The substitutions of Strontium by yttrium and their effects on $\text{Bi}_2\text{Sr}_{2-x}\text{Y}_x\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}$ superconducting compound

Laheeb A.Mohammed¹, Kareem A. Jasim¹

¹ Collage of Education for Pure Science - Ibn Al-Haitham/University of Baghdad, Baghdad, Iraq

E-mail: laheeb.a.m@ihcoedu.uobaghdad.edu.iq

Abstract. Superconducting compound $\text{Bi}_2\text{Sr}_{2-x}\text{Y}_x\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}$ were Synthesized by method of solid state reaction, at 1033 K for 160 hours temperature of the sintering at normal atmospheric pressure where substitutions Yttrium oxide with Strontium. When $\text{Y}_2\text{O}_3$ concentration (0.0, 0.1, 0.2, 0.3, 0.4 and 0.5). All specimens of $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}$ superconducting compounds were examined. The resistivity of electrical was checked by the four point probe technique, It was found that the optimum and maximum transition temperature $T_c = 125 \, \text{K}$. The crystal structure studied by using XRD analysis and it was showed that the all specimens have tetragonal structures. $\text{Bi}_{2223}$phase increase by increasing $\text{Y}_2\text{O}_3$ concentration up $x=0.4$, The increasing addition Yttrium oxide concentration produce increasing in high-phase ($\text{Bi}_{2223}$) and c lattice parameter.

Keywords: Transition temperature: Superconductors; $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}$ oxide; XRD

1. Introduction

Superconducting is a phenomenon of total loss of electrical resistivity in some materials when cooled to a low temperature, and these materials are characterized by their ideal conductivity and diamagnetic behavior [1]. The primary properties of interest in solid-state physics at extremely low temperatures for many compounds and elements are electrical resistivity. Where there are two types of superconducting materials [2]. Depending on the way in which the electrical resistance decreases when the temperature decreases until it becomes zero. The first type of materials the resistance decreases suddenly when cooled to the critical temperature degree, and the other type is gradually decreasing until it becomes zero, meaning that it has two critical temperatures. The first type includes metals and metal alloys, including elements such as tin, tin Aluminum, forms of different metal alloys, while the other type includes ceramic materials with a perovskite composition, such as some high-doping semiconductors and some ceramic compounds. Where the second type contains layers of copper oxide and these compounds are referred to as “cuprates Superconducting materials” with high critical transport temperatures, and the phenomenon of superconductivity is not obtained in noble metals or in magmatic metals [3-5].
The bulk of superconducting materials are additives and alloys, which are not pure elements. The temperature of the transfer of compounds affected by substitution elements is completely different from pure compounds or metal alloys and their parts. In fact, many researchers have observed that there is a very clear rise in the temperature of transformation in alloys and compounds upon partial replacement of some elements of the compound with other elements other than it in the pure compound [5]. One of the very important properties of a material is electrical resistance, and it is the most common method for determining the transition temperature of a superconducting material. In this article, some measurements will be made of the structural and electrical properties of samples of Bi$_2$Sr$_2$Y$_x$Ca$_2$Cu$_3$O$_{10+\delta}$ with various x, such as X-ray, electrical resistance and the effect of partial precipitation of Sr with Y element.

2. Experimental Work

The Bi$_2$Sr$_2$Y$_x$Ca$_2$Cu$_3$O$_{10+\delta}$ compounds with (x=0.1, 0.2, 0.3, 0.4, 0.5) were synthesized by the (SSR) method after weighing specific quantities of high-purity pure powder oxides with a purity (99.99%) of the Bi$_2$O$_3$, Sr$_2$O$_3$, Y$_2$O$_3$, CaO and CuO. The materials included in the composition of the compound were weighed using a high sensitivity balance of up to (10^{-4} g) arranged, and the oxides of the reactants were mixed with each other using a slurry with the addition of a little isopropanol (C$_2$H$_3$O$_5$) to make the mixture homogeneous. To get rid of the water vapor in the mixture, the powders were dried for 1.5 hours at a temperature of 150 ° C, after which the mixture was grinded by a spiral electric mixer for a period of six hours in order to obtain fine homogeneous powders. The powders were pressed with a hydraulic press of 0.7G Pa for a period of 2 minutes, in the form of tablets with a diameter of 0.75 cm and a thickness of 0.3-0.35 cm.

Samples were placed in a thermal furnace for the purpose of sintering and its temperature was raised to 760 ° C for a period of (160 hours) with an average rise (5 ° C per minute) to obtain smooth bonding and to ensure the optimum gradual diffusion between the atoms to form the compound. Then the samples were cooled to room temperature at 5 ° C per minute (same heating rate).

