Partial Substitution of Cadmium and its Effect on the Electrical Properties of the Superconducting System (YBCO)

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ABSTRACT

In this work, the effect of partial substitution of Cadmium (Cd) instead of Copper (Cu) on the electrical properties of the compound ($YBa_2Cu_{3-x}Cd_xO_{6+\delta}$) was studied, where Cadmium fills the spaces between the granule cells. The compound was prepared using the state reaction method. Solid (SSR) with replacement ratios (x=0,0.1,0.2, and 0.3) The results were analyzed by conducting X-ray diffraction (XRD) examination to find the lattice constants and to know the crystal structure of the samples, so all samples showed a specific behavior based. As the electrical resistivity was studied as a function of the critical temperature, it was found that all samples showed superconductivity behavior, and the optimal sample was at the replacement ratio (X = 0.3), where the highest critical temperature was recorded (K 101.3Tc (offset=)) and the highest energy gap where the highest recorded Its value is (Eg = 0.030842051ev).

Keywords: partial substitution of the elements, yttrium, YBCO, solid state reaction method (SSR), superconductivity, critical temperature

Introduction

The phenomenon of (excess) superconductivity of materials is a phenomenon that occurs in some materials when they are cooled to a very low temperature approaching absolute zero (zero Kelvin), as the superconductors allow current to pass through them without almost any electrical resistance [1] and the superconducting state occurs In a wide variety of materials such as tin, aluminum, materials or ceramic compounds, heavy alloys, and some semiconductors, and in general, superconductors cannot be made of noble metals such as gold and silver, nor of ferromagnetic materials. It is at a very low temperature close to absolute zero (4.2 K), that the resistance of mercury drops suddenly to a very low value [2], as this discovery is the starting point in the world of superconductivity.

The compound $YBa_2Cu_3O_6$ is one of the perovskite compounds, and it is a ceramic material [3] where perovskite compounds are characterized by an abundance of atoms in its crystalline structure because it consists of layers of oxides [4]. General quantitative chemical formula (ABX3) and special crystal structure, where (A) and (B) represent positive ions and negative ions. The ions (A) and (B) may have a variety of charges. The original composition of perovskite is (CaTiO3), where calcium (Ca) represents the positive ion (A), while the second positive ion is represented by titanium (Ti). The crystal structure of perovskite compounds contains a small positive ion (B) within the octahedral oxygen lattice, while the large positive ion (A)

is surrounded by twelve oxygen atoms [5, 6]. One of the most important and interesting properties of perovskite compounds, which physicists, materials and chemists considered them to be their playground, is its giant magnetic resistance and superior conductivity [7]. It has been used in many applications, including waste containers and energy production, and was also used as a resonant insulator for communications [8]. The compound (Y-Ba-Cu-O) was declared to have superconductive properties in 1987 due to its transition temperature, which reached 90 degrees Celsius and thus exceeded the boiling point of nitrogen of 77 degrees Celsius [9].

All compounds (CuO) are insulators, and by replacing certain atoms in a unit cell, these materials can behave metallicly and can become superconducting materials because the transition temperature depends on the density of states at the Fermi level and this factor mainly affects when the compounds are grafted Ceramic atoms have other atoms that differ in their valency to provide them with holes and additional electrons, which they provide in order for the material to turn into a superconducting material [10].

The main objective of the research is to produce a superconducting material and to know the effect of adding Cadmium instead of yttrium on the YBCO system by observing the increase in the critical temperature of the compound

($YBa_2Cu_{3-x}Cd_xO_{6+\delta}$), where x = (0,0.1,0.2,0.3)

Practical Part

The samples were prepared by the solid-state reaction method, and this process went through several stages, which can be summarized as follows:

1-The samples were obtained in the form of oxides and were of high purity (99%) and included (Y_2O_3, BaO, CuO, CdO).

2-The appropriate quantities of oxides were weighed using a sensitive digital balance

3-The materials were grinded for 30 minutes using a hand mortar, then the materials were mixed for 30 minutes using the electric vortex sewer so that the ton process was done well and to ensure the homogeneity of the materials

4-The samples were formed into discs by pressing the powders using the hydraulic press for one minute under pressure (7 ton/cm2).

5-The last stages of sample preparation were sintering them for 24 hours using a special oven and under a temperature of 800°C at a rate of (10°C/min). After that, the samples were cooled gradually and at the same heating rate.

6-After the sintering process has been completed, the samples are ready to take the required measurements on them, which consisted of two stages

The first stage, in which the electrical resistance was measured as a function of temperature, and this stage was carried out using the four sensors system

It was noted that the voltage drop passing through the electrodes occurs when current flows through the sample, and the electrical resistance was calculated using the following relationship: [11, 12].

$$\rho = \frac{V\ W t}{I\ L} \quad \text{.....(1)}$$

where I is the current passing through the sample, V is the voltage in the sample, t is the thickness of the disk, L is the length running between the electrodes, and W is the width of the sample.

