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Study the partial substitution of Tl and Ba on Structure and Electrical Properties of Bi2-xTlxSr2-yBayCa2Cu3O10+δ High Temperature Superconductor

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A R T I C L E I N F O

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A B S T R A C T

Polycrystalline samples of high temperature superconductivity of the type 2223, Bi2-xTlxSr2-yBayCa2Cu3O10+δ have been prepared by using solid state reaction process. The influence of the substitution of Tl for Bi and Ba for Sr have been studed with different rates (x=0.1-0.4) and (y= 0.1-0.4) at variable sintering temperature, sinterinr time and annealing at 850ºC for 24 h, at average heating 2ºC/min. The best Tc value obtained for the compound is x=0.3,y=0.3. The x-ray data of all superconductor samples showed a tetragonal structure with a high ratio of Bi-2223 superconducting phase and the resistivity measurements were done using the electrical resistively instruments. The substitution of Tl by Bi and Ba by Sr increases the grain size of the superconductingphase and the density of the pellets. Also give a best value of Tc =133 K respectively.

Introduction :

In 1911 a Dutch physicist, H. Kamerlingh-Onnes discovered the phenomenon of superconductivity. He measured the electric resistance of mercury at very low temperature. Onnes wanted to know how small the resistance to an electric current can decome if a substance is purified and the temperature is lowered as much as possible. The result of this investigation was unexepected: at a Temperature below 4.15 K[1] the resistance almost instantaneously.

Valldor et.al. (2000)[2] studied the $(Tl,Hg)_2$ $(Ba,Sr)_2$ (Sr,Ca) $Cu_2O_{8+\delta}$ superconductor system. They found that $T_{c(onset)}$varies within (45–100)K with a decreasing formal oxidation state of Cu in the superconducting plane.

Wang et.al. (2003)[3] studied the structure and Electrical properties of high temperature Bi_2Sr_2 Ca_2 $Cu_2O_{8+\delta}$ superconductor by namilly (Bi –2212). The x –ray data of the samples showed a tetragonal structure with a high ratio of Bi – 2212 superconducting phase.

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The samples showed a transition at 85 K. The Bi –2223 showed a superconductivity transition with typical value of $T_c \geq 110K$. Yuan at.al.(2004)[4] studied the variation of T_c due to partial Pb substitution for Bi in $(Bi,Pb)_2$ $Sr_2Ca_2Cu_3O_x$ (Bi – 2223). They showed that, T_c increasing rapidly with increasing Pb content for both Bi –2223 system. Ali A.D. (2007)[5] studied superconducting of Bi_2Ba_2 $Ca_2Cu_3O_{10+\delta}$ ceramics prepared by a solid state reaction under optimum conditions (850 ºC sintering in flowing O_2 for 24 h). Using transmission temperature of 135 K and lattice constants were a=b= 5.42 Aº and c= 33.1 Aº by x-ray diffraction measurement.

Experimental procedure

In the present of samples are given and explaining the different techniques which used to characterize our samples.

In this study appropriate amounts of high purity Bi_2O_3, Tl_2O_3, $Sr(NO_3)_2$, $BaCO_3$, CaO and Cu_3 powders have been weighed, mixed and ground in a gate mortar for two hours to get a powder of uniform gray color. The mixture homogenization took place by adding a sufficient quantity of 2-propanol to make think slurry. This process was repeated several times to produce a homogenous, soft as fine as powder particles. Drying the mixture in oven at 80 ºC for 60 min, then putting the mixture in a tube furnace that has programmable controller type Eurothrem 818 for calcinations in air, which is the best treatment to remove (CO_2 and NO_3) gases from the mixture. The powder was heated to temperature at 850ºC for 24 hours with a heating rate of 2ºC/min, then cooled to room temperature by the same rate.

Measuring the weight of the mixture after calcenation (W_2), the color of it was black. If the difference in the sample weight before and after the calcinations process (W_2- W_1) is less than the theoretical value of gases.

The mixtures were pressed into a pellet of (0.2-0.3)cm in thickness and 1.3 cm in diameter, under a pressure of about 9ton/cm^2 by using hydraulic press type (specac).