The samples were examined with X-ray diffraction, the (X-ray) diffraction angle ranging from (10-80) to obtain the samples structural properties. The crystal lattice constants (a, b, c) were mathematically calculated using the values of each d and (Miller indices) for the observed patterns during a computer program [6-8]. Volume fraction phase in addition, density of mass was measured, and Volume fraction phase calculation based on the following formula [7-8]:

$$V_{ph} = \frac{\sum I^0}{\sum I^0 + \sum I1 + \sum I2} \times 100\% \quad .......... \quad (1)$$

The concentrations of hole-carrier per Cu ion, It is calculated by means of the formula of following [11]:

$$P = (0.16) - \left[ \left(1 - \frac{T_c}{T_{c(max)}} \right) \right]^{1/2} \quad .......... \quad (2)$$

P is the concentrations hole-carrier per Cu ion.

Four probe method at temperature range (77-300) K was used to measure the resistivity($\rho$). Critical temperature (Tc) calculated using the relation [9].

$$\rho = \frac{(R*{A})}{L} \quad .............. \quad (3)$$

Where R is resistance of electric, A is specimens area and L is specimens length.

3. Result and Discussions

3.1 structural properties

XRD was examined for pure samples Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+\delta}$ and samples containing Y$_2$O$_3$ Bi$_2$Sr$_2$,Y$_x$Ca$_2$Cu$_3$O$_{10+\delta}$ for a deflection angle ranging between (10° to 80°), the results shown in Fig. 1.
Indicated that all samples have polycrystalline structure with a tetragonal structure. The illustration the (XRD) pattern for Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+δ}$ doped by (Y$_2$O$_3$) shows that all the samples contain a high percentage of the high temperature phase Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+δ}$ (Bi-2223) and a few low-intensity phase peaks (Bi-2212 & Bi-2201) that have a low temperature, with some impurity phases appearing[10]. By comparing the phase ratio (Bi-2223) in the pure sample and the partially replaced samples with yttrium, it was found that there is a significant increase in this phase corresponding to a fluctuation in the phases (Bi-2212) and (Bi-2201) as well as in the percentage of impurities that accumulate it may be due to defects in The internal structure of the compound. The substitution of Y$_2$O$_3$ by SrO produce very small shifting in the diffraction angle 2Θ and change in magnitude of peaks intensities. Calculation of lattice parameters was shown in Table 1. This table noticed that the increase of yttrium substitution concentration produce increasing in c-axis values due to the variation in radius of the ionic.

![Fig. 1. XRD pattern of Bi$_2$Sr$_{2-x}$Y$_x$Ca$_2$Cu$_3$O$_{10+δ}$ compound (x=0.1, 0.2, 0.3, 0.4 and 0.5).](image)

The change in the (c) axis can be attributed to the increase in the oxygen percentage resulting from substituting (Y$_2$O$_3$) instead of (SrO) and that this increase in oxygenation is taken by the double bismuth oxide layers which cause stronger bonding due to the equivalence of yttrium tertiary. It leads to an increase in the strength of the ionic bonds formed in the bismuth oxide layers and thus changes the lattice constant (c). The parameters of lattice a, b, c based on method of Cohen's least square, calculation by software program, density of mass $D_m$ and fraction of volume ($V_{phase}$) were calculated from the above equation which are revealed in Table 1. It was clear show that Y$_2$O$_3$ concentrations increasing produce variations on a, b, c values, concentrations of hole-carrier, c/a, mass density and volume fraction of unit cell [6-8].
Table 1. Values of a, b, constants, \( \rho_M, c/a \), \( V_{\text{phase}} \), \( V_{\text{of Bi}_2\text{Sr}_2\text{Y}_x\text{Ca}_2\text{Cu}_3\text{O}_{10+\delta}} \) compound (\( x=0.1,0.2,0.3,0.4 \) and 0.5).

| X  | \( a=b \) (Å) | c(Å) | c/a ratio  | \( v(\text{Å}^3) \) | \( D_m(\text{g/cm}^3) \) |
|----|----------------|------|------------|-------------------|--------------------------|
| 0  | 5.409          | 37.209 | 6.87909    | 1088.634         | 435.7377                 |
| 0.1| 5.417          | 37.214 | 6.869854   | 1092.003         | 432.1169                 |
| 0.2| 5.433          | 37.619 | 6.924167   | 1110.418         | 742.9946                 |
| 0.3| 5.439          | 37.723 | 6.93565    | 1115.949         | 896.5545                 |
| 0.4| 5.458          | 37.792 | 6.924148   | 1125.815         | 1053.091                 |
| 0.5| 5.4201         | 37.391 | 6.898581   | 1098.454         | 1212.616                 |

\( V_{\text{ph}} \) (2223)%, \( V_{\text{ph}} \) (2212)% , \( V_{\text{ph}} \) (2201)%, \( V_{\text{ph}} \) impurities%, \( T_c \) (mid)K, \( P \) (Holes) concentration.

