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Superconducting and normal-state transport properties in bulk YBaCuO, doped with Zn

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Abstract

We have investigated the resistivity, the Hall number, n_H, and the Hall conductivity, σ_H, in bulk $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$ within the range of Zinc content 0<x<0.06. The magnetic field values were up to 5 T and the temperature range 20 K-300 K. The superconducting transition temperature Tc, as well as, the slope of the normalized resitivity in the normal-state decrease with increasing Zn concentration. The T^3 dependence of σ_H^{-1}, with a change of the slope around 230 K-240 K is correlated with the T-dependence of the carrier concentration.

1. Introduction

In cuprate superconductors with high critical temperatures, Tc, the substitution of 3d transition metals for Cu is a good probe for studying the origin and the nature of the high-Tc superconductivity. Thus, there have already been many investigations of the solid solution series $YBa_2(Cu_{1-x}M_x)_3O_y$ (where M = Ni, Fe, Co, Zn, Ga and Al) [1-8].

Among the interesting properties observed in the cuprate superconductors, mention should be made of the normal-state transport properties and more particularly of the temperature dependence of the Hall coefficient $R_H(T)$, or $n_H = 1/R_He = aT + b$ (where n_H = Hall number, R_H = Hall coefficient).
In this work, we have simultaneously measured the two independent quantities the resistivity, $\rho(T)$, and $R_H(T)$ in zinc doped bulk YBaCuO.

2. Experiment

The samples of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$, were prepared by a standard solid-state reaction, as discussed in previous work [1].

Careful examination by X-Ray diffraction (XRD), thermogravimetric analysis (TGA), energy dispersion X-Ray analysis (EDAX), scanning electron microscopy (SEM) and optical microscopy were performed . The oxygen content in the samples was determined by the iodometric titration method. The following compositions were measured (x = 0, y = 6.91; x = 0.02, y = 6.91; x = 0.039, y = 6.91; x = 0.053; y = 6.89 and x = 0.058, y = 6.89.)
The Hall measurements were performed from 20 K to 300 K, with DC or AC current in the sample, by a standard method using a five terminal Hall-bar shape. For the AC - measurements, we used a lock-in technique .

3. Results and discussion

According to results on polycrystalline samples of $YBa_2(Cu_{1-x}M_x)_3O_{7-\delta}$ (M = Fe, Ni, Zn, Co and Al) published by a few research groups [1-8], the introduction of these dopants causes the degradation of the superconductivity. Tc decreases almost linearly with increasing x. The linear temperature dependence of the resistivity, over a wide range of the temperature (above Tc), is common almost to all the cuprate superconductors (figure 1).

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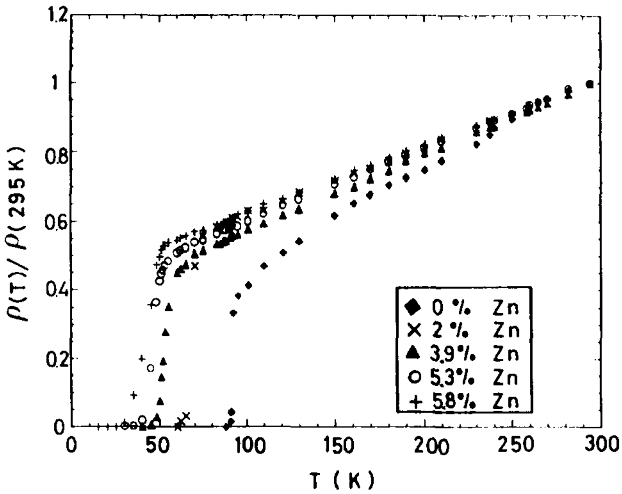

Figure 1. Temperature dependence of the relative resistivity of bulk $YBa_2(Cu_{1-x}Zn_x)_3O_y$.

All our samples show metallic behavior in the normal state. The resistivity at a given temperature (above Tc) is linearly dependent of the Zn concentration, and the transition temperature, Tc decreases rapidly with the Zn content. The samples with the higher Zn doping levels exhibit a slightly broader transition width, possibly arising from substitutional disorder. If the resistivity curve is extrapolated linearly to T = 0 K, the residual resistivity shows a positive value, in agreement with the data of Chien et al. [4] on $YBa_2Cu_{3-x}Zn_xO_{7-\delta}$ twinned crystals, with x = 0 - 0.11 and with the data of Tamegai et al. [5].

