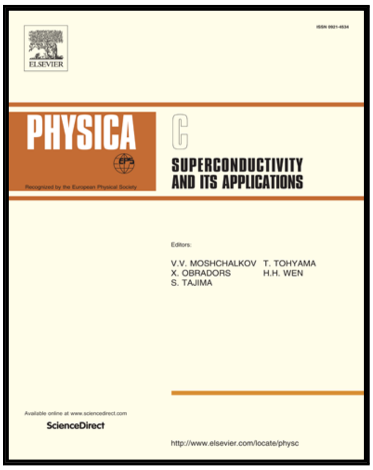

Investigation of Sm substitution on structural and superconducting properties of $Y_1 Ba_{2-x} Sm_x Cu_3 O_{7-\delta}$ superconductors

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Highlight

- YBSCO superconducting samples were prepared with the X-values 0.0, 0.01, 0.03, 0.05 by solid state reaction.
- The transition temperature of superconductivity was investigated by the R-T measurement method. It was found that the composition has a superconducting transition.
- The superconducting transition temperature decreases by increasing Sm, and in contrast, increases the special electrical resistance and the transitional width.
- X-ray diffraction measurements showed that the Sm substitution at the Ba site in Y_1 Ba_2 Cu_3 O_(7-?) (Y-123) confirms the formation of the 123 phase and specifies that all samples are orthorhombic with the Pmmm space.
- It was determined from SEM images that by increasing the Sm the size of the grain decrease, and increases the porosity in the samples. Weakness of inter-grain connections can predict that the critical current density of these samples decreases with increasing concentrations of Sm.

Investigation of Sm substitution on structural and superconducting properties of Y1 Ba 2-x Smx Cu3 O 7-δ superconductors.

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Abstract

In this work, samples of a nominal composition Y_1 Ba_(2-x) Sm_x Cu_3 O_(7-δ) With Sm substitution (X=0.00, 0.01, 0.03, 0.05) were prepared by the solid state reaction method. And the effect of substituting Sm instead of Ba was investigated on the structural and superconducting properties of the samples. Measurement of electrical resistance and critical temperature was done using 4-Probe connection method. Results indicate that Sm substitution affects the YBSCO superconducting samples, decrease the transition temperature of the superconductor and increases the special electrical resistance and the transition width. Also, XRD studies show that in all samples of the Y-123 phase, the formation and structure is orthorhombic. SEM images showed that the porosity in the samples increased with increasing Sm due to disruption in grain growth and instead, increase Sm in the samples cause decreasing the size of the grain.

Keywords: High- Tc superconductors, Substitution, X-ray diffraction, SEM.

1. Introduction

Studies based on cationic substitution in cuprate superconductors are important to understand the behavior of these materials. The high transition temperature of these compounds is the most important characteristic of these materials compared to conventional superconductors. The importance of the substitution problem in superconductors is very important that many compounds of copper oxide superconductors is due to the study of the replacement of different elements in this category of materials. [1] The doping in YBCO compounds is due to two reasons: The first is to explain the superconducting properties of the compound and the second to improve the physical properties and grain texture. Typically, in the first case the chemical substitution is used and in the second cases the addition of impurities to YBCO ceramics. [2] Doping can affect the amount of oxygen as well as the superconducting transition temperature. [3] Varying the oxygen content of $Y_1Ba_2Cu_3O_{7-\delta}$ results in significant changes of its physical properties. Many studies have shown that the critical temperature and crystal structure of $Y_1Ba_2Cu_3O_{7-\delta}$ change with oxygen content.[4-5-6-7-8]

The existence of grain boundaries in a high temperature superconductor causes weak connections. These weak connections reduce the critical current of high-temperature superconductors. [9] Possible reasons for the formation of these weak connections can be the inappropriate orientation of grains in the grain boundaries, structural or combinational changes and lack of oxygen in them. [10-11] Another factor in reducing the critical current is the existence of secondary phases. [12-13] These secondary phases usually come between the grains and play the role of weak connections and reduce the critical current density. [14]

In this paper, YBCO superconducting prototypes were constructed in solid state reaction method and the effect of replacing SM in place of Ba was studied in YBCO (structural orthorhombic phase).There are several methods for examining the properties and detection of superconductivity in a sample. Some of these methods include, measuring the electrical resistance, measuring the critical temperature, X-ray diffraction analysis was used to determine the sample structure and examining the phases, and SEM analyzing were performed for determining the quality of the samples and microstructural study.

