Effect of Silver and copper partial substitution on the structural and electrical properties of Bi$_2$Ba$_2$Ca$_2$Cu$_3$O$_{10+\delta}$ superconducting

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ABSTRACT

In our research, the compound Bi$_2$-x (Ag + Cu)xBa$_2$Ca$_2$Cu$_3$O$_{10+\delta}$ superconductors was prepared using a solid state reaction metallurgy method with studying the partial substitution of bismuth with (Ag 50%, Cu 50%) at a concentration of x = 0,0.2,0.4,0.6, 0.8, samples were sintered at a sintering temperature of 760 °C 160 h. The structural and electrical properties and the effect of partial substitution on them have been studied. The results of the X-ray diffraction analyzed, lattice parameters (a, b, c), the volume per unit cell were calculated. The results showed that all samples have polycrystalline and orthorhombic structure, in addition, all samples under experiment have the highest 2223 major phase compared to the other phases. The partial substitution affected the values of the lattice constants. The electrical properties examination was performed to obtain the critical temperature using the four-point technique and showed the highest critical temperature when x = 0.2 equals 124K for Bi1.8AgO0.1CuO0.1Ba2Ca2Cu3O10+δ compound.

KEYWORDS

Solid state reaction, critical temperature, orthorhombic structure and Superconductors

INTRODUCTION

The search for new materials and their discovery to enrich the developments that human beings are going through and their other requirements was to save effort, time and cost, which were continuous and massively, among the discoveries that were marked by the great importance of the so-called superconducting materials, the study and research in these materials does not only aim to Obtaining an information base in materials science, in addition to expanding it in improving the engineering and technological applications of materials. Superconducting materials are very important in high performance electronic and electrical applications. Superconductivity is the phenomenon in which a conductor completely loses resistance to electric current through certain conditions and is completely magnetic permeability. Superconductivity is defined as a phenomenon of electrical resistivity lack in some materials when were cooled under a certain temperature, which is called the critical temperature (Tc) or transition temperature, which varies from one to another material [1-2].

The discovery of High-Temperature Superconducting Material sparked the first spark for a new revolution in industrial applications and materials science [3-6]. Examples of high temperature superconducting systems are (Bi-2201), (Bi-2212) and (Bi-2223) [7-9], which are characterized by being two-base and have a layer structure, so they are composed of three phases, namely Bi-2201, Bi-2212 and Bi-2223. A last number of each phase indicates the number of CuO layers thus containing the critical temperatures (10K, 80K & 110K); The latter means the temperature at which the electrical resistance is zero (R = 0) [10-12]. The phase (Bi-2223) is difficult to prepare which has the advantage of being a single phase with the highest critical temperature (110 K) among
the three phases [13]. The properties of the superconductors can be regulated by adding or removing a different element in their ionic radius and their bonding properties, and the improvement or deterioration in the properties of the superconductors depends on the properties of the added or substituted elements that differ in their radius and bonding. Most of the studies focus on improving the shape and properties of (Bi-2223) based on the substitution study [14-16].

EXPERIMENTAL WORK

The compound Bi2-x (Ag + Cu) xBa2Ca2Cu3O10+δ superconductors was prepared using a solid state reaction metallurgy method SSR-method. Whereas, approximately high purity pure amounts of oxides (99.99%) of Bi2O3, AgO, CuO, BaO and CaO were used. The proportions of the reactants were determined and calculated using a sensitive balance. The sensitivity is estimated at (4-10) g, after which the reactants were mixed with each other manually for half an hour and then using an electric mixer with the addition of isopropanol (C2H3O5) for the purpose of homogenization. The powders were dried for two hours under a temperature of 120 °C to get rid of H2O vapor, after which they were ground and then mixed by a helical-shaped electric mixer for an hour in order to obtain the fine powders of high homogeneity. The resulting powder was pressed with a hydraulic press for two minutes under a pressure of 0.7 kPa., To obtain discs with a 0.75 cm diameter and 0.3-0.35 cm thickness. Samples were sintered at a temperature of 760 °C for a period of (160 hours) with a range of (5 °C per minute) to obtain bonding between the atoms and to ensure the optimum gradual diffusion between them. Then the samples are cooled at the same rate of heating to 300 K. The samples were examined using X-ray diffraction in order to obtain the structural properties of their lattice densities, phase ratios and volumetric fractures for each phase, within the diffraction angle range (10-80). The parameters of the lattice (a, b and c) were calculated mathematically using the Miller indices and d-values of the observed XRD reflections through a computer program applying Bracke’s law. In addition, density of unit cell was measured for all samples [2-4]. Volume fraction of phase was calculated by use the following formula [17]:

\[ V_{\text{phase}} = \frac{\sum I_n}{\sum I_1 + \sum I_2 + \ldots + \sum I_n} \times 100\% \]  