Sintering the pellets in air atmosphere of 850ºC for 12h with a heating rate 2º C/min in order to make the particles of the materials ionized together and gradually reduce the volume of pore spaces between them. Then the pellets were cooled to room temperature by the same rate of heating.

Regrinding, repressing and resintering the sintered pellets were reground. In this work, three sets of samples were produced for each superconducting compound. The first set of samples was cooled to room temperature in the furnace with a cooling rate 2ºC/min, the second set of samples were removed from the furnace and quenched in air, while the third set of samples were sintered for 12h in flow O_2, the preparation methods are shown in Fig.(1).

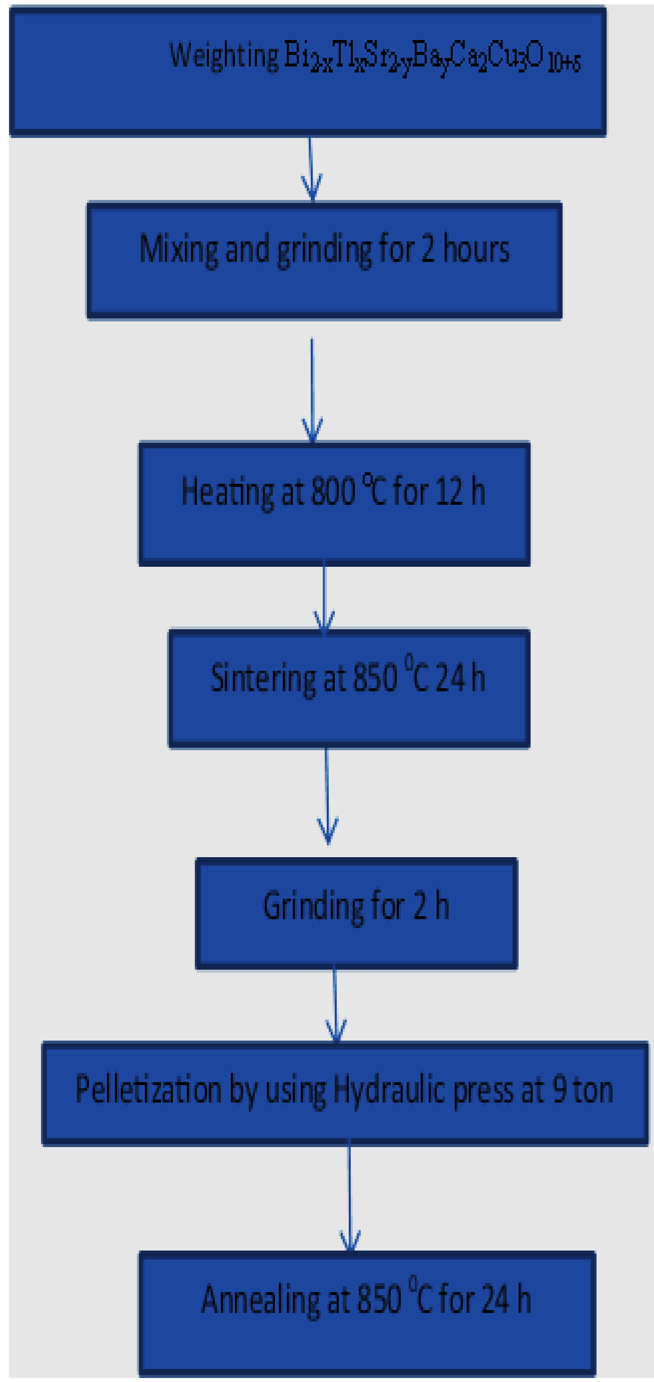

Fig.(1) Schematic Diagram showing preparation of $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ samples

Results and Discussion

Our results will be presented and discuss their mean features. This will include the x-ray diffraction results .

X-Ray Diffraction (XRD):

The powder x-ray diffraction method has been used for structural characterization and to determine the lattice parameters of the samples processed that used in this study , by using computer controlled diffractometer.

X-ray diffraction type (Phillips), having the following features,was used to examine the structure of the prepared samples.

