutions, the one with the value of (x=0.05) has the best structural features. The properties of the obtained samples may be significantly impacted by the preparation procedures (sintering time, pressure, the powder's granularity, sintering temperature, mixing technique, and grinding). The sintering process' temperature and length are crucial factors in the creation of high-frequency samples because they not only have the potential to cause microscopic cracks in the sample but also to bring the material closer to a state of solubility, which encourages the growth of low phases and impurities at the expense of the high phase and its formation. According to studies, a temperature just below the melting point is ideal for sintering(14).

Fig.(2). Illustrates the relationship between temperature and electrical resistivity, which causes the material to enter the superconducting state, all the samples displayed metallic behavior. The likelihood that more impurities and secondary phases might contribute additional energy levels to the (CuO) layers, which correspond with the (CuO) level and result in a bond between the two levels, is what causes the abrupt reduction in resistivity. Additionally, the critical temperature for this compound varied from that recorded for the samples; the maximum critical temperature for substitution (x=0.05) is (116.2) K, as shown in Table 2.

Figure 2. The relationship between temperature and electrical resistivity of (Y1−xInxBa2Cu2.85La0.15O6+δ) for (x=0, 0.05,0.1,0.15,0.2and 0.25).



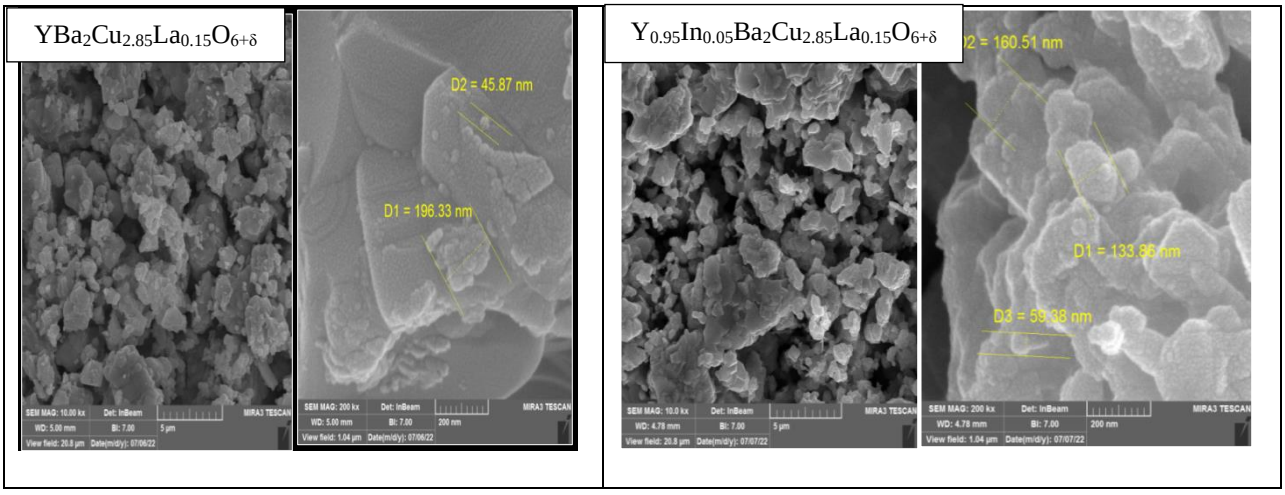
which leads us to the conclusion that the superconducting samples' electrical resistivity gradually decreased. Regarding the transition width (Tc), we observe that it had low values, which suggests that the sample was homogeneous. The samples' low phases and impurities, which are present in different amounts, are the cause of this behavior. The substitution of lead for yttrium, which tends to modify the concentration of charge carriers and conductive layers in this system, maybe the cause(8, 15, 16).