(1)

Where Ia is the XRD phase peak intensity, I1, I2, I3, I4…..In are the intensity of peaks for all XRD. P is The concentrations of hole per copper ion, which is calculated by means following formula [13]:

\[ P = (0.16) - \left[ (1 - \frac{\tau_c}{\tau_{c(max)}})/(82.6) \right]^{1/2} \]  

(2)

RESULTS AND DISCUSSION

Results of X-Ray Diffraction

The crystal structure assays represented by the examination of X-ray diffraction were performed. Sample’s crystal structure prepared using the solid-state reaction method was studied for all x values, and we obtained the data for all samples shown in Fig. 1 and were analyzed and followed up. There are three important factors, including the location of the peaks, their intensity, and the crystal lattice constants. Where a shift is observed in the locations of the diffraction peaks and a change in their intensity as the copper and silver concentration increases. Through Figure (1), the X-ray diffraction results showed that all samples contain multiple crystals and possess a rhombus crystal structure. Where it is noticed from this figure that all the diagrams contain the vast majority of the phase Bi-2223 in addition to some phases (Bi-2212, Bi-2201) with some impurities, and this indicates the high rate of the high phase (Bi-2223) in the pure sample with a change in The intensity of the peaks of the remaining phases, which represent simple ratios of the phases (Bi-2212, Bi-2201) in addition to low levels of impurities as the concentration of the substituted elements increases, and the appearance of different phases in the pure sample in particular and the rest of the samples in general due to the displacement of atomic defects or lack of oxygen. Or the vacuoles or irregularities of the positive ions leading to the accumulation of stacking defects. Along the (c) axis, ultimately leads to a distortion of the crystal structure [16-18]. The phase ratios were calculated after determining the peaks, intensity and type by comparing them with standard schemes and according to equation (1) the ratio (c / a) and unit cell density were measured. Varying values were shown as shown in Table (1), the reason for this is due to the sintering temperature and the sintering time as both
temperature and sintering time are necessary and required to obtain thermodynamic equilibrium phases and long sintering time is necessary to introduce additional Cu-O and Ca-O layers in the low-phase structures, and this gave positive results in terms of the proportion of high phase formation in the sample [19-21].

Figure 1. XRD pattern for Bi2-x(Ag + Cu)xBa2Ca2Cu3O10+δ compound (x=0.2,0.4,0.6 and 0.8)

The lattice parameters were obtained using Equation (1) through the use of a program (a Cohen's program method) where values of a, b, and c were as shown in Table 1. It is noticed from the table that increasing the concentration of partially transcendent elements leads to a clear change in both the network constants and their size. Where there was an increase in the value of c and then there was a variation in the value of the concentrations x = 0.4,0.6,0.8, due to the disturbance in the number of CuO chains and CuO2 levels responsible for the various isotropic materials and the critical temperatures Tc of the superconducting materials where the decrease of the coefficient c leads to a decrease The intensity of the energy levels of Fermi reduces the critical temperature Tc, imbalance and variability, and influences the unit cell volume in a compound [4,17]. This change in lattice constants occurs due to the difference in the ionic radius of the substituted elements due to an increase in the substitution concentration [11].

Table 1. Lattice parameters a, b, c, c/a, mass density m, volume fraction V ph(1223), V ph(1212), and P (Hole) concentration of compounds