As for the second stage, it was represented by measuring the free transition temperature, using the electrical resistance curve as a function of the degree. The following relationship was used to find the critical temperature: [13, 14]

$$\text{Tc (Onset)+Tc (Offset)} \quad (2) = Tc\ (Mid)2$$

Where: Tc (Onset) is the initial transition temperature, Tc (Offset) is the final transition temperature at (ρ = 0), and Tc

(Mid) is the average temperature. [15th]

The ceramic superconducting (YBCO) system is an electrically active mass because both copper and oxygen form a chain of copper oxide layers. gaps, and this is necessary for superconductivity to occur.

Segmentation And Results

In the beginning, the X-ray diffraction analysis of the pure sample, which had a substitution ratio (x=0.3), which represents the high phase of the superconducting system (YBCO), where we noticed the formation of the high phase (Y123) with the presence of some impurities and the high proportion of the high phase (Y123). In the pure sample with a decrease in the intensity of the peaks of the remaining phases in addition to a small percentage of impurities due to the lack of oxygen or to the displacement of atomic defects or to the irregularity of the positive ions, which leads to the accumulation of defects in stacking along the (c) axis, which eventually leads to the distortion of the structure Crystal [14,15] Then the lattice constants for the sample were calculated mathematically and by determining (2θ) and Miller's coefficients (hkl) for each vertex and using equation [3]

$$\frac{1}{d2} = \frac{h2}{a2} + \frac{\mathrm{k2}}{b2} + \frac{\mathrm{l2}}{c2} \quad \ldots\ldots(3)$$

And it was very close to the standard calculations, as the results showed that all samples had an (Orthorhombic) structure, and then the phase ratios were calculated by comparing them with the standard schemes and according to equation [4]

$$(vph)\% = \frac{\Sigma I0}{\Sigma I1 + \Sigma 2\ \ \Sigma other(peaks)} \times 100\% \ldots\ldots\ldots\ldots\ldots(4)$$

Where: I represents the intensity of the peaks in each phase, and the ratio (c/a) was calculated. As for the unit cell density

The results showed varying values as shown in Table (1) and the reason for these results is due to both the sintering time and temperature, as their increase causes a greater time and energy for the mobile mass, and this is necessary to obtain the thermodynamically balanced phases, as a long sintering time is necessary To introduce additional layers of (CuO) in the structures of the lower phases, and this gave positive results in terms of the percentage of high phase formation in the sample. [16]