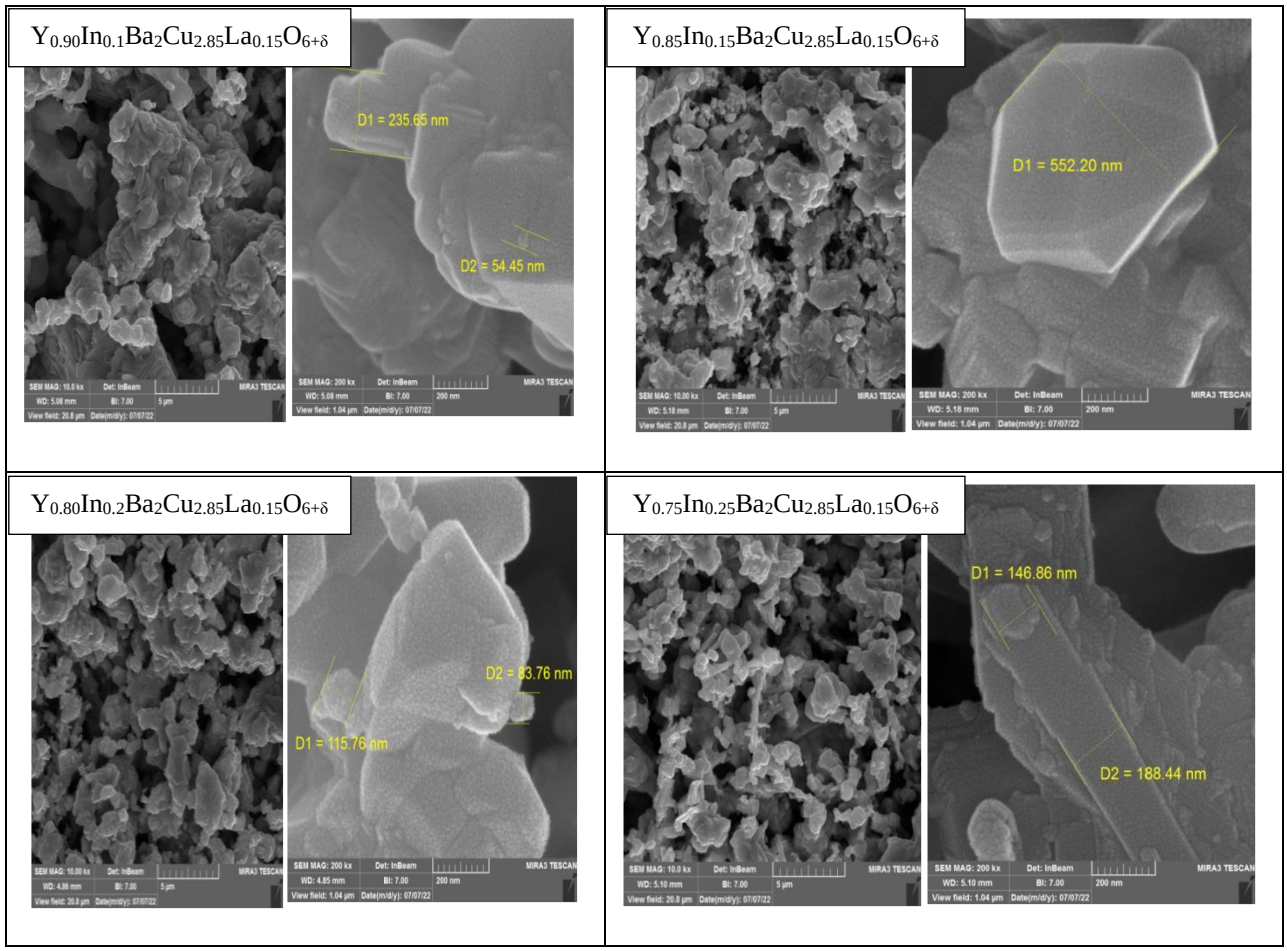
Table 2. The critical temperature, energy gap, and concentration of the hole of Y1-xInxBa2Cu2.85La0.15O6+δ compounds

X	Tc(off) (K)	Tc(on) (K)	Δ Tc (K)	Tc mid (K)	Eg (eV)	P(Hole) concentration
0	104.5	130.9775196	26.47751956	117.7387598	0.031545938	0.125085981
0.05	**116.2**	**130.8905379**	**14.69053788**	**123.5452689**	**0.035077875**	**0.16**
0.1	106.4	130.9814542	24.58145418	118.6907271	0.0321195	0.128046389
0.15	100.7	130.7986333	30.09863332	115.7493167	0.030398813	0.119814187
0.2	105.8	130.6899577	24.88995771	118.2449789	0.031938375	0.127082747
0.25	104.1	130.7914892	26.6914892	117.4457446	0.031425188	0.124494176

