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Determination of Hole Concentration and Characteristic Pseudogap Temperature in Underdoped and Overdoped $YBa_2Cu_3O_{7-\delta}$ System

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Abstract. Electrical resistivity measurements in the temperature range 14 – 300K have been carried out on superconducting materials of the composition, $Y_{0.9-x}Pr_xCa_{0.1}Ba_2[Cu_{1-y}Zn_y]_3O_{7-\delta}$. with different values of x and y ($0 \le x \le 0.2$ and ($0 \le y \le 0.06$). In order to study the underdoped region Ca content is reduced to zero and Pr content is changed from x = 0.1 to 0.2. for varying contents Zn . For the overdoped region Ca = 0.1 and x is varied from 0 to 0.2 for two values of Zn content 0.02 and 0.06. From the analysis of the electrical resistivity data obtained for the above cuprates the characteristic pseudogap temperatures and the exponent, m, in fits to $\rho(T) = \rho_o + aT^m$ have been found out. The planar hole concentration, p has been determined by the room temperature measurements of thermoelectric power . Using these results a doping phase diagram has been constructed for these superconducting materials.

Keywords : High T_c Superconductors, Peudogap, Transport properties
PACS :7470V , 7430F,7460M

INTRODUCTION

Zn substitution for $YBa_2[Cu_{1-y}Zn_y]_3O_{7-\delta}$ superconductors has a strong influence on the critical temperature T_c and offers an opportunity to characterise the high T_c superconducting state. Zn in the CuO_2 plane is itself a nonmagnetic impurity with a closed d shell and is expected to be a strong potential scatterer for charge carriers [1]. In Pr doped $YBa_2Cu_3O_{7-\delta}$ Tc is strongly suppressed as a function of Pr concentration. The suppression of by Pr doping in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ has been attributed to several possible mechanisms[2,3]. The substitution of Ca^{2+} for Y^{3+} is interesting Since the valence of Ca^{2+} is smaller than that of Y^{3+}, Ca doping supplies the mobile holes into the CuO_2 planes and in fact substitution of Ca^{2+} for every Y^{3+} ion increases carrier concentration with ½ hole per plane. [3]. The T_c decreases with Ca substitution is attributed to the material becoming overdoped [4]. Keeping this in mind , we have undertaken electrical resistivity and thermoelectric power measurements in order to see the combined effect of all three substituents Pr, Ca and Zn on underdoped and overdoped superconducting cuprate systems. This is of great interest as the presence of Pr at Y site together with Zn at Cu site drives the system into the underdoped region and gives rise to a normal pseudogap effect. Furthermore, the presence of Ca and Pr at Y site and Zn at Cu site takes the system to overdoped region giving rise to the anomalous pseudogap.

EXPERIMENTAL ANALYSIS

Polycrystalline samples of $Y_{0.9-x}Pr_xCa_{0.1}Ba_2[Cu_{1-y}Zn_y]_3O_{7-\delta}$. with different values of x and y ($0 \le x \le 0.0.2$ and ($0 \le y \le 0.06$) were synthesized by standard solid-state reaction methods using high-purity(> 99.99%) powders.

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All samples were characterized by X-ray diffraction (XRD) using a Rigaku X-ray Diffractometer with CuK_{α} radiation and the phase purity of the samples was checked using Rietveld Analysis. . The oxygen content of the samples was determined by iodometric titration which is found to be 6.67 ± 0.03. The resistivity was measured on Four Probe setup using silver point contacts in the temperature range 14-300K, The planar hole concentration, p has been estimated from the room-temperature thermoelectric power measurements.

RESULTS AND DISCUSSION

In Fig. 1, a plot of electrical resistivity versus temperature is shown for a representative sample $Y_{0.9-x}Pr_xCa_{0.1}Ba_2[Cu_{1-y}Zn_y]_3O_{7-\delta}$ with y = 0.06 and x = 0.075. In the inset of this figure the method for determining the characteristic pseudogap temperature (PG) T* obtained either from the temperature at which downturn in the ρ-T curve appears or from the derivative of ρ-T curve as per the procedure given in refs. [4] is illustrated.

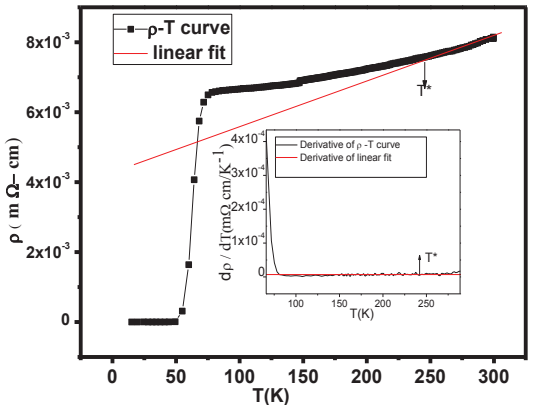

FIGURE 1. Resistivity ρ versus temperature plot for Y0.9-xPrxCa 0.1Ba2[Cu1-yZny]3O7-δ. with y = 0.06 (Zn) and x = 0.075 (Pr). Method of determining pseudo gap temperature T* is illustrated

In the underdoped case at x = 0.1 and x = 0.2 the system is in the hole depletion region. The planar hole concentration p is varied by increasing Zn concentration (Zn pins the holes in the plane and opposes the action of Pr to remove holes). The resistivity measurements carried out on the underdoped samples show normal pseudogap behaviour i.e. T* decreases linearly with increasing p (see Fig.2).