Source : Cu Kα
Voltage : 40 KV
Current : 20 mA
Wavelength : 1.5405 A°

A computer program [6] was workedout to calculate the lattice parameters a,b,c . This program is based on Cohen's least square method.

The XRD technique has been used in this study to calculate the lattice parameters and the size of unit cell. In this technique an electromagnetic radiation (beam of X-ray) of high energy and short wavelength were used.The wavelength is of the order of the atomic spacing for solids-incident on a solid crystalline material. A part of beam will be scattered due to the electrons associated with each atom or ions that lies within the path of the beam. If we consider an X-ray of wavelength λ is incident at an angle θ on two parallel planes of atoms that are separated by interplanar spacing d_{hkl}, and then get constructive interference if Bragg's law satisfied:

$n\lambda = 2d_{hkl}\sin(\theta)$ --------------------------(1)

Where n is the order of reflection, λ is the wavelength of incident X-ray, d is the distance between two parallel planes of atoms(interplanar spacing d_{hkl}), θ is the angle between the plane and incident beam of X-ray. In our study, λ is fixed by using cooper or cobalt source, for cooper source λ is equal 1.54056 A° and n=1. We determine the angle θ from the peak position in diffraction pattern then we calculate d using eqution (1). Each value of d associated with a set of Miller indices (h k l) . The lattice parameters(a,b,c) are determined using the following equation (2)[7]:

$1/d^2=h^2/a^2+k^2/b^2+l^2/c^2$---------------------(2)

A powder of these samples has been used. The data obtained by using computer controller diffractometer.

Our results for the type 2223, $Bi_{2-x}Tl_xSr_2Ca_2Cu_3O_{10+\delta}$ Systems have been prepared by solid state reaction is shown in figures(2-5) .

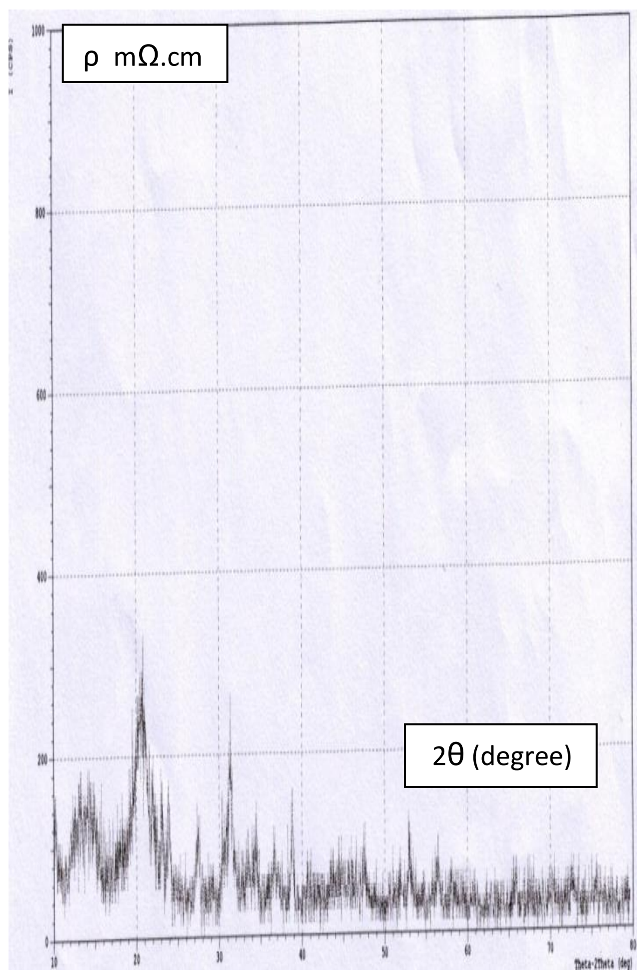

Fig.(2) Powder X-Ray diffraction of $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ samples for x= 0.1 and y= 0.1

