High Magnetic Fields Reveal Pinning Mechanism in P-doped Ba-122

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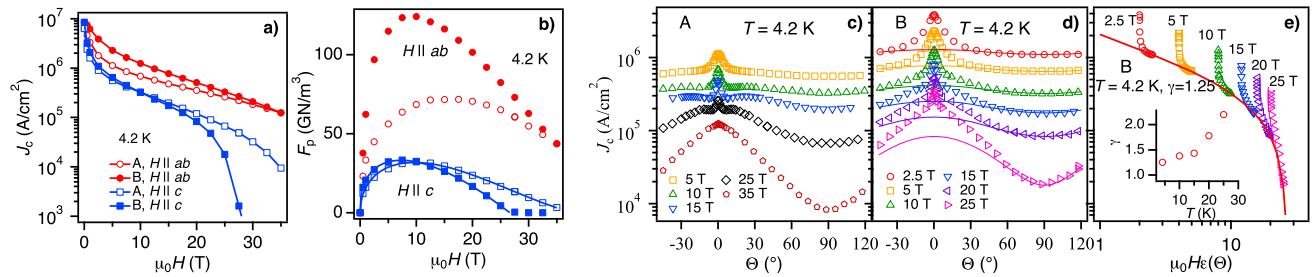

Fig. 1 Field dependence of J_c (a) and pinning force density F_p (b) for H||c and H||ab at 4.2 K for both samples, A and B. Angular dependence of J_c for the sample A (c) and B (d) at 4.2 K in various magnetic fields. The solid lines are random-pinning contribution. e) The scaling behavior of the sample B. The solid line is the measured $J_c(H||c)$ presented in Fig. 1 a). Inset: temperature dependence of scaling parameter γ.

High-field transport critical current properties of epitaxial $BaFe_2(As,P)_2$ (P-doped Ba-122) thin films have been investigated. By analyzing pinning properties we have identified the dominant pinning mechanisms and evaluated the pinning-related electronic anisotropy of this class of materials.

P-doped Ba-122 films with 115 nm (A) and 45 nm (B) were prepared on MgO(100) substrates by molecular beam epitaxy. Both films are biaxially textured with small out-of-plane and in-plane FWHM values (< 1°). Bridges of 40 μm width and ~1 mm length were prepared by laser cutting for transport measurements of $J_c(\theta,T,H)$ by a four-probe method. J_c was evaluated with an electrical field criterion of 1 μV/cm. The magnetic field $\mu_0 H$ (up to 35 T) was applied in maximum Lorentz force configuration (*H* perpendicular to the current).

Field dependences of J_c of P-doped Ba-122 thin films for both principal crystallographic directions (*H*||*c* and H||*ab*) are shown in Fig.1 a). For *H*||*c.* In low fields, sample A shows higher J_c values than sample B. However, sample A is superior to B in high-fields. For *H*||*ab,* the crossover between the samples is expected at $\mu_0 H$ >35 T.

In Fig. 1 b) the corresponding pinning force densities F_p are plotted as a function of *H*. Here, F_p is expressed as $F_p \propto (H/H_{irr})^p(1-H/H_{irr})^q$, where *p*, *q* and H_{irr} are fitting parameters. The solid lines in Fig. 1 b) are the results of fitting by using the above formula. The determination of all free parameters for *H*||*ab* is difficult in part because Hirr is larger than the maximum applied field. For both films, *p* values are near 0.5. On the other hand, *q* varies depending on the samples indicative of different pinning mechanisms. The exponent *q* is ~1.5 for A and ~1.0 for B, respectively. The former indicates a mixture of the surface core pinning and the shear modulus C_{66}. The latter suggests surface core pinning. The respective H_{irr} values at 4.2 K in the *c*-direction for samples A and B are 39 and 27 T. Shown in Figs. 1 c) and d) are the angular dependencies of J_c in various magnetic fields at 4.2 K for both samples. Sample A (c) showed a broad shoulder next to the large *ab*-peak (Θ=0°, *H*||*ab*) at 10 T, which is gradually shifting towards *H*||*ab* with increasing *H*. Sample B (d) has only one large *ab*-peak indicating negligible correlated *c*-axis defects. In this case, J_c may be scaled with an effective field $H\varepsilon(\Theta)$, $\varepsilon(\Theta)=(\sin^2\Theta+\cos^2\Theta/\gamma^2)^{0.5}$ by employing an appropriate γ value. The resultant scaling is summarized in Fig. 1 e). The inset of Fig. 1 e) shows the temperature dependence of γ. Additional points at 10 and 20 K were obtained via PPMS measurements. The solid lines in Fig.1 d), re-calculated from Fig. 1 e), are the random-defects contribution.

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