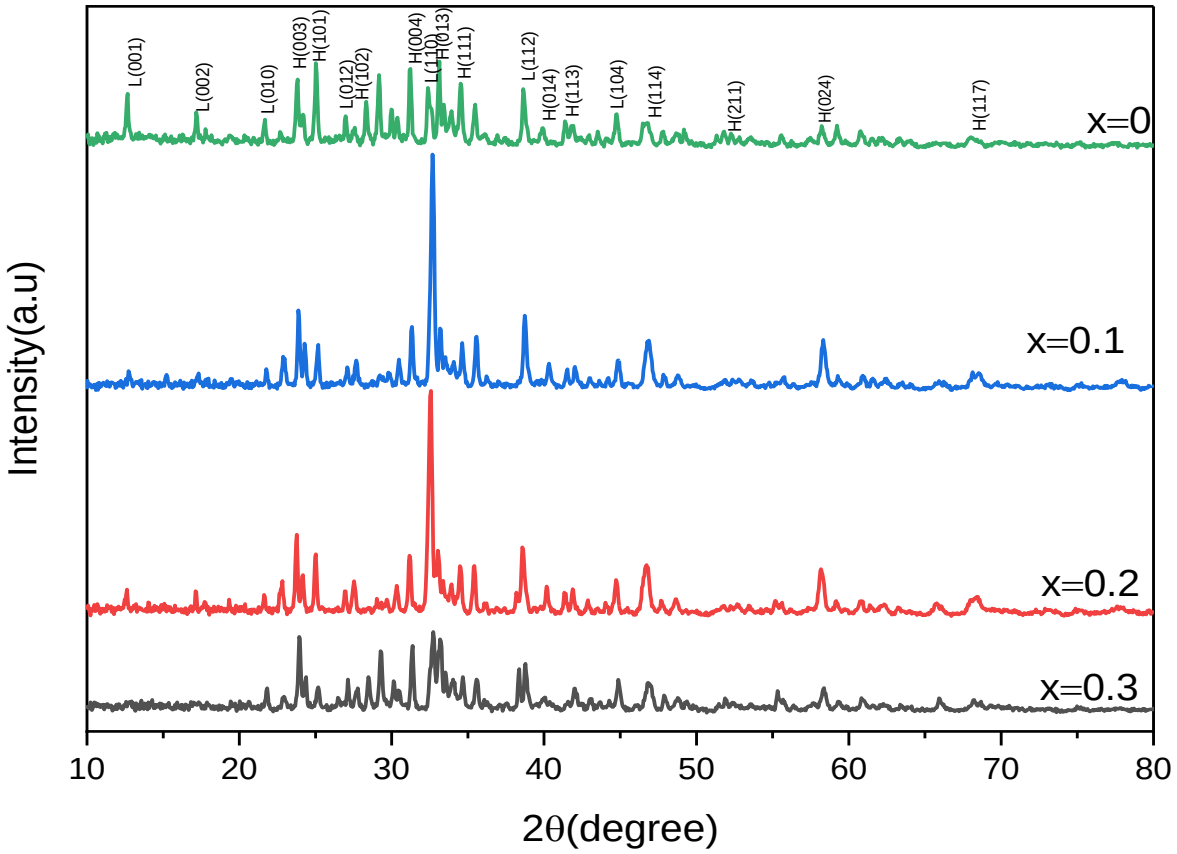

Figure (1) represents the X-ray diffraction diagram of the group samples

Table (1) shows the phase ratios, lattice coefficients, (c/a) of the formed samples

x	Vph(H)%	Vph(L)%	a (A°)	b(A°)	c(A°)	c/a
0	63.15%	36.84%	3.747	3.832	11.198	2.988
0.1	60.52%	39.47%	3.847	3.875	11.7	3.041
0.2	61.09%	38.91%	3.846	3.874	11.726	3.048
0.3	61.11%	38.89%	3.838	3.888	11.748	3.060

From Figure (2), which represents the X-ray diffraction scheme for the group samples, where X represents the ratio of substitution of yttrium to magnesium (X = 0,0.1, 0.2, 0.3), and using Table (1), we notice that the sample with a substitution ratio (X = 0.3) has the properties The optimum composition in this sample, which is clearly visible through the high phase rise, where it reached (Vph(H) =61.1%), the low phase decrease and the increase in density. Thus, this ratio can be considered as the optimal replacement ratio in terms of replacing Cadmium instead of copper, followed by the sample with the replacement ratio (X = 0.1), while the rest of the samples showed a significant decrease in the percentage of the high phase and an increase in the percentage of low phases, especially for the sample (X = 0.2), where we notice a sharp decrease in the high phase with a significant increase in the low phase. The increase in the substitution ratio had a positive effect in raising the rate of higher phase formation. The lengths of the lattice constants can expand or contract with the change of electrons in the orbitals, as well as it could be due to the difference in ionic

radii, which causes distortion in the lattice coefficients [17].