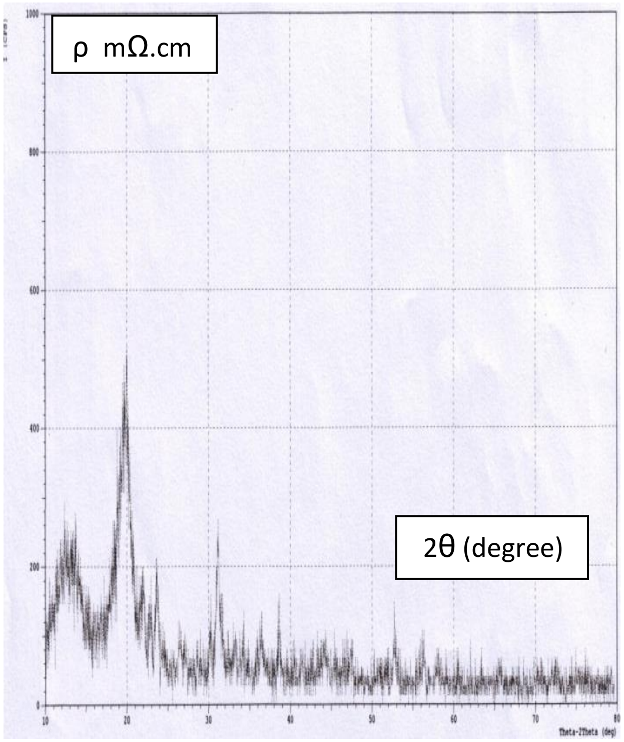

Fig.(3) Powder X-Ray diffraction of $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ samples for x= 0.2 and y= 0.2

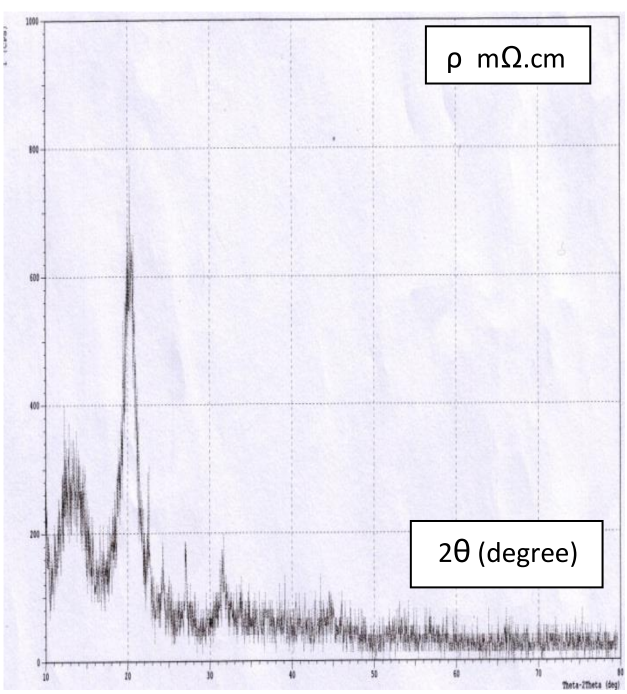

Fig.(4) Powder X-Ray diffraction of $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ samples for x= 0.3 and y= 0.3