2. Material and methods

The bulk ceramics are prepared by solid state reaction technique with a mixture of $BaCO_3$, Y_2O_3 , CuO and Sm (99.99% purity). In advance, the carbonates and oxides are mixed in an agate mortar for 1h to attain homogeneous mixture. The mixture of powders is subjected to calcination process in programmable tube furnace at 930 ^{0}C for 24h with a heating rate of 3 ^{0}C/min when the cooling rate is adjusted to be 2 ^{0}C/min. Then, the obtained blackish mixture of powders is pelletized into a rectangular bar of $20 \times 5 \times 5$ mm^3 at a load of 60 MPa in air atmosphere at the room temperature. The rectangular bars obtained are annealed in the tube furnace with 3

^{0}C/min heating rate at 935 ^{0}C for 24 h in air atmosphere. Oxygen content expanded during the heat treatment is restored to the samples at the temperature range of 716 ^{0}C - 416 ^{0}C (cooling rate of 1 ^{0}C/min). Here, the superconducting samples prepared with different SM stoichiometry such as 0, 0, 0.01, 0.03, and 0.05 will be abbreviated as A, B, C, and D, respectively. The electrical resistivity measurements are investigated by four probe method in the He gas contact cryostat with provision for the vacuum. X-ray diffraction patterns allow us to verify the crystal structures, grain sizes, cell constants, crystal plane alignments and phase purity parameters belonging to the compounds are studied by use of a Rigaku Multiflex +XRD diffractometer in the presence of the CuK$_a$ radiation (λ= 1.5418 A) in the range of 2θ=10-60 in air atmosphere at the room temperature. SEM imaging was carried out to verify the quality of samples manufacturing, microstructural study, homogeneity, grain size and shape, porosity and dimensions of inter-granular connections at 500nm magnification.

3. Results and discussion

In this section, the results of the replacement of SM instead of a Ba are provided and discussed in the composition of YBSCO with A (x =0. 0) B (x = 0.01) C (x = 0.03) D (x = 0.05).

3-1. Electrical resistivity measurements

The variation of resistivity as a function of temperature consists of two steps: The first stage is a relatively sharp drop in the resistance at temperature, which indicates the inter-grain transition, and the second stage is a relatively weak drop in the resistance, which, with full grain pairing, finally resistance reaches to zero at the temperature and the whole system is in superconducting state.

Figure 1 shows the resistance as a function of temperature for YBCO and YBCO doped with Sm sample. For all samples, the resistance of the normal state that points to the regions above the start of the transition temperature the metal behavior is shown. For YBCO sample (x =0.0), =91.37k and = 82.70k. By increasing the content of x in the composition, the superconducting transition temperature decreases.

Reducing by increasing Sm doping can be attributed to more SM valence. When the Sm is replaced by Ba, it injects more electrons into copper superconductor plates and thus fills the superconducting holes and reduces the density of the charge carriers (holes). In the pure sample, the resistance of the normal state is small. The low special resistance in the normal state indicates a higher conductivity, improved inter-granular connections, and finally, an increase in critical current density. By increasing the amount of Sm doping, the resistance of the normal state increases, which is due to the weakness of inter-granular connections and the reduction of . The superconducting transition width (- = 8.67) for pure YBCO, is less than YBCO doped with Sm. By increasing the amount of Sm impurity in composition, the samples' superconducting transition width increase; that is reasons for the increase of impurity phases and the weakning of inter-granular connections. The values obtained from the initial transition temperature of superconductivity ( ), final transition temperature ( ) and transition width ( ) are presented in Table 1.

3-2. XRD Measurement

X-ray diffraction pattern was used to study the sample structure and to ensure the formation of the desired phase. The XRD pattern for samples $_{\delta}$ (x= 0.0 , 0.01 ,0.03,0.05) is shown in Fig 2. According to Miller's indexes related to the peaks, it can be seen that the dominant phase of the sample is the phase 123 with orthorhombic structure with the Pmmm space group. The main peak in all of the samples belongs to the 123 compound, which shows that Sm-doped atoms do not affect the orthorhombic composition of Y-123. By comparison of the pure YBCO sample diffraction pattern with the Sm -doped YBCO samples, it can be seen that 123 peaks have appeared, but the intensity and position of the peaks have changed and moved to larger angles. One of the factors behind these changes is the presence of Sm in the YBCO sample, which causes tension in superconducting particles and also due to x-rays contact with Sm, cause the displacement and intensity of the peaks. The lattice parameters obtained using the X-ray diffraction pattern is according to Table 1. It is seen from the table that by increasing X content, the values of the unit cell lattice parameters change, which the change in the lattice parameters of this samples is due to the difference in Sm and Ba ionic radius. In all samples, by increasing Sm-doped value to the YBCO sample, the lattice parameter a increase, but the lattice parameters b, c have decreased. It is to be noted in YBCO, the oxygen in the Cu-O chains are located along the b direction so depletion of oxygen causes a reduction of the b parameter.