| X  | \( V_{\text{ph}} \) (2223)% | \( V_{\text{ph}} \) (2212)% | \( V_{\text{ph}} \) (2201)% | \( T_c \) (mid)K | \( P \) (Holes) concentration |
|----|--------------------------|--------------------------|--------------------------|-----------------|-------------------------------|
| 75.102 | 10.196         | 7.501         | 7.201         | 115             | 0.132775                     |
| 78.375 | 9.763          | 7.171         | 4.691         | 119             | 0.141402                     |
| 80.007 | 2.501          | 1.895         | 15.597        | 118             | 0.138911                     |
| 85.171 | 3.411          | 2.761         | 8.657         | 122             | 0.15297                      |
| 86.341 | 5.996          | 2.293         | 5.37          | 125             | ----------------------------|
| 80.532 | 11.025         | 3.131         | 5.312         | 122             | 0.15297                      |

### 3.2 Electrical properties

The electrical properties of the samples were examined by relying on the four-sensor technique, where the voltage and current readings were taken as a function of temperature, and then the electrical resistance was calculated as a function of temperature and was drawn in Fig. 2. shows a measured of temperature versus resistance (T) at variable concentrations of Y. From Fig. 2, it is noticed that resistance as a function of temperature of the Bi\(_2\)Sr\(_{2-x}\)Y\(_x\)Ca\(_2\)Cu\(_3\)O\(_{10+\delta}\) compound with (\( x=0.1,0.2,0.3,0.4 \) and 0.5) that all sample ratios showed metallic behavior at temperatures higher than the initial transition temperature (\( T_{c(\text{onset})} \)) and then fell to zero at the transition temperature. Depending on the ratios of yttrium and that the concentration \( x = 0.4 \). The best partial substitution ratio for yttrium oxide is (125K). This can be attributed to the fact that the crystal structure became perfect with the presence of Y\(_2\)O\(_3\) and that the transition width (\( T_c \)) is the narrowest compared to the other samples due to the width range. It shows the transition and represents the purity of the superconducting material. The transition temperature values (\( T_c \)) for Bi\(_2\)Sr\(_{2-x}\)Y\(_x\)Ca\(_2\)Cu\(_3\)O\(_{10+\delta}\) when \( x = 0, 0.1, 0.3, 0.4 \) phases of 115 K, 119 K, 118 K and 122 K, respectively. We can observe the increase in the degree of critical temperature values (\( T_c \)) up to It reaches the best sample by partially substituting yttrium oxide at a concentration of \( x = 0.4 \) so that a critical transition temperature of 125K is obtained[11].
Fig. 2. The Electrical Resistivity as temperature function of Bi$_2$Sr$_2$Y$_x$Ca$_2$Cu$_3$O$_{10+\delta}$ compound ($x=0.1$, 0.2, 0.3, 0.4 and 0.5).

4. Conclusions

Through our experimental research in the study of the effect of partial substitution of yttrium oxide with strontium of the superconducting compound (Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+\delta}$), where we were able to obtain superconducting samples under the preparatory conditions that we adopted during the work. Through the X-ray diffraction analysis, it was revealed that all samples have a quadruple crystal structure and that the partial substitution (Y$_2$O$_3$) did not change the crystal structure of all samples with respect to the pure sample. Also, all samples contain phases (Bi-2223, Bi-2212, Bi-2201) with low levels of impurities. As for the electrical resistance tests, all samples revealed that it has a metallic behavior where its resistivity changes with a decrease in temperature before transforming into the superconducting state and the best sample was obtained at a concentration of $x = 0.4$ and equals 125K.

References

[1] M.A. Omar 1993 Elementary solid state physics 5th ed., Addision – Wesley
[2] W. Meissner, and R. Ochsenfeld 1933 Naturwissenschaften. 21 787
[3] A. W. Sleight, J. L. Gillson, and P. E. Bierstedt 1975. Solid State Commas. 17 27
[4] I. H. Gul, A. Maqsood 2008 J. Supercond. Nov. Magn. 21 399
[5] M. Q. Tan, X. M. Tao, Q. R. Zhang, and Y. B. Xu, Prog. 1997 Phys. (in Chinese) 15 173995.
[6] K. A. Jasim and I. A. Mohammed 2018. J. Phys. Conference Series. 1003
[7] Laheeb A. Mohammed, Kareem A. Jasim 2019. Energy Procedia 157 135
[8] Laheeb A. Mohammed, Haider S. Hussein, Haider M. J. Haider, Kareem A. Jasim 2019 AIP Conference Proceedings. 2190. (020018)
[9] Laheeb A. Mohammed, Kareem A. Jasim 2018 IbnAl-Haitham Jour. for Pure & Appl. Sci. 31 (3)
[10] K. A. Jassim, H. S. Hussein, 2017. IbnAl-Haitham Jour. for Pure & Appl. Sci. 30 (3)
[11] B. S. Keeceong, M. S. Park 2007. The University of Texas at Austin. 36 84.