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Superconducting transition temperature of co-doped $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ superconductors for $x \leq 0.02$

Bhasker Gahtori*, R Lal & S K Agarwal
Superconductivity Division, National Physical Laboratory, New Delhi 110 012
and
Anirban Das[1], Tirthankar Chakraborty[2] & Ashok Rao[3]
[1]Sikkim Manipal Institute of Technology, Sikkim
[2]Department of Electronics and Telecommunication Engineering,
Jadavpur University, Kolkata
[3]Manipal Institute of Technology, Manipal
*E-mail: bhaskergahtori@yahoo.co.in

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Values of the superconducting transition temperature T_c extracted from the resistivity and *ac* susceptibility of $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ ($x \leq 0.02$) are found to follow the same qualitative variation with the Mn content. Both lead, in particular, to lower T_c for the x=0.005 sample than those of the x=0.0, 0.0075 and 0.01 samples. Comparing T_c with difference of resistivities with and without Pr for various x, it has been argued that electronic effects dominate over the potential scattering in suppressing T_c below x=0.02. Superconducting volume fraction f_g (as deduced through imaginary part χ'' of the *ac* susceptibility at the peak temperature) when considered in conjunction with the average grain size for the x=0.005 sample, indicates that the smaller size of the grains in x=0.005 sample leads to stronger fluctuations. This is an additional source for the larger T_c degradation in the x=0.005 sample.

Keywords: Superconductors, $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$

1 Introduction

Effect of Pr on the $YBa_2Cu_3O_{7-\delta}$ system has been studied extensively by researchers, both experimentally[1,2] as well as theoretically[3,4]. About 55% of Pr suppresses superconductivity of this system completely[5]. Compared to Pr studies, however, only limited work has been carried out with Mn doping in the cuprate systems perhaps due to its low solubility limit[6] of 2.5 at%. Yang *et al*[7]. have studied the neutron diffraction of $YBa_2Cu_3O_{7-\delta}$ with 5% Mn and have found Mn to preferably substitute at the chainer Cu-sites with an average T_c – degradation rate of about 11.0 K/at% Mn. Saini *et al*[8]. have also suggested Mn to occupy the chainer Cu-sites with a reduction in the density of mobile charge carriers. T_c reduction, however, was found only to be ~3.6 K/at % Mn. This is considerably smaller than that found by Yang *et al*[7]. Dhingra *et al*[9]. have made a study of the microstructural features and superconducting properties of $YBa_2Cu_3O_{7-\delta}$ with Mn doping up to 15%. They found in particular that 5% Mn reduces T_c by ~10 K. Nishida *et al*[10]. have made ESR observations in Mn-doped $YBa_2Cu_3O_{7-\delta}$ with substitution of Mn up to 10%. These researchers suggest Korringa type interaction between Mn localized moments and Cu spins. Recently, Samuel *et al* [6]. have made a study of *dc* magnetic behaviour of Mn-doped $YBa_2Cu_3O_{7-\delta}$ (up to 5% Mn). They found that 5.0% Mn reduces T_c by only 1.9 K. This is too low in comparison to that mentioned above by other researchers[7,8]. Kochelaev *et al*[11] have studied the effect of Mn (up to 2%) in $La_{2-x}Sr_xCuO_4$ where a T_c depression rate of 13K/at% Mn was seen. Xu *et al*[12]. have made a study of the transport properties of the Mn-doped $La_{1.85-x}Sr_{0.15+x}Cu_{1-x}Mn_xO_4$ system ($0<x<0.13$). They found that Mn doping induces a strong lattice deformation and leads to a gradual localization of holes. This reduces T_c by about 27 K with 2% Mn.

Because of its low solubility limit[6], in the present study,we have limited to low concentration of Mn in the co-doped $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ system. The experimental details for the synthesis of various samples of this system, and for the measurement of the resistivity and *ac* susceptibility are reported elsewhere[13]. Here, our main aim is, in particular, to see how far the electronic effects play a role in determining the superconducting transition

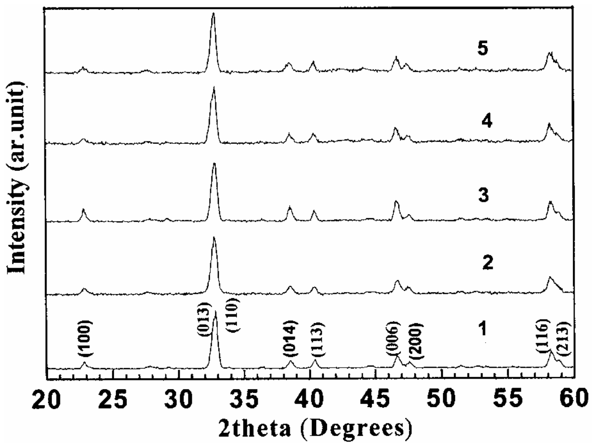

Fig. 1—X-ray diffraction patterns for the $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ system for various values of *x*. The numerals 1,2,3,4 and 5 correspond respectively to the x = 0.0, 0.005, 0.0075, 0.01 and 0.02.

