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Structural Characterization of Iron Doped Layered YBCO Superconductor

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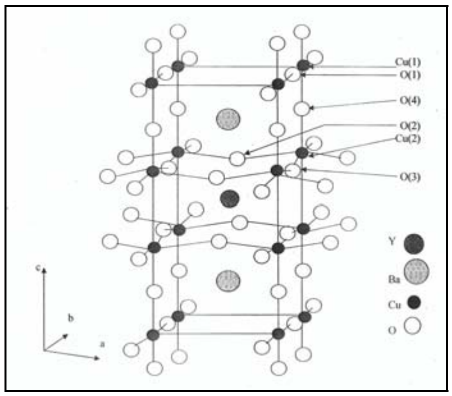
ABSTRACT



YBCO is very well known material for its superconducting properties. This material has superconducting properties because of the presence of CuO layers in the YBCO crystal. Transition metal present in the crystal can be replaced by some another transition metals. Addition of the impurity to the crystal causes change in the properties of material drastically. Using sol-gel method in the environment controlled conditions; copper atoms in the YBCO have been replaced by some iron impurities to produce iron doped material YBCFO. Characterization of the same is done to study the effect of addition of iron to the YBCO.

Keywords: carrier density, superconductor, YBCO, transition

INTRODUCTION

Layered superconductors are well known for exhibiting superconductivity and many layered superconductors are known till date[1-7] . Most of these cuprates which are common one and also very important for the phenomenon of superconductivity. High temperature superconductivity in cuprates is dramatically different from the conventional superconductors. These materials are comprised of one or more crystal planes per unit cell consisting of only Cu and O atoms in a square lattice as shown in Figure 1. Superconductivity originates among the strongly interacting electrons in these CuO2 planes. Crystal structure of YBCO is either orthorhombic or tetragonal depending upon oxygen deficiencies and ordering of oxygen over the two available sites on a and b axis. Two distinct sites for copper: one site labeled Cu(I) between two barium planes and forms one dimensional Cu(I)-O(I) chains in the orthorhombic phase, the other site Cu(2) situated between Y and Ba planes that form two dimensional Cu(2)-O(2,3) planes. The effect of adding impurities to the YBCO crystal is one of the important areas of interest for the scientists working in superconductors and their properties. Impurities have drastic effect on the properties of the superconductors. Pinglin[8] Li et al investigated the structural and superconducting properties of YBCO by introducing the Al and Zn in replacement to Cu atoms in the crystal and they found increase in the superconductivity of the material. In 2005, Liu[9] et al introduced iron atom in the YBCO material and observed that the high-pressure synthesis makes only a slight amount of Fe located at Cu(2) sites migrate to Cu(1) sites and there is no

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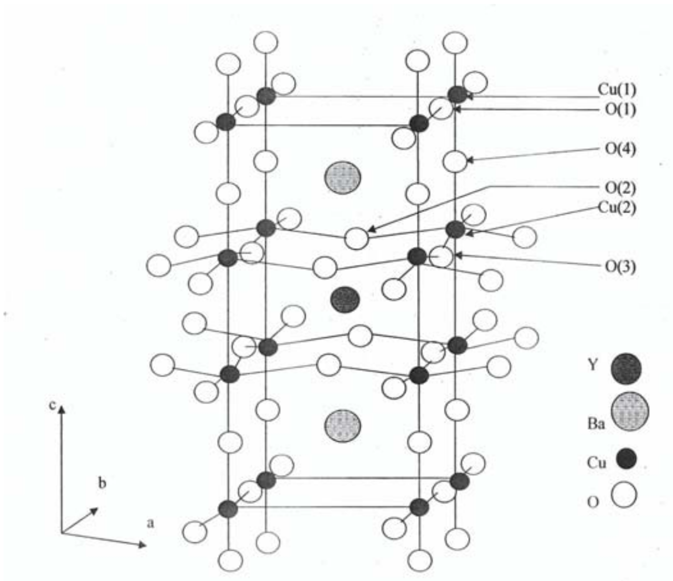
obvious magnetic pair-breaking effect induced by Fe located at Cu(2) sites.