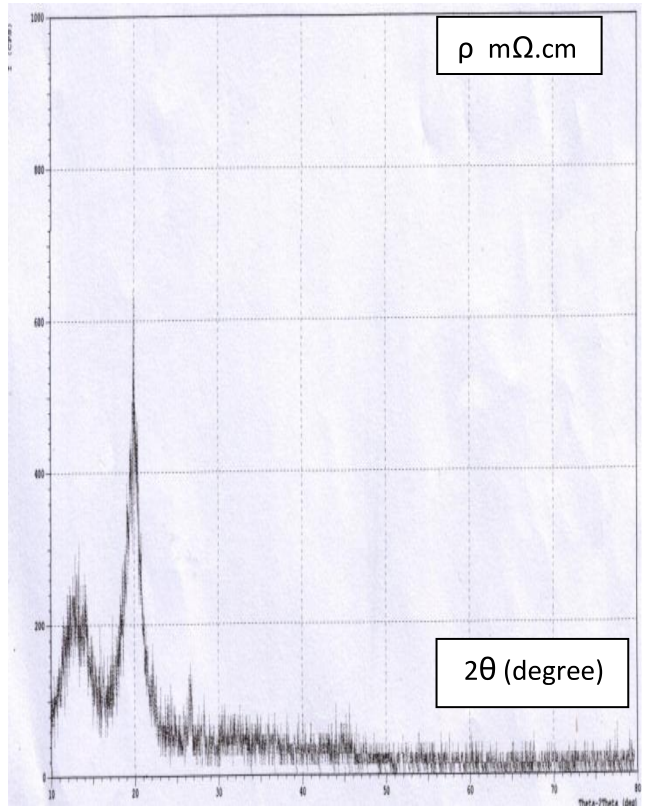

Fig.(5) Powder X-Ray diffraction of $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ samples for x= 0.4 and y= 0.4

By comparing the peaks positions in the X-ray diffraction the interplanar spacing (d-values) has been calculated at each peak in the spectra by using equation(1):

Where n=1 and λ = 1.54056 A° for copper source.

Table (1) shows the each value of d obtained using equation (1), there are a set of Miller indices (h,k,l), then calculate the lattice parameter (a,b,c) by using equation (2):

The x-ray data of all superconductor samples showed a tetragonal structure with a high ratio of Bi-2223 superconducting phase showing in Fig (6).

Ratio x,y	**a=b (A°)**	**c(A°)**	**d (A°)**	**hkl**
$Bi_{2-0.1}Tl_{0.1}Sr_{2-0.1}Ba_{0.1}Ca_2Cu_3O_{10+\delta}$	**4.148**	**34.37**	**5.0495**	**104**
$Bi_{2-0.2}Tl_{0.2}Sr_{2-0.2}Ba_{0.2}Ca_2Cu_3O_{10+\delta}$	**4.021**	**35.75**	**2.7627**	**131**

$Bi_{2-0.3}Tl_{0.3}Sr_{2-0.3}Ba_{0.3}Ca_2Cu_3O_{10+\delta}$	**3.645**	**37.61**	**5.0495**	**104**
$Bi_{2-0.4}Tl_{0.4}Sr_{2-0.4}Ba_{0.4}Ca_2Cu_3O_{10+\delta}$	**3.765**	**36.88**	**2.7627**	**131**

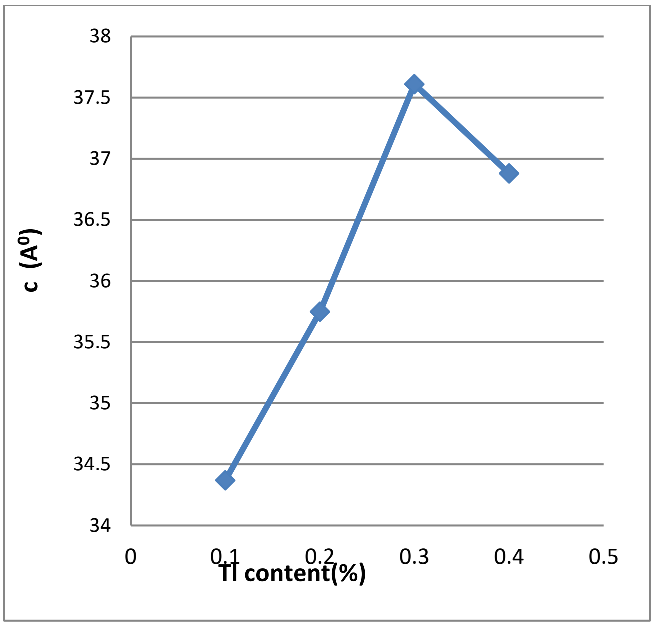

Fig.(6) Variation of the c-axis lattice constant with Tl content for $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$

Resistivity and Critical temperature Measurement

A four – point probe is the most common method to determine the T_c of a superconductor[8]. Wires are attached to a material at four points with a conductive adhesive. Through the outer two of these points a voltage is applied and if the martial is conductive a current will flow. Then, if any resistance exists in the material a Voltage will appear across the inner two points accordance to ohm's law. When the material enters a superconductive state, its resistance drops to zero and no Voltage appears a cross the second set of points.

