Doping Dependence of Critical Current Density and Vortex Pinning Mechanism in $Bi_2Sr_2CaCu_2O_{8+\delta}$ Single Crystals

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Abstract

Understanding how critical current density (J_c) depends on carrier concentration (p) and which vortex pinning mechanisms contribute is a key step toward enhancing J_c and achieving broader practical applications of high-T_c cuprates. Here, we systematically evaluated the p dependence of J_c in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals. In the low-temperature regime where pancake vortices are pinned, J_c exhibits two peaks at $p \sim 0.12$ and $p \sim 0.17$ (Fig. 1a).[1] This non-monotonic behavior of J_c is likely caused by changes in the pinning mechanism, then, we analyzed the magnetic-field and temperature dependence of J_c. As an example, Fig. 1b shows the temperature dependence of J_c under 1 T for the optimally doped sample (p = 0.16), decomposed into weak collective pinning (J_c^{wk}) and strong pinning (J_c^{st}) contributions using an expression

$$J_c(T) = J_{c0}^{wk}\exp(-T/T_p^{wk}) + J_{c0}^{st}\exp[-3(T/T_p^{st})^2],$$

where J_{c0}^{wk} and J_{c0}^{st} are the J_c values at 0 K, and T_p^{wk} and T_p^{st} are characteristic temperatures related to the pinning energy scale, for the weak collective and strong pinning contributions, respectively.[2] The doping dependence of J_{c0}^{st} and J_{c0}^{wk} is summarized in Fig. 1c, demonstrating that strong pinning dominates in the underdoped region ($p \lesssim 0.13$), whereas weak collective pinning becomes dominant in the overdoped region ($p \gtrsim 0.17$). The strong pinning contribution, which gives rise to the unexpected J_c peak in the underdoped region ($p \sim 0.12$), is likely a consequence of spatial inhomogeneity of superconductivity in the CuO_2 planes induced by oxygen deficiency and/or competing orders.

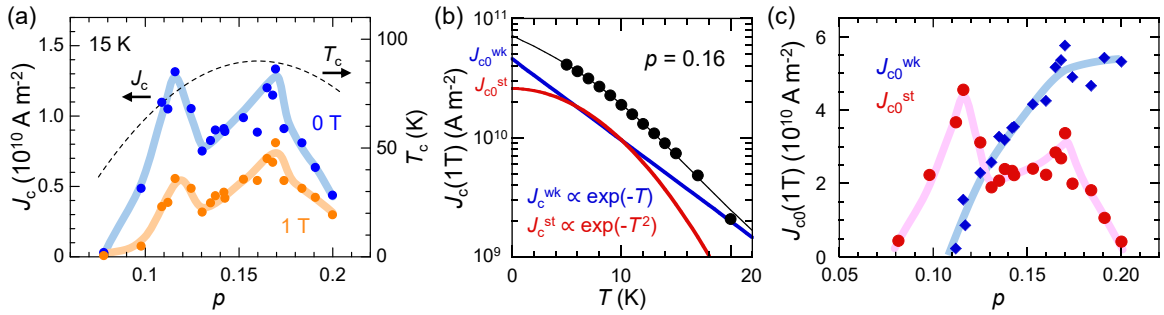

Figure 1 (a) Doping dependence of J_c at 15 K under the fields of 0 T (blue) and 1 T (orange), together with T_c (dashed curve). (b) Temperature dependence of J_c for p = 0.16, decomposed into J_c^{wk} (blue) and J_c^{st} (red). (c) Doping dependence of J_{c0}^{wk} (blue) and J_{c0}^{st} (red) obtained by the fitting.

References

1) J. Kato, S. Ishida et al. Jpn. J. Appl. Phys. 64, 080905, 2025

2) J. Plain et al. Phys. Rev. B 65, 104526, 2002

Keywaords: High-T_c cuprates, Bi2212, Single Crystal, Critical Current, Vortex Pinning