In order to discover the effects of oxygen ordering and carrier concentration on YBCO superconductivity, Zn-and Fe-doped systems were investigated as function of dopant concentration and of stoichiometry, and with respect to resistive characteristics, bulk symmetry and oxygen stoichiometry, and with respect to resistive characteristics, bulk symmetry and oxygen micro-domain ordering by Licci[10] et al. They have further reported that the pair-breaking imputable to Zn substitution is found to be very effective on superconducting temperature. In other work reported by Matsunami[11] et al, it was found that with the addition of Mg impurities in YBaCuO (YBCO) films on MgO substrate, the critical temperature Tc decreases by 10 K for inclusion of 5% Mg in YBCO. Recently Mohanta[12] et al have studied effect of inclusion of Ga and Zn doping in YBCO material.



Structure of $YBa_2Cu_3O_{7-\delta}$

Figure 1. Structure of YBCO. For YBCFO few Copper sites are replaced by Iron atoms.

In the present course of work, the copper have been replaced in fraction of amount by iron and chemical route of sol-gel technology has been used being nonflourine method as used by many research groups.[13-17] Characterization techniques like XRD and FTIR have been used to investigate the structural properties of the samples so obtained.

Theoretical consideration

Many scientists have tried substitution of copper by iron, cobalt, nickel, gallium or aluminum and it helps that certain fraction converts the orthorhombic structure to the tetragonal one without destroying the superconductivity.[18-22]

As far as doping of iron is concerned, iron ions enter directly into the subsystem related to the transfer of current leading to the considerable change in the superconducting properties of the material. The literature reports the effect of iron doping in YBCO in terms of thermal conductivity, resistivity, number density and their superconducting energy gaps etc. and the scientists have tried to study these effects by exploiting thermal as well as phonon echo method[23-26]. Pleshakov et al studied the effect of incorporation of the iron impurities in YBCO in terms of phonon echo method and found some parameters related to superconducting transition, whereas Houssa et al investigated the thermal properties of the same.

In the present course an attempt has been made to compare the results from two different methods: thermal and phonon echo method for the iron doped YBCO. Charge carrier density (number density) of the samples has been investigated from thermal as well as acoustic results of Houssa et al and Pleshakov et al . The temperature dependence of the carrier charge density is given as:

$$ne(T) = nc \exp\frac{-\Delta(T)}{k_B T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

where nc ~ 10^{27} electrons/m3

and

$$\Delta(T) = \chi k_B T_c \sqrt{\frac{T_c - T}{T_c}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

where χ is the ratio of the energy at absolute zero $\Delta(0)$ to the energy at critical temperature Tc and is given as

$$\chi = \Delta(0) / kBTc \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

Experimental Method of preparation

Sol-gel method is used for the preparation of the samples. Precursor is prepared by mixing Yttrium, Barium and Cupric acetate solution in 1:2:3 molar ratios, with 13 molar equivalents of malic acid. In order iron, the copper acetate is replaced by a mixture of 5% iron acetate and 95% cupric acetate keeping above molar ratio fixed. Firstly, solution is stirred continuously in beaker on a magnetic stirrer with hot plate till all the material dissolves. In the process of formation of solution, lots of acetic acid is produced which is evaporated by repeated heating and dissolving in water. When solution becomes acetic acid free, little glycerol is added to it with constant stirring and then heated in the temperature controlled furnace slowly up to a temperature of 300°c. Sold samples are then annealed in furnace at temperature of about 900°C. Fine black power of YBCFO ($Y_1Ba_2(Cu_{1-x}Fe_x)_3O_7$) is obtained.

Characterization: Characterization techniques of FTIR and XRD are employed for the YBCFO so obtained to investigate the structural properties of the sample by inclusion of the Iron impurity. Perkin Elmer (Spectrum, BX II) instrument is used to record FTIR spectra. XRD spectra are recorded by using Rigaku (Miniflex II) instrument.