Fig.(7) shows the circuit diagram of the resistivity measurement. The cryostat system joined to a rotary pump to get a pressure of (~10^{-2} mbar) inside the cryostat, and is also joined to a sensor of a digital thermometer type (doric 450A-TT) and thermocouple type T near the sample position. Four wires have been connected to the cryostat. The two outer most leads are for current and two inner leads are for Voltage. A small current is passes through the sample, by a current source D.C. power supply type (6236A triple output), and a keithely model (180 nanovoltmeter) measures the voltage across the sample with sensitivity about 0.1 nV.

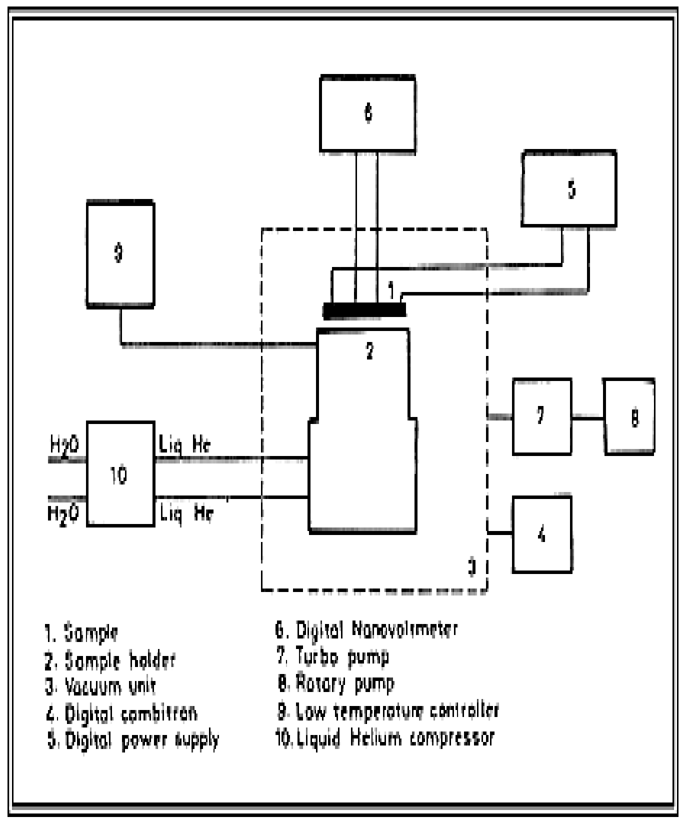

Fig.(7): Circuit diagram of the sample of resistivity measurement.

The resistivity (ρ) could be found from the relation:

ρ = (V/I)(wt/L) (four points probe)

Or found from equation [9]

ρ = 4.533 (V/I) (linear – four points probe)

The resistivity versus temperature curves are shown in Fig.(8). The critical temperature Tc could be found from this figure or from the relation :

$$Tc = (Tc1 + Tc2)/2$$

Where Tc1 : the onset of the transition temperature.

Tc2 : the offset of the transition temperature at the zero resistivity point[10].

Effect of Tl and Ba substitution in Bi_2-x$Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$system:

We have investigated the effect of Tl doping in the Bi-2223 superconductor by preparing a series of samples (at 850 ºC for 24h) with complete stoichiometry $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ with x ranging from 0.1 to 0.4 .

The superconducting properties of the samples have been examined by electrical measurements . Fig.(8) shows the temperature dependence of the electrical resistivity for $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ sample with x ranging from 0.1 to 0.4.

However, a point of interest is that there are obvious phase fluctuation as well as in T_c in these data and as will be seen all the coming results, this we believe the main characteristics of cuprate HTSC at least of the types we are studing. The reason,in our openion is that the variation in the Cu-o bonds and c-parameter are due here to the variation of δ. The later lead to variation in CuO_2 layer thickness. Obviously here for all the doping range the fluctuation in T_c is within the HTSC regeme. The highest transport mechanism is at x=0.3. This means higher resonant tunneling occurs between CuO_2 layers through localized centers across the c-parameter.