temperature. Here, by "electronic effects" we mean[13] the process of transfer of electrons from the Pr or Mn ions to the CuO_2 layers and transfer of electronic spectral weight from the higher energy states to the lower energy states.

2 Results and Discussion

The X-ray diffraction technique was used to determine the lattice parameters of the superconducting compounds used for the present studies. The X-ray diffraction patterns of the $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ system for x = 0.0, 0.005, 0.0075, 0.01 and 0.02 are shown in Fig. 1. We observed that all the samples exhibit are single phase in nature. The *a*, *b, c* parameters are presented in Table 1. It can be seen from the Table 1 that the *a*-parameter increases with increasing Mn concentration up to a level of about 0.5%, thereafter, it slightly decreases. It again starts increasing beyond a concentration of 0.75%. On the other hand, the *b*-parameter increases with increasing Mn concentration up to a concentration of 0.75% and beyond this it decreases with Mn content. The *c*-parameter increases with increase in Mn concentration (Table 1). It may be mentioned that doping by Mn does not change the crystal structure of the compounds.

Superconducting transition temperature $T_c(x)$ of the $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ system, deduced from the resistivity curves[13] in a way described by Osofsky *et al*[14,15]. are shown in Fig. 2. While applying the method of Osofsky *et al.*[14] we have noted that whether we consider determination of T_c on the basis of the onset of superconducting effect or on the basis of zero-resistivity, the suppression of T_c always occurs in the order x=0.0, 0.0075, 0.01, 0.005, 0.02. The value of T_c for the pristine sample is 93.7 K. With increasing x, T_c (x) first decreases for the x=0.005 sample to 92.8 K, then it increases for the x=0.0075 and x=0.01 samples attaining values of 93.2 K and 93.5 K, respectively. Finally, T_c decreases for x=0.02 sample to have a value of 91.8 K.

The values of T_c extracted from the *ac* susceptibility data are lower than those extracted from the resistivity data. However, the relative variation of T_c with x from χ'-T measurements is the same as from the ρ-T measurements. Since both the sets of T_c values would essentially lead to the same inference, we shall, for specificity, consider the set of T_c values obtained from the ρ-T measurements in the following analysis. It may be noted that the present study corresponds to rather low concentrations of Mn. Other researchers[6-9,11,12] have considered, generally, higher concentration of Mn. Let us see how the average T_c

Table 1—Lattice parameters for Mn-doped compounds $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$

x (%)	*a* (± 0.001 Å)	*b* (± 0.001 Å)	*c* (± 0.001 Å)
0	3.816	3.884	11.667
0.5	3.823	3.895	11.661
0.75	3.817	3.896	11.665
1.00	3.820	3.891	11.674
2.00	3.825	3.884	11.679

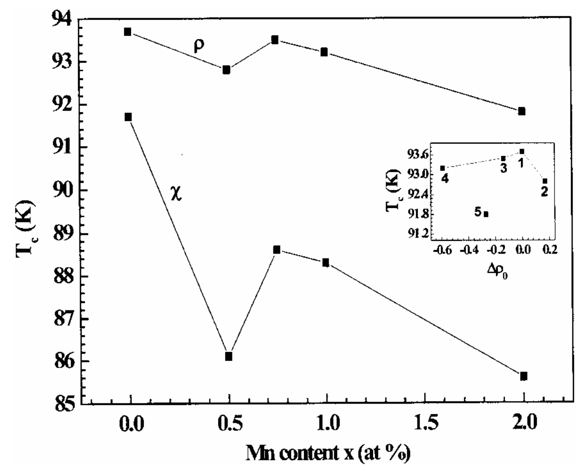

Fig. 2—Values of the transition temperature T_c of the system $Y_{0.95}Pr_{0.05}Ba_2(Cu_{1-x}Mn_x)_3O_{7-\delta}$ extracted from the ρ-T plots[13] and χ'-T plots[13] for different values of x. These values of T_c are marked respectively by ρ *and* χ. The inset shows the variation of T_c with $\Delta\rho_0$.