3- 3. SEM Measurement

SEM images show that the sample surfaces consist of inter-continuous particles, which are characteristic of superconducting ceramic materials, reported by other researchers. [15-16].Figure 3- shows the SEM images of pure and Sm doped YBCO samples. From the images, we can see that in the pure sample (A) the grains grow better and are larger because of crystalline structure formation; that represents strong inter-grain connections of the sample, which can result in an increase in critical current density. By increasing doping Sm (B, C, D) , there is a noticeable change in SEM images cause decreasing the size of the grains and increasing the porosity of the samples. This is probably due to the fact that the presence of Sm particles among the YBCO grains limits grain growth and reduces the size of the. In fact, with doping Sm, the inter-grain connections are reduced, which is a factor in the degradation of critical current densities. Reducing the critical temperature can be attributed to the reduction of particle size. Reducing the critical temperature has already been reported by reducing particle size in high temperature superconductors. [17]

4 . Conclusion

In this paper, YBSCO superconducting samples were prepared with the X-values 0.0, 0.01, 0.03, 0.05 by solid state reaction. The transition temperature of superconductivity was investigated by the R-T measurement method. It was found that the composition has a superconducting transition. The superconducting transition temperature decreases by increasing Sm, and in contrast, increases the special electrical resistance and the transitional width. X-ray diffraction measurements showed that the Sm substitution at the Ba site in (Y-123) confirms the formation of the 123 phase and specifies that all samples are orthorhombic with the Pmmm space. It was determined from SEM images that by increasing the Sm the size of the grain decrease, and increases the porosity in the samples. Weakness of inter-grain connections can predict that the critical current density of these samples decreases with increasing concentrations of Sm.

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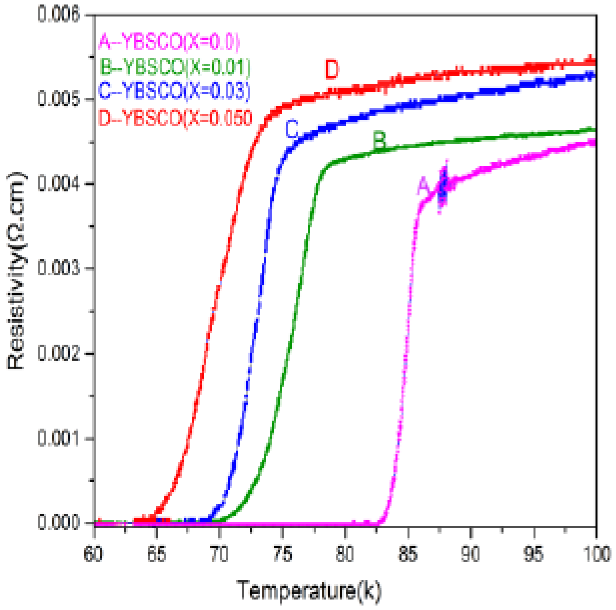

Fig1-The variation of resistivity as a function of temperature in YBSCO.