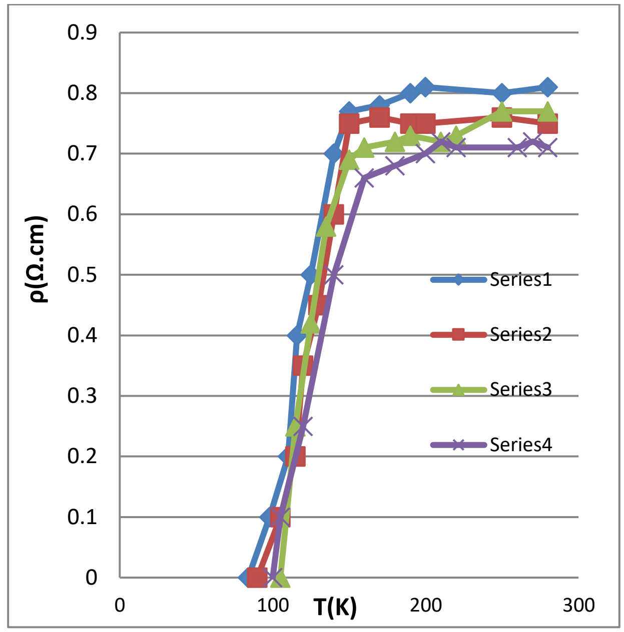

Fig.(8): Temperature dependence of normalized resistivity for $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ sample with different Tl,Ba content.

With x= 0.1, y= 0.1 shows a behavior typical of Bi-2223 : a critical transition temperature (T_c) at 120 K and with x= 0.2, y= 0.2 shows critical transition temperature T_c at 125 K. The sample with x= 0.3, y= 0.3 shows a higher transition temperature T_c= 133 K , while the sample with x= 0.4, y= 0.4 display a T_c at 131 K. Table (2) shows the T_c's with Tl and Ba doped Bi-2223 versus Tl and Ba concentration. The data indicates a maximum T_c near x= 0.3 and y= 0.3 , T_c a gain for higher percentage T_c decreases .

Table(2) Shows the values of the critical transition temperature T_c of these samples

sample	**Ratio of x and y**	**T_c**
$Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$	**X=0.1, y=0.1**	**120 K**
$Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$	**X=0.2, y=0.2**	**125 K**
$Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$	**X=0.3, y=0.3**	**133 K**
$Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$	**X=0.4, y=0.4**	**131 K**

Conclusions :

XRD pattern have shown a Tetragonal structure, the substitution of Tl and Ba for the compound $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ leads to the increase of the grain size of superconducting phase, and the best value of T_c (T_c=133 K) obtained for the compound is x= 0.3, y= 0.3.

Suggestions :

1- Using the differential thermal analysis (DTA) to study the rang of stability , phase transformation and activation energy of Bi-2223 .
2- Studying other important parameters , such as the critical current , critical field.
3- Preparing HTSC as a thin film by a pulsed laser deposition technique.
4- Studding the effect of proton and ion irradiation on the physical properties and superconductivity of the prepared samples

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دراسة التعويض الجزئي لـ Tl و Ba على الخواص التركيبية والكهربائية للمركب $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$ فائق التوصيل عند درجات الحرارة العالية

نهاد علي شفيق محمد حسن درويش

الخلاصة :

حضرت عينات متعدد التبلور فائقة التوصيل عند درجات الحرارة العالية من نوع $Bi_{2-x}Tl_xSr_{2-y}Ba_yCa_2Cu_3O_{10+\delta}$(2223) باستخدام طريقة التفاعل الحالة الصلبة وتم دراسة تأثير التعويض Tl في Bi و Ba في Sr بنسب مختلفة (y=0.1-0.4), (x= 0.1-0.4) عند درجات تلبيد مختلفة, زمن مختلف وتلدين عند 850 ºC لمدة 24 h بمعدل تسخين 2ºc/min. افضل قيمة Tc تم الحصول عليها للمركب عند x=0.3, y=0.3. بينت قيم فحص اشعة اكس للعينات ان التركيب البلوري هو من النوع الرباعي القائم, والعينات تحتوي على نسبة عالية من الطور Bi-2223 وكذلك ادى تعويض Tl بـ Bi و Ba بـSr الى زيادة حجم الحبيبات طور التوصيل الفائق وكثافة العينات وكذلك تم الحصول على افضل Tc هي 133 K.