Results and Discussion

FTIR analysis: FTIR spectra for the standard sample of YBCO obtained from Sigma-Aldrich and the other synthesized with iron doping is presented in figure 2. The lower curve represents the

FTIR spectra of YBCO from Sigma-Aldrich and the upper curve represents that of YBCFO obtained by the sol-gel process. The various peaks corresponding to the samples are in conformity with the standard one and are in good agreement with the other research scientists.[26]

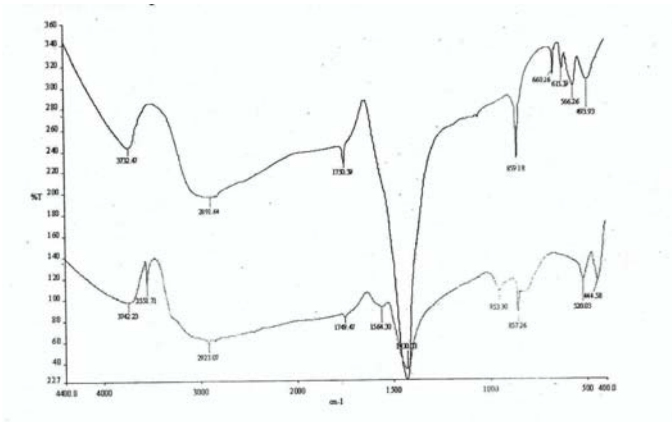


Figure 2: FTIR spectra of YBCO samples: Lower curve is for the standard Sigma procured; upper curve is for YBCFO

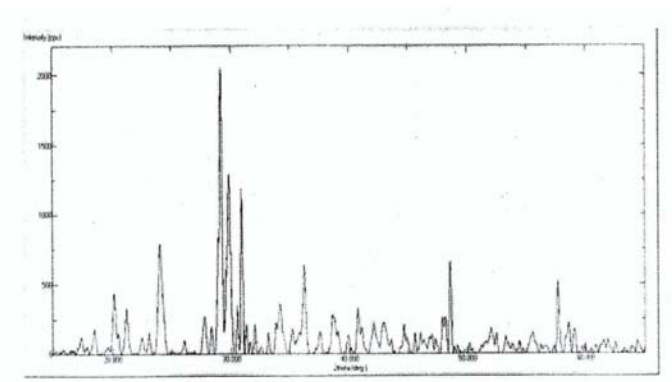


Figure 3: XRD spectra of YBCFO

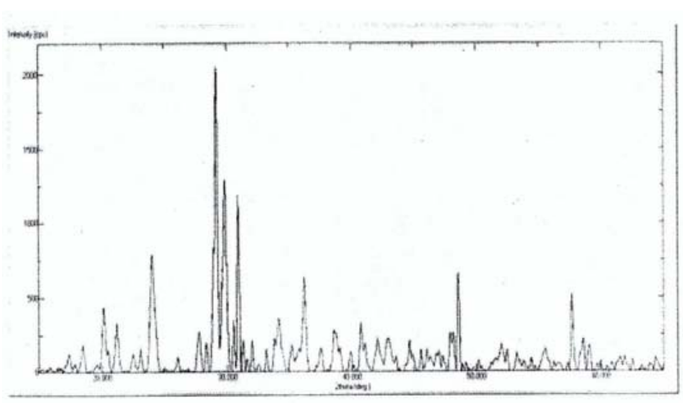


Figure 4: XRD Spectra of YBCO procured from Sigma-Aldrich

Figure 3 presents the XRD spectra of the YBCFO and that of YBCO (Sigma Aldrich) is shown in figure 4. Peaks corresponding to the angles ~20°, 24°, 30°, 35°, 39°, 47° and 58° are in conformity with the earlier reported XRD pattern of YBCO samples. Some of the peaks present in the YBCFO are missing in YBCO and also the peaks corresponding to angles 23°, 33°, 38° and 48° are more prominent than in YBCO samples which clearly indicate the rise in orthohombicity that is expected to increasing the superconducting properties of the YBCO. The results are in conformity with Sood et al.