Several theoretical models based on BCS theory [9-11], have predicted that non-magnetic disorder, by increasing the residual resistivity by impurity scattering, can give rise to a depression of superconductivity. As shown in Figure 1, the samples with the higher Zn concentration (x = 0.053 and 0.058), show a modest increase in resistivity at 100 K, with r(x = 0.058)/ r(x = 0.00) ~ 1.45. This increase in the resistivity is very small compared with the expected values from the models [9-11].

As shown in Figure 2, Zn-doped YBaCuO samples with the Zn-doped give a Hall number n_H proportional to T above Tc. This behaviour of n_H (T) is difficult to understand in a Fermi-liquid framework consisting of a single band model of the normal state and a paired-hole superconducting state, which predicts a constant Hall density of carriers as a function of the temperature.

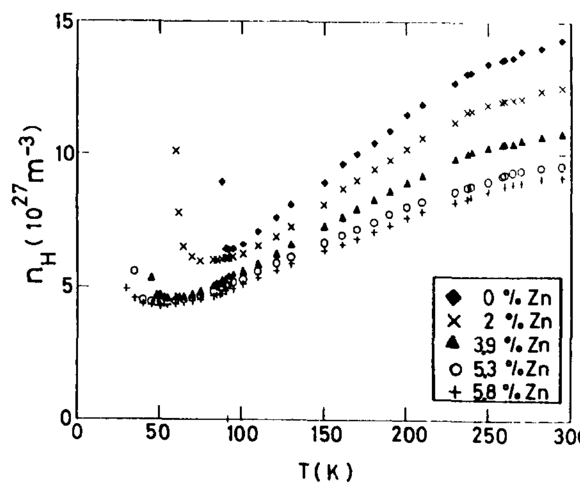

Figure 2. Temperature dependence of $n_H = 1/R_He$ in $YBa_2(Cu_{1-x}Zn_x)_3O_y$.

In the simplest band-model for the conduction holes, $\sigma = n_He^2\tau/m^*$. The hole density per unit cell $n = n_HV_{unit\ cell}$, calculated from our Hall data at 100 K, is = 0.8 - 1.1 hole. A theoretical estimate for the effective mass is about m^* ~45 m_e [4] and the scattering in the normal-state is due to inelastic processes $h/\tau = \eta k_BT$ [12] (with η = 2). In this model, if n_H~T, the energy involved in the scattering is much larger than the characteristic energy of the boson scattering. This process is thus not at the origin of the scattering mechanism [13].

Figure 3 shows the inverse of the Hall conductivity $\sigma^{-1}_H = r^2/R_H$ as function of T^3. For all the samples, the data fall on straight lines in the temperature range, from 100 K to 230-240 K, where the slope of the straight lines is changing to a new value. (The values of the slopes are slightly dependent on the Zn content). These results can be an indication for the presence of a change in the scattering mechanism of the carriers around 230-240 K. This deviation from a single line fit of σ^{-1}_H (T^3) can also be seen in Zn-doped YBaCuO single-crystals data [4], which were interpreted in the frame of the Resonance-Valence-Band model (RVB) [12-14].

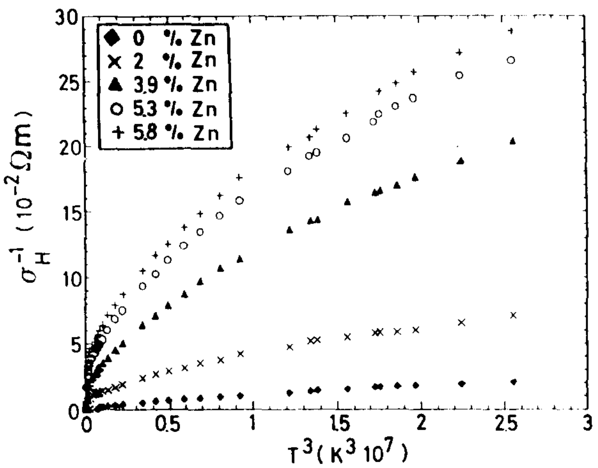

Figure 3. Inverse of the Hall conductivity as function of T^3 in $YBa_2(Cu_{1-x}Zn_x)_3O_y$.