The fig.(3) shows the scanning electron microscopy (FESEM) images that were examined for the compound (Y1-xInxBa2Cu2.85La0.15O6+δ) where (x = 0,0.05,0.1,0.15,0.2,0.25), we notice a significant change The size, shape, and distribution of particles have different proportions, which affects the morphology of the samples. We also notice that there are dark and light areas in addition to the presence of different zigzags from one sample to another. We also notice the improvement in the specifications of the superconducting compound when the indium concentration is (0.05), where we notice the presence of agglomerations and clusters, which raises the critical temperature to (116.2).

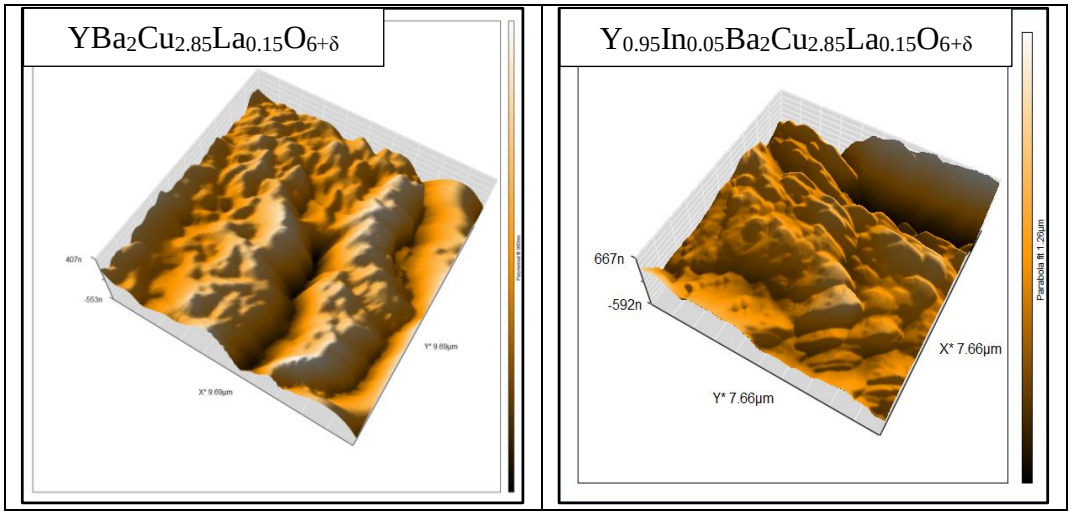
Figure 3. Shows the SEM of (Y1−xInxBa2Cu2.85La0.15O6+δ) for (x=0, 0.05,0.1,0.15,0.2 and 0.25) at degree of magnification (5µm,200nm).