Number density in YBCFO below Tc: As mentioned in table 1, experimental data from both the authors land up with the different result TC for pure YBCO from both studies is almost same but simultaneously the gap energy at absolute zero is more is case of acoustic studies and same is observed for the iron doped materials. Lowering in Tc by addition of iron is understandable, as its addition gives rise to more free electrons in the YBCO sample and just destroying a bit the symmetry of CuO basal planes. It does not allow the charge carriers to make cooper pairs easily thereby decreasing Tc. Figure 5 depicts and interesting result, where number density of charge carriers is plotted against temperature ratio. In figure 5 triangle (from thermal results of Houssa et al) and empty circles (from phonon studies of the Pleshakov[25] et al) represent the number density for pure YBCO superconductor which is almost in agreement with each other with a slight shift. Solid circles (from thermal results of Houssa et al) exhibits a slight increase in the number density relative to pure YBCO whereas squares (from phonon studies of the Pleshakov et al) represents relatively slight decrease in the number density in comparison to pure YBCO. Reverse trend in thermal and acoustic studies needs further explanation. The explanation lies in the fact the blow Tc, charge carriers condenses into cooper pairs that does not carry any heat thus thermal conductivity is solely dependent on free charge carriers. Due to the presence of structural defects caused by impurities, the free charge carriers are getting scattered and thereby cause a significant decrease in the charge carrier concentration in comparison to pure YBCO.

Table 1 Various parameters of doped and undoped YBCO

Samples	T c (K)	**To calculate Δ(0)**		**Δ(0) (meV)**
		2Δ(0)l kBTc [25]	X	
Pure YBCO (Houssa et al)	91	------	1.5	11.77
YBCO + 3% Fe (Houssa et al)	77	-----	1.2	7.866
Pure YBCO (Pleshakov et al)	90	3.7	---	14.36
YBCO + 5% Iron (Pleahakov et al)	60	4.4	----	11.385

In case of iron doped YBCO material, the energy provided by the thermal radiation is sufficient to excite more free charge carriers than the loss caused by impurities in thermal investigations. So there is increase in the number density as compared to the pure YBCO. But is phonon-echo investigations such type of energy is not transferred to the electrons present in the valance band of the iron doped samples, so number of charge carriers does not exceed beyond a limit thereby not giving extra charge carrier. It means that there is an effect only due to the scattering by the impurity ions and hence a decrease in the number density of the sample.

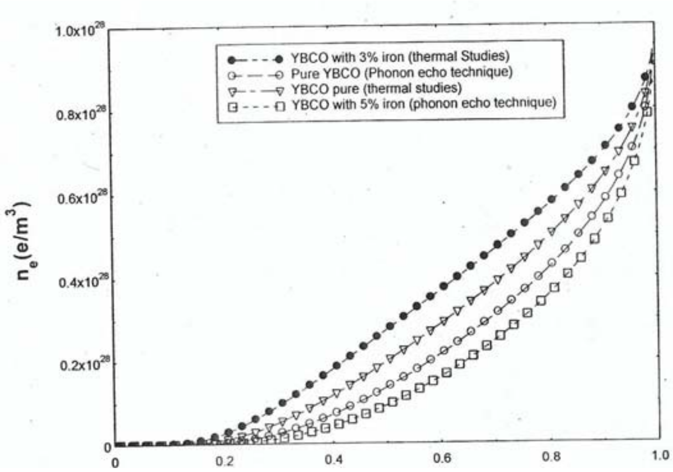


Figure 5: Plot of number density of charge carriers vs ratio of absolute temperature to critical temperature for different samples

Conclusion

As the XRD and FTIR characterization data is in good conformity with the results reported in the literature, it is inferred that solution method (sol-gel based) is equally good for preparing the doped Superconducting material, where acetates are used Sol-gel method is more useful than the solid method in which oxides of the materials are used. This solution method is non-toxic and also sintering helps in homogeneous mixing of the dopant material.

It has already been reported in the literature that in case of iron doping, the effect is due to prefential substitutional site and therefore the characteristics and dominant due to structural effects rather than electronic characteristics. The study reveals that for further investigations the phonon echo method is much superior that the thermal method as the electron-electron interaction is dominant in thermal method while in phonon echo method, phonon-electron interactions are the dominant that are due to structural transition. The future work would consider the superconducting properties of the materials grown in the laboratory and hence further study of increase in superconducting properties by adding the other metal dopants.

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