<table>
<thead>
<tr>
<th>X</th>
<th>a (Å)</th>
<th>b (Å)</th>
<th>c(Å)</th>
<th>c/a ratio</th>
<th>v(Å³)</th>
<th>m(g/cm³)</th>
<th>V ph(1223)%</th>
<th>V ph(1212)%</th>
<th>P (Hole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.42</td>
<td>5.429</td>
<td>36.676</td>
<td>6.76679</td>
<td>1079.198</td>
<td>2.777507</td>
<td>79.102</td>
<td>7.826</td>
<td>0.1136</td>
</tr>
<tr>
<td>0.2</td>
<td>5.408</td>
<td>5.4134</td>
<td>37.291</td>
<td>6.891957</td>
<td>1092.284</td>
<td>2.717772</td>
<td>86.214</td>
<td>0.1436</td>
<td>0.16</td>
</tr>
<tr>
<td>0.4</td>
<td>5.4119</td>
<td>5.4221</td>
<td>37.271</td>
<td>6.88686</td>
<td>1093.675</td>
<td>4.703973</td>
<td>79.201</td>
<td>7.943</td>
<td>0.1338</td>
</tr>
<tr>
<td>0.6</td>
<td>5.4115</td>
<td>5.4188</td>
<td>37.25</td>
<td>6.883489</td>
<td>1092.313</td>
<td>5.69268</td>
<td>77.18</td>
<td>9.283</td>
<td>0.1379</td>
</tr>
<tr>
<td>0.8</td>
<td>5.412</td>
<td>5.4261</td>
<td>36.8819</td>
<td>6.814837</td>
<td>1083.076</td>
<td>6.732454</td>
<td>76.852</td>
<td>9.813</td>
<td>0.04997</td>
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</table>

RESULTS OF ELECTRICAL RESISTIVITY

The relationship between electrical resistivity and temperature is one of the most important properties of the superconducting material, which gives us a good indication in determining the value of the critical transfer temperature (Tc). The resistivity as a function of temperature was measured using 4-point probe technique for range of the temperature from 77 to 300 K.
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Figure 2. The resistivity vs. temperature for specimens with x=0, 0.2, 0.4, 0.6 and 0.8

Figure (2) shows the electrical resistance behavior as a function of the temperature of the five samples before and after the partial replacement, and the results showed that all samples had metallic behavior and critical temperature increasing by increase x concentration. That is, its electrical resistance decreases with the decrease in temperature in the region preceding (Tc(onset)), as the material moves from its natural state. To the superconducting state, noting that the transition to the superconducting state took place in several steps, due to its multiple transitions due to the multiple stages that were formed in the sample and the presence of some crystal and impurities in the samples. The results also showed that the Tc changes with increasing x concentration [11,17]. As the highest Tc at zero resistivity Tc(off) was obtained 119 K at x = 0.2, but at other concentrations, it increased with the x concentration as shown in table 2.

Table 2. values of Tc (OFF) , Tc(ON), ∆Tc , a(Å0) and energy gap Eg for Bi2-x(Ag + Cu)xBa2Ca2Cu3O10+δ compound (x=0,0.2,0.4,0.6 and 0.8)

<table>
<thead>
<tr>
<th>Simplex</th>
<th>Tc(On)(K)</th>
<th>Tc(Off)(K)</th>
<th>∆Tc (K)</th>
<th>Eg(eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>106</td>
<td>98</td>
<td>102</td>
<td>0.031026</td>
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<tr>
<td>0.2</td>
<td>129</td>
<td>119</td>
<td>124</td>
<td>0.037718</td>
</tr>
<tr>
<td>0.4</td>
<td>119</td>
<td>115</td>
<td>117</td>
<td>0.035589</td>
</tr>
<tr>
<td>0.6</td>
<td>121</td>
<td>117</td>
<td>119</td>
<td>0.03635</td>
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<tr>
<td>0.8</td>
<td>120</td>
<td>118</td>
<td>118.5</td>
<td>0.036197</td>
</tr>
</tbody>
</table>

CONCLUSION

In our work preparing and studying the superconductor compounds Bi2-x(AgO, CuO) xBa2Ca2Cu3O10+ by substituting CuO, ago in Bi through solid state reaction technique and observed the improvement in electrical and structural properties. XRD patterns show that all samples obtained have a polycrystalline standing specific composition. It was found that the increase in the AgO and CuO concentrations for all of our samples leads to changes in the network constant a, b, c, c / a, the critical temperature. The shift indicates a change in the locations of the peak stresses to with increasing the partial substitution concentrations of CuO, AgO in Bi. As for the electrical resistance tests, all the samples revealed that they have metallic behavior, where the electrical resistance decreases with the decrease in the temperature before the transformation and then turns to the superconducting state, and the best sample was obtained with a concentration of x = 0.2, highest critical temperature at zero resistivity Tc (off) was obtained 119 K at x = 0.2, but at other concentrations, it increased with the x concentration.
REFERENCES