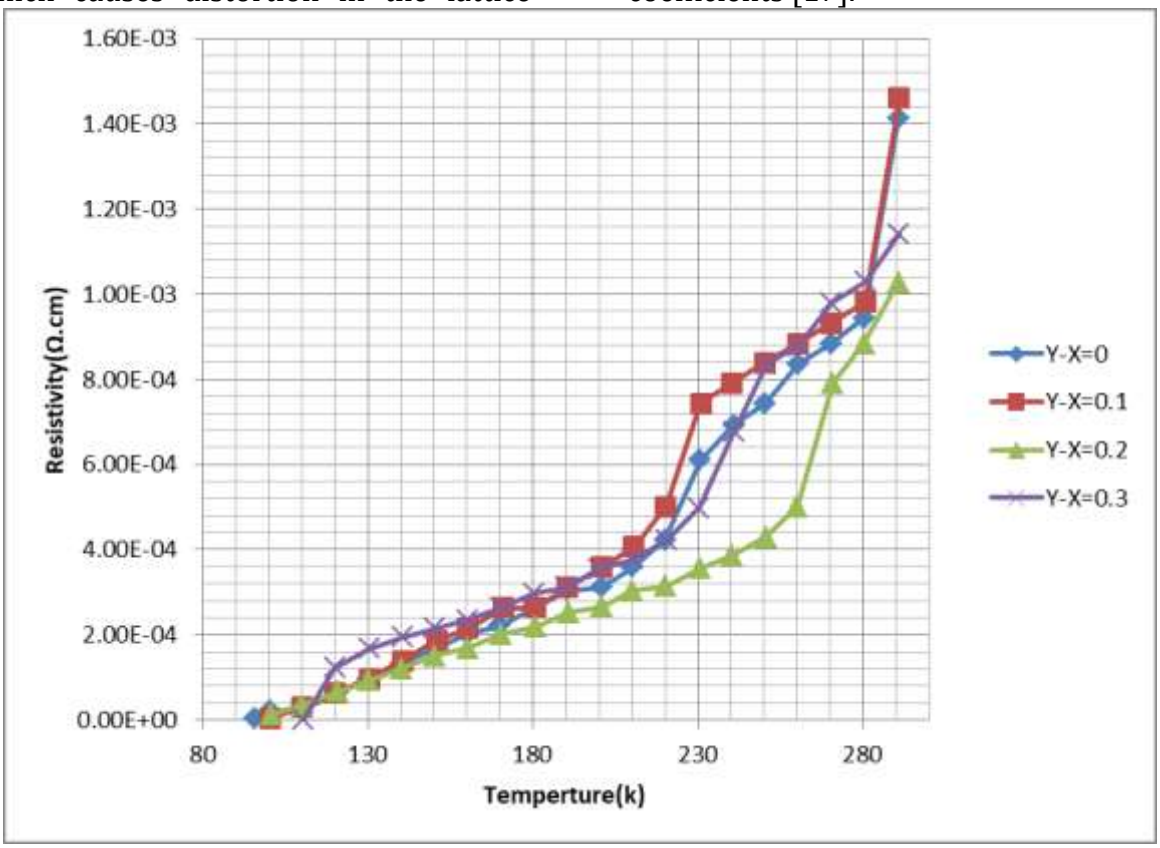

Figure (3) Variation of electrical resistivity as a function of temperature

In Figure (3), which represents the behavior of electrical resistance as a function of temperature with different substitution ratios (X=0, 0.1, 0.2, 0.3), in which we note that all samples showed superconducting behavior with a difference in critical transition temperatures, noting the height In the presentation of the transition to the superconducting state, which is attributed to the presence of impurities and low phases, as well as to the generation of some internal distortions in the crystal structure due to the replacement process

Table (2) shows the phase ratios, critical temperature and energy gap of the samples

X	Tic (K)	Tc(of) (K)	Tc(on) (K)	ΔT (K)	Tc(mid) (K)	Eg (ev)
0	95	95	100.23	5.23	97.615	0.028
0.1	99.2	99.2	110.12	10.92	104.66	0.030
0.2	95.9	95.9	110.01	14.11	102.955	0.029
0.3	101.3	101.3	120.08	18.78	110.69	0.0308

Through Table (2), we notice that there is a clear difference in the ratios of phases and critical temperatures of the samples, where we notice an increase in the ratio of the high phase and critical temperature of the samples (X = 0.3,0.1) and a decrease in the ratio of the high phase and critical temperature of the samples (X = 0, 0.2), as well as a change in the concentration of the gaps, and the highest percentage appeared in the sample with the replacement ratio (X = 0.3), which was free of impurities, which can be considered the optimal sample in this group and in all samples, as it has the highest percentage of the high

phase and the highest temperature The reason for this can be attributed to reaching the optimum substitution ratios that coincided with the preparation and forming factors, as well as having the highest concentration of vacuoles, and also that the replacement process may result in that some additional charges move into (CuO) layers, which leads to Some copper atoms move from the oxidation state (Cu + 2) to (Cu + 3), and this mixed state of valence leads to a significant improvement in superconductivity [18]. Dense, large grain size, and fewer pores All of them guarantee a great conductivity between the grains, which is governed by the state of the layers (CuO)[20], while we notice in the sample (X=0) a decrease in the ratio of the high phase, which led to a decrease in the critical temperature as well as in the concentration of the gaps, as the decrease in the concentration of The gaps in the (CuO) layers are evidence that the low phase grows at the expense of the higher phase, and this decrease and deterioration can be attributed to the large substitution ratios that caused the generation of mechanical and thermal stresses in the crystal structure of the samples during the heat treatment process, causing distortions and defects. In the crystal structure of the samples, and the decrease in critical temperatures can also be attributed to the loss and evaporation of some yttrium and oxygen atoms due to the sintering time, which leads to a distortio of the crystal structure of the samples.

Conclusions

The current study included the preparation of the superconducting compound ($YBa_2Cu_{3-x}Cd_xO_6$)Successfully at annealing temperature of 800°C for a period (24 hours) with partial substitution of elemental Cadmium instead of elemental Copper(Cu). A set of results were observed, the most important of which is that all samples have a metallic behavior in terms of changing their electrical resistance with decreasing temperature before switching to the superconducting state.It was also found that the type and amount of substitution are very necessary to introduce additional layers of copper oxide (CuO) into the composite layer and to obtain the highest percentage of the upper phase.Through the use of X-ray diffraction examination, all samples showed an existing rhombic structureIt was found that the replacement ratio x = 0.3 represents the optimal ratio to replace Copper with Cadmium through a higher phase elevation and an increase in density and obtaining the highest critical transition temperature of (101.3 k).

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