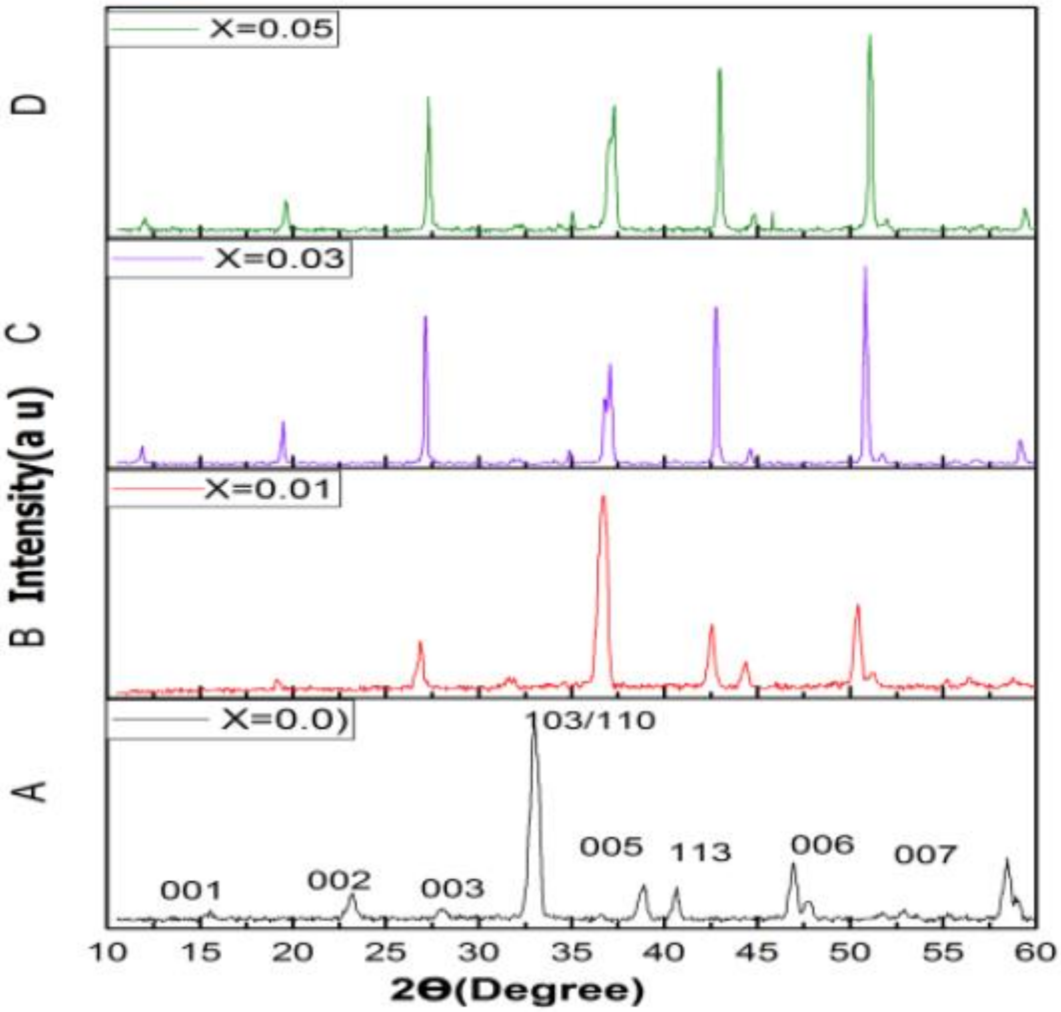

Fig2- X-ray Diffraction pattern of YBSCO Superconductors.

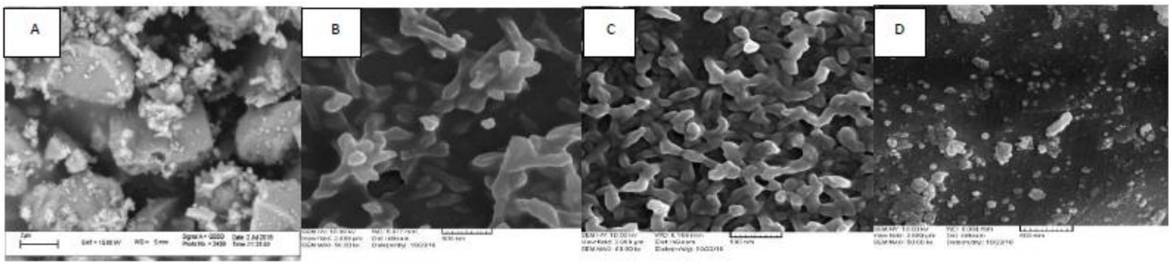

Fig 3 -SEM micrographs for all materials.

Table 1- lattice parameters, , and for YBSCO samples.

	(k)	(k)	(k)	a( )	b( )	C( )
X=0.0	**82.70**	**91.37**	**8.67**	**3.8200**	**3.8800**	**11.6760**
X=0.01	**70.48**	**82.58**	**12.15**	**4.0488**	**3.7241**	**11.1719**
X=0.03	**69.06**	**81.59**	**12.53**	**4.0422**	**3.7011**	**11.1024**
X=0.05	**64.48**	**79.11**	**14.63**	**4.0096**	**3.6886**	**11.0509**