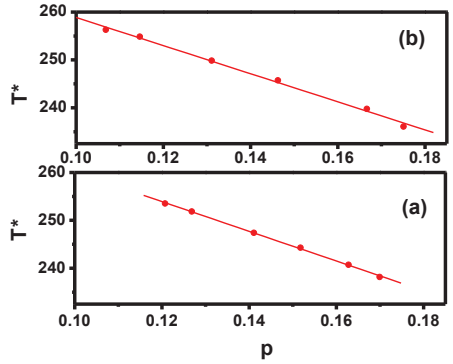

FIGURE 2. Plot of T* (in K) against p for $Y_{1-x}Pr_xBa_2(Cu_{1-y}Zn_y)_3O_{7-\delta}$ samples with Ca = 0 and for different values of y with x = 0.1 (a) and 0.2 (b)

For the overdoped case we have set y = 0.02 and y = 0.06 and x is varied. For this the T* - p curves are shown in Fig 3 .

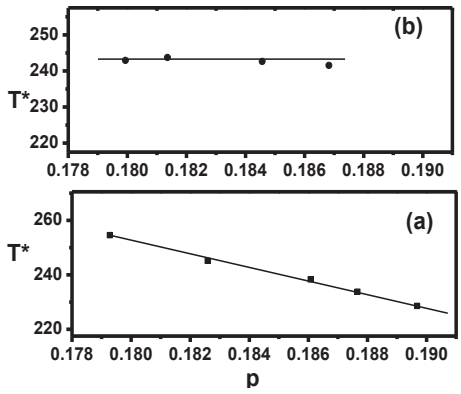

FIGURE 3. Plot of T* against p for $Y_{0.9-x}Pr_xCa_{0.1}Ba_2(Cu_{1-y}Zn_y)_3O_{7-\delta}$ sample and for different values of x with y = 0.02 in (a) and y 0.06 (b)

For y = 0.02 concentration, T* shows normal behaviour However, at y = 0.06 concentration T* remains almost constant and is independent of p. This agrees well with the results obtained by Naquib et al .[5] They showed that this kind of anomalous behaviour appears for y ≥ 0.05. Our findings thus corroborate the results obtained by these researchers and hence the theoretical explanation given by these researchers [5] still holds good. As can be seen from Figs.2 and 3 that the magnitude of this anomalous T*(p) depends only on the amount of Zn in the CuO_2 planes. These observations indicate that the origin of this pseudogap - like feature is due to the CuO_2 plane disorder in the structure of the system studied by us.

From ρ -T data one can also determine the p dependence of the exponent, m, in fits to $\rho(T) = \rho_o + aT^m$ for overdoped compounds. As both T^* and m are measures of the deviation of ρ(T) from linearity, we plot T^* and m vs p in Fig.4 and construct a doping phase diagram for high T_c superconductors. we see that both T* and p show the universal behaviour i.e., with increase in p , T* decreases whereas m increases with value lower than 2 which is the canonical low-T Fermi liquid value with dominant electron –electron scattering .

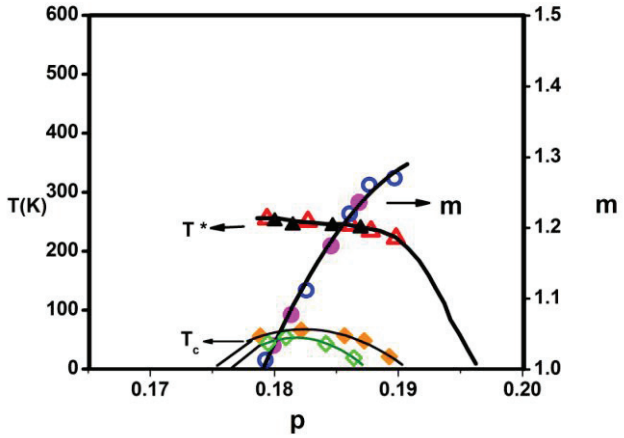

FIGURE 4. Doping Phase Diagram of $Y_{0.9-x}Pr_xCa_{0.1}Ba_2(Cu_{1-y}Zn_y)_3O_{7-\delta}$,where, O – m vs p for y= 0.02 and different values of x, ● - m vs p for y= 0.06 and different values of x, Δ- T* vs p for y= 0.02 and different values of x, ▲- T* vs p for y =

0.06 and different values , ♦ - T_c vs p for y= 0.02 and different values of x, ◊ - T_c vs p for y= 0.06 and different values of x

From Fig .4 we see that a crossover between T* and m is obtained at p = 0.185 ± 0.01 well above T_c suggesting hereby that the system is still in the non-Fermi liquid state. This is in contrast to the findings by Naquib et al.[4]. Where they obtained crossover at p = 0.19 ± 0.01,well below the Tc indicating the vanishing of the pseudogap. The difference in the results may be due to the simultaneous presence of Pr and Ca at Y site and Zn at Cu site which makes the system to remain in the non Fermi liquid state.

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