

# Systematic Variation of Magnetic Phase Diagram with Electromagnetic Anisotropy Observed in Bi2212 and Bi(Pb)2212 Single Crystals

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## Abstract

Macroscopic magnetization and anisotropic resistivity of Bi2212 and Bi(Pb)2212 single crystals having various carrier and Pb doping levels were systematically studied. Single crystalline samples of Bi2212 and Bi(Pb)2212 were grown by the floating zone method with starting compositions of  $\text{Bi}_{2.1}\text{Sr}_{1.8}\text{CaCu}_2\text{O}_y$  and  $\text{Bi}_{2.2-x}\text{Pb}_x\text{Sr}_{1.8}\text{CaCu}_2\text{O}_y$  ( $x=0.1, 0.2, 0.3, 0.4, 0.6$ ), respectively. Carrier doping levels of the samples were controlled by post-annealing under various temperatures and  $P(\text{O}_2)$ . Magnetization measurements were performed using SQUID susceptometers, HOXAN 2000X and MPMS XL-5 under magnetic fields up to 50kOe applied parallel to the crystallographic  $c$ -axis. Temperature dependence of resistivity along the  $a$ ,  $b$  and  $c$ -axes, ( $\rho_a$ ,  $\rho_b$  and  $\rho_c$ ) was measured by the a.c. four-probe method.

With increasing Pb-doping level,  $x$ , and further carrier doping,  $\rho_c$  decreased dramatically and its temperature dependence became metallic down to  $T_c(\text{onset})$ , while magnitude of in-plane resistivity,  $\rho_a$ ,  $\rho_b$ , were almost unchanged by Pb-doping. The electromagnetic factor,  $\gamma^2$ , estimated from anisotropic resistivity ratio,  $\rho_c / (\rho_a \rho_b)^{\frac{1}{2}}$ , at  $T_c+10\text{K}$  was varied approximately two order of magnitude from carrier underdoped Bi2212 ( $\gamma^2 \sim 10^5$ ) to heavily Pb-doped Bi2212 in carrier overdoped state ( $\gamma^2 \sim 10^3$ ).

Irreversibility fields of these crystals were also dramatically improved by Pb-doping and further carrier doping and they were found to be well scaled by  $\gamma^2$  and  $T/ T_c$ . For pure Bi2212 and Bi(Pb)2212 with low Pb-doping level ( $x \leq 0.2$ ), samples showed magnetization step corresponding to the first order FLL transition, while any abrupt magnetization changes were not observed in the heavily Pb-doped Bi2212 samples.

Magnetic phase diagram which includes the irreversibility line, second peak field and FLL transition lines of Bi2212 and Bi(Pb)2212 will be discussed from view points of the electromagnetic anisotropy and pinning effect.