Effects of chemical substitution on transport properties of Bi-based high temperature superconductors

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Abstract: This report describes some transport and magnetic properties of doped Bi2212 and Bi2223 superconducting whiskers. These materials have advantages over polycrystalline sample as well as large bulk crystals in that they provide narrow transitions in resistance versus temperature as well as in magnetization versus temperature curves. In addition they are easy to grow and have short oxygen annealing times. Here Data on transport and magnetic properties of these superconducting whiskers are presented.

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I. INTRODUCTION

One characteristic of the copper-oxide superconductors is the close relation between magnetism and superconductivity. In particular it has been found that transition metal substitutions for Cu in $YBa_2Cu_3O_7$ (YBCO) and its rare earth analogues, dramatically affect the transition temperature $T_c$. On the other hand substitutions of rare earth impurities metals for Y were found to have little or no effect on $T_c$.[1]

In the case of Bi-based high $T_c$ superconductors of the form $Bi_2(SrCa)_{2+n}(Cu_{1-x}M_x)_{2+O_y}$, where M represents transition metals such as Zn and Ni as well as rare earth metals such as Gd, it is found out that both groups depress $T_c$ in sharp contrast to what is observed in the YBCO system.[1]

$Bi_2Sr_2CaO_7$ (Bi2201), $Bi_2Sr_2CaO_3$ (Bi2202), $Bi_2Sr_2CaCu_2O_8$ (Bi2212) and $Bi_2Sr_2CaCu_2O_8$ (Bi2212) whiskers were prepared at various doping levels[2]. Starting powders were mixed and melted at 1200°C for 30 min. The molten material was then quenched to room temperature in about two seconds to form a glassy material. The whiskers were grown by annealing the resulting glassy material in an oxygen environment at 840°C for five days and followed by cooling to room temperature.

II. EXPERIMENTAL RESULTS

Typical dimensions of the whiskers used in our measurements are 2 $\mu$m to 10$\mu$m (a axis) X 10$\mu$m to 100$\mu$m (b axis) X 2$\mu$m to 10$\mu$m (c axis). They have mass up to 100 $\mu$g to 300 $\mu$g. The electric field and magnetic field configurations relative to the crystal planes is shown in Figure 1.

The resistance, Meissner effect and critical current measurements were performed. The field dependence of critical current density and resistance versus temperature were also measured. Shown in Figures 2, is a typical normalized resistance ($R/R_{250K}$) versus temperature of Bi2223 with 0.08 Zn concentration measured using the four probe technique.

Our best measurement showed a transition width of less than 10K for most samples. These samples undergo double transitions. The first transition near 100 K and the second near 80 K; showing the presence of both Bi2223 and Bi2212 phases in any batch.

We also measured the superconducting transition temperature using a Quantum design SQUID magnetometer with the aim of determining bulk superconductivity. Figure 3 shows a typical magnetization curve for $x = 0.08$ Zn concentration. For most samples the observed Meissner effect was only due to the Bi2212 phase with transition near 80K. The high temperature transitions observed in the resistance data were due to filamentary conductivity. Figure 4 shows the transition temperature

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decreases as the concentration of Zn increases at the rate \( \frac{dT_c}{dx} \sim 250 \text{K/moleZn} \). This decrease shows that Zn is a chemical impurity that introduces some modification of superconductivity as opposed to a magnetic impurity that would dramatically reduce \( T_c \) to Zero.

![FIG. 3: Magnetization versus Temperature at \( H = 100 \text{e} \) and \( x = 0.08 \)](image)

**FIG. 3:** Magnetization versus Temperature at \( H = 100 \text{e} \) and \( x = 0.08 \)

We have also measured the resistance of this sample in magnetic field in the range of \( 0 < H < 9 \text{T} \) as shown in Figure 5. We observed that the high temperature transition (110K) became broad. The transition corresponding to Bi2212 became too broad to observe. The magnetic field \( (H_c) \) is plotted against the mid point of the transition to superconductivity in Figure 6. The rate of decrease of the critical magnetic field as a function of \( T_c \) \( (\frac{dH_c}{dT_c}) \sim -0.5 \text{T/K} \).

We measured the superconducting critical currents for the \( x = 0.06 \) Zn in field \( (0 < H < 1 \text{T}) \) parallel and perpendicular to the \( c \)-axis. The results are shown in Figures 7 and 8. \( J_c \) at 64K in field parallel to a-b plane, ranges from 1600 \( \text{A/cm}^2 \) (Zero field) to 600 \( \text{A/cm}^2 \) (1 Tesla). On the other hand the data for the case of the field parallel to the c-axis at 64K, show a rapid decrease of \( J_c \) in field and it was suppressed to zero using a field of 0.1 T.

We conducted similar \( I - V \) measurements when the field is parallel to the \( ab \) plane, the extracted critical density is shown Figure 8. In this case the current density is much more robust to the applied magnetic field and it decreases linearly as the field increases.

### III. CONCLUSIONS

In this work we have measured typical transport and magnetic properties of Zn doped Bi based high temperature superconductors. Our data indicate that the whiskers are bulk superconductors mostly composed of the Bi2212 phase. We have shown that the critical current density is dependent on the crystal direction. Its value is higher when the magnetic field is parallel to the \( ab \) plane, than when the later is parallel to the \( c \)-
FIG. 8: $J_c$ when the filed is parallel to the ab plane. The data fit an a linear function.

axis. The critical currents, obtained at 64K in 0-1T field range, of our Bi2223 and Bi2212 whiskers are small compared to the values for polycrystalline Ag-sheathed Bi2223 tapes\(^3\). This is an indication that doping with Zn didn’t introduce effective pinning centers. The dependence of the critical temperature on Zn concentration is typical of the presence of chemical impurity in the system.

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