In a recent theoretical work, Mott [15], using the t-J model of Zhang and Rice [16], has suggested that the oxygen 2p holes from bipolarons, form a degenerate gas of bosons, interacting, but not strongly overlapping (as do the pairs in BCS theory) and the critical temperature, Tc, is attained when the Bose gas becomes non-degenerate. In YBCO-Zn doped, he assumes that zinc prevents pairing and does not cause an Anderson localization, suggesting that the current carriers are fermions, forming a degenerate gas (a Fermi liquid).

4. Conclusions

We report an investigation of the resistivity and the Hall effect in $YBa_2(Cu_{1-x}Zn_x)_3O_{6.9}$ with x in the range of 0. to 0.058. The bulk samples were prepared by conventional solid-state reaction. The superconducting transition temperature Tc was strongly depressed by the Zn substitution. The slope of the temperature dependent normalized resistivity in the normal-state decreases with Zn concentration. From room temperature, when cooling down, the carrier concentration, $n_H(T)$, is linearly decreasing with the temperature down to T ~ 230K-240K. Below this temperature there is a change of the slope of n_H (T) and a decrease towards a minimum value, at a temperature T > Tc.

The T^3 dependence of σ_H^{-1}, with a change of the slope around 230K-240K, is correlated with the T-dependence of the carrier concentration.

These results although in partial disagreement with Anderson's model, can not be fully explained by a theoretical model (Zn concentration dependence of $R_H(T)$ as is also the case for the Zinc dependence of Tc.

Acknowledgments

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References

1 M. Mehbod, W. Biberacher, A.G.M. Jansen, P. Wyder, R. Deltour and P.H. Duvigneaud, Phys. Rev. B 38 (1988) 1181; G. Xiao, M.Z. Cieplak, A. Gavrin, F.H. Streitz, A. Bakhshai and C.L. Chien, Phys. Rev. Lett. 60, (1988), 1446.

2 J.M. Tarascon, P. Barboux, P.E. Miceli, L.H. Green, G.W. Hull, M. Eibschutz and S.A. Sunshine, Phys. Rev. B 37 (1988) 7458;B. Jayaram, S.K. Agarwal, C.V. N. Rao and A.V. Narlikar, Phys. Rev.B 38, (1988), 2903.

3 J. Clayhold, N.P. Ong, Z.Z. Wang, J.M. Tarascon and P. Barboux, Phys. Rev. B39 (1989) 7324.

4 T.R. Chien, Z.Z. Wang and N.P. Ong, Phys.Rev. Lett. 67 (1991) 2088; M. Affronte, D. Pavuna, O. Martin, F. Licci, T. Besagni and S. Cattami, Solid State Comm., 70, (1989), 951; K. Agarwal, R. Suryanarayanan, O. Gorochov, V.N. Moorthy, A.V. Narlikar, Solid. State Comm. 79, (1991), 857.

5 T. Tamegai and Y. Iye, Phys. Rev. B 44 (1991) 10167.

6 Y. Iye, Physical Properties of High temperature Superconductors III, ed. by D.M. Ginsberg, World Scientific, Singapore, (1992) 287.

7 R. Liang, T. Nakamura, H. Kawaji, M. Itoh and T. Nakamura, Physica C, 170 (1990) 307.

8 R. Suryanarayana, G.T. Bhandaye, M. Rateau, O. Gorochov, H. Pankowska, M. Ghorayeb, G. Villers and C. Vard, Journal Less Comm. Metals 151 (1989) 109.

9 L. Coffey and D.L. Cox, Phys. Rev. B 37 (1988) 3389.

10 R. Levin, J.H. Kim, J.P. Les and Q. Si, Physica C 175 (1991) 449.

11 W.E. Pickett, R.E. Cohon and H. Krakner, Physica B 169 (1991) 45.

12 P.W. Anderson, Physica C 185-189 (1991) 11.

13 M. Gurvitch and A.T. Flory, Phys. Rev. Lett. 59 (1987) 1337.

14 N. Nagaosa and P. Lee, Phys. Rev. B 43 (1991) 1233 .

15 N.F. Mott, Phil. Mag. Lett. 63 (1991)35 ; 64 (1991) 41 ; Physica C 196 (1992) 369.

16 F.C. Zhang and T.M. Rice, Phys. Rev. B37 (1988) 5759.