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Properties of polycrystalline $Hg_{1-x}Bi_xBa_2Ca_2Cu_3O_y$ superconductors

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Abstract

Polycrystalline $Hg_{1-x}Bi_xBa_2Ca_2Cu_3O_y$ materials, with Bi-content $x = 0.1, 0.2$ and 0.3, were prepared by a direct, one-step synthesis. Characterization methods included X-ray diffraction, SEM, and studies of the magnetization M. The T_c's were 133.5, 133 and 128 K, respectively. The persistent current density J_p falls off roughly exponentially with field H and temperature T. The irreversibility fields $H_{irr}(T) \sim (1 - T/T_c)^n$, with $n \approx 3$, were similar for the three materials. Analysis of the equilibrium M with London theory provided the London penetration depth $\lambda(T)$.

Keywords: Magnetization; Penetration depth

The Hg-cuprate $HgBa_2Ca_2Cu_3O_y$ with three adjacent Cu–O layers has the highest known superconducting transition temperature $T_c = 135$ K. With this high-T_c and relatively simple tetragonal structure, the material is a natural candidate for further development. To improve the formation and stability of Hg-1223, partial substitutions of Hg by Bi, Pb, and Bi–Pb have been studied [1].

Here we investigate the properties of polycrystalline $Hg_{1-x}Bi_xBa_2Ca_2Cu_3O_y$ materials with Bi-content $x = 0.1, 0.2$ and 0.3, which were prepared directly from the metal oxides without use of a precursor [2]. Using a SQUID-based MPMS-7 magnetometer, the isothermal magnetization $M(H)$ was measured at temperatures T between 5 and 120 K in magnetic fields H up to 6.5 T. Values of M were corrected for the paramagnetic background, measured for T up to 295 K and extrapolated to low temperatures.

Measurement of the low-field susceptibility $4\pi\chi$ in $H = 4$ Oe revealed T_c's of 133.5, 133 and 128 K, respectively. At 5 K, the zero-field-cooled (ZFC) values of $4\pi\chi$ were -0.80, -0.67 and -0.13; the corresponding field-cooled (FC or Meissner) signals were $4\pi\chi = -0.50$, -0.28 and -0.04, respectively. These values are lower bounds for the superconducting volume fraction. For $x = 0.1$ and 0.2, the ZFC and FC transitions have "two-step" structures due to decoupling of current flow between grains. With Bi-content $x = 0.3$, there was only a single "one-step" transition.

The persistent current density J_p was obtained from the irreversible magnetization using the Bean critical state model. At low temperatures, the J_p values for the $x = 0.1$ and 0.2 materials almost coincide. They begin to separate near 40 and by 77 K, the J_p for the $x = 0.2$ material is substantially larger than that for the $x = 0.1$ sample. With $x = 0.3$, the current density is considerably smaller than either of the other materials, qualitatively consistent with a reduced superconducting volume fraction. At low and intermediate temperatures, J_p falls off quasi-exponentially with H and T, then drops more quickly as one approaches the irreversibility line. The irreversibility field $H_{irr}(T)$ was obtained from the $J_p(T)$ results using the criterion that $J_p(T) = 10^3$ A/cm^2; at this level, the isothermal J has decreased by a factor of 10^3 or more from its low-T value and is falling rapidly. The results follow an approximate power-law dependence

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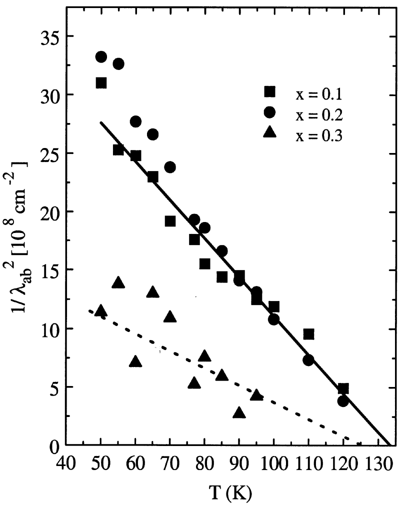

Fig. 1. The in-plane London penetration depth λ_{ab}, plotted as its inverse square, versus temperature T. Results are shown for $Hg_{1-x}Bi_xBa_2Ca_2Cu_3O_y$ with Bi-content $x = 0.1, 0.2$ and 0.3. Solid line is fitted to $x = 0.1$ data and shows a Ginzburg–Landau dependence; dotted line is schematic.

$H_{irr}(T) \propto (1 - T/T_c)^n$ with similar exponents $n \approx 3$ in each case.

Further studies of the equilibrium magnetization M were analyzed using standard London limit theory [3], which provides a logarithmic field dependence $M \sim \ln(H)$. The averaged magnetization $\langle M \rangle$ at field H accurately followed this dependence. For a polycrystal, the slope $\mathrm{d}M/\mathrm{d}\ln(H) = \phi_0/64\pi^2\lambda_{ab}^2$ [3]. Results for the London penetration depth in the *ab* plane, $\lambda_{ab}(T)$, are shown in Fig. 1 as a function of temperature. For the materials with $x = 0.1$ and 0.2, the resulting values are very similar. In the plot of $1/\lambda_{ab}^2(T)$ versus T, Ginzburg–Landau theory provides a linear variation near T_c. This dependence is indeed observed, over an extended range of T; note the solid line, fitted to all the data for $x = 0.1$, which intersects the axis very close to the observed low field T_c. A similar extended region of linear dependence was observed in a series of Hg-1201 materials [4]. Extrapolating linearly to $T = 0$ gives $\lambda_{ab}(0) = 150$ nm, similar to the values for Bi-free Hg-1223 prepared less directly [5]. For the material with $x = 0.3$, the data are more noisy and the dashed line schematically shows the Ginzburg–Landau dependence; no corrections have been made for a reduced volume fraction, which likely accounts for the larger *apparent* values of λ in this case.

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References

[1] K. Isawa, A.Tokiwa-Yamamoto, M. Itoh, S. Adachi, H. Yamauchi, Appl. Phys. Lett. 65 (1994) 2105.
[2] D. Loebich, H.R. Khan, Czech. J. Phys. 46 (Suppl. S3) (1996) 1183.
[3] V.G. Kogan, M.M. Fang, S. Mitra, Phys. Rev. B 38 (1988) 11 958.
[4] J.R. Thompson, H.R. Khan, K.J. Song, Physica C 272 (1996) 171.
[5] J.R. Thompson, in: A.V. Narlikan (Ed.), Studies of High Temperature Superconductors, Vol. 26, Nova Science Publishers, Commack, NY, 1998, pp. 113–131.