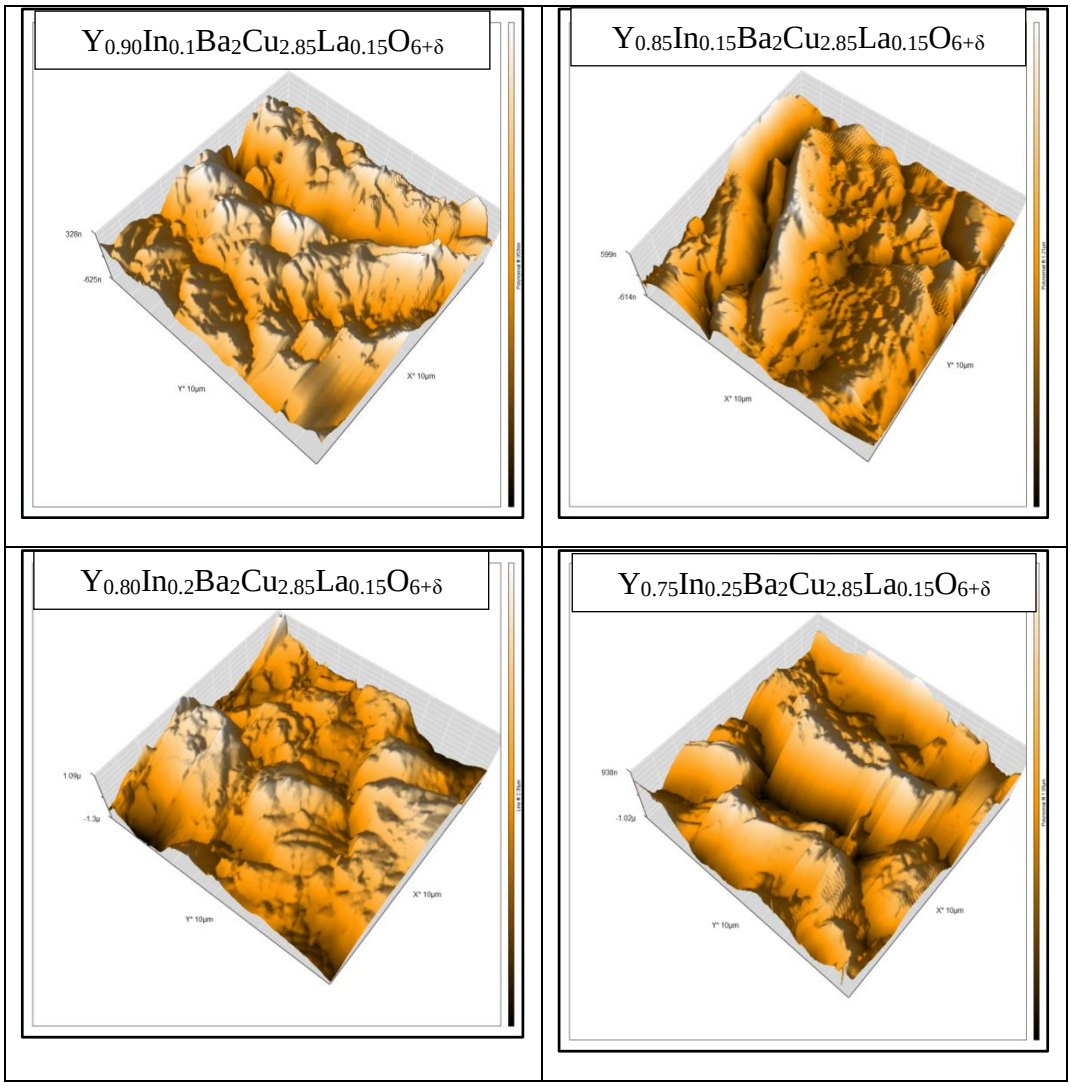




Through the (AFM) examination shown in Fig. (4), we notice that the surface of the samples has good crystalline regularity and high homogeneity with high density due to the small grains.

Figure 4. reveals the (3-D) AFM images and the chart distribution of (Y1-xInxBa2Cu2.85La0.15O6+δ).





Conclusion

The superconducting compound (Y1-xInxBa2Cu2.85La0.15O6+δ) with (x = 0.00, 0.05, 0.1, 0.15, 0.20, 0.25) was prepared as part of the present investigation using the (SSR) method. Through the () tests, it was found that all samples show metallic behavior and have a certain orthorhombic structure and that the sample with (x = 0.05) has the best structural properties, from which we conclude that the distortion of the parameter c as a result of forcing the development of hole coupling in the Cu-O layers, and that the partial replacement modulates the amount of charge transfer from the Y-O layer to the Cu-O layer in Y-123. The highest critical temperature was at a concentration (x = 0.1), where (Tc = 116.2 k), and the importance of prolonged sintering was shown to add more layers of copper oxide (Cu-O). As indicated by the high phase height and low phase slope (Y-123) and by looking at the microscope images (FESEM and AFM). Thus, when compared to other samples, it can be considered the best substitution ratio for substituting Indium instead of Ytrium.

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Authors' declaration:

- Conflicts of Interest: None.

- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.

- The author has signed an animal welfare statement.

- Authors sign on ethical consideration's approval

- Ethical Clearance: The project was approved by the local ethical committee in University of Kufa.

Authors, Contributions statement:

This work was carried out under the supervision and follow-up of (Haider M.J. Haider) in addition to conducting laboratory tests, analyzing and discussing the results, and reaching the final results of this work.

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