

Pinning-Force Density and Critical-Current Density in Superconducting Rb_3C_{60} Fullerene†

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The magnetic critical-current density J_c and the volume-pinning-force density F_p in a well-characterized Rb_3C_{60} fullerene with $T_c = 30.3$ K have been measured as functions of magnetic field and temperature. They were determined by *dc* magnetic hysteresis loops at temperatures between 5 and 30 K in an applied field up to 15.5 T. J_c appears to be a monotonically decreasing function of T and H in the temperature and field regions measured. At $T = 5$ K, F_p initially increases rapidly with increasing field, and it seems to level off when $H > 0.5$ T, and finally it reaches a saturation value of about 10^{10} dyne/cm³ at $H \sim 1.4$ T. For $T > 5$ K, however, $F_p(H)$ appears to peak at a maximum value, $F_{p,\max}$ at field H_p that occurs between 0 and the irreversibility field (H_{irr}). Both H_p and $F_{p,\max}$ are temperature-dependent and they seem to be proportional to $(1 - T/T_c)^n$.

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The flux-pinning mechanisms and thermally-activated-flux motion in the mixed state are believed to be responsible for magnetic and electric properties of superconducting materials. Hence, they may be important for future possible applications. The studies made on the thermally-activated-flux motion and the irreversibility line in Rb_3C_{60} fullerene were reported elsewhere [1,2]. The volume-pinning-force density, F_p , and critical current density, J_c , are two important physical quantities for the investigation of the flux-pinning mechanism. They can be determined directly from *dc* magnetic hysteresis loops. In this paper, we present the temperature- and field-dependencies of J_c and F_p in a well-characterized Rb_3C_{60} fullerene with $T_c = 30.5$ K.

The sample preparation procedures for a powdered Rb_3C_{60} sample of an average particle size of about, $50 \mu\text{m}$ were described in detail before [1-6]. *Dc* hysteresis curves at various temperatures between 5 and 30 K were measured by using a Quantum Design SQUID magnetometer in fields up to ± 5.5 T. In order to ensure the field stability: the stable mode of point-by-point field-setting, instead of scan mode of fast hysteresis loop, was chosen during these measurements.

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Magnetic J_c , i.e., intragranular J_c was determined from the hysteresis loop based on the Bean's critical-state model [1,4]. As shown in Fig. 1(a), J_c decreases with increasing field and temperature except at low temperatures ($T < 12$ K) and low fields ($H < 0.2$ T) where flux jumps were observed. At $T = 5$ K, J_c decreases slowly from 2×10^6 to 2×10^5 A/cm² as H increases from 0 to 4 T. When temperature reaches to 25 K, the J_c value remains at 1.8×10^5 A/cm² for $H = 0$ T. The J_c values are larger than other powdered superconductors with comparable sample sizes, except for $\text{YBa}_2\text{Cu}_3\text{O}_y$. The large J_c and the occurrence of flux jump at low temperatures implies that flux-pinning strength and high pinning-force density in our sample were large. The plot of J_c vs H for $T > 10$ K agrees well a simple scaling-law behavior: $J_c(H, T) = k_1 / (1 + H/H_{01})^\alpha$. However, for $T < 10$ K it shifts to an exponential expression: $k_2 \exp(-H/H_{02})$. Here, k_1, k_2, H_{01}, H_{02} , and α are all temperature-dependent parameters. The dependence of J_c on temperature thus obeys the empirical scaling relationship: $J_c(H, T) = J_{c0}(1 - T/T_c)^m$, where J_{c0} and m are field-dependent parameters. For $0.4 \text{ T} < H < 1 \text{ T}$, the value of m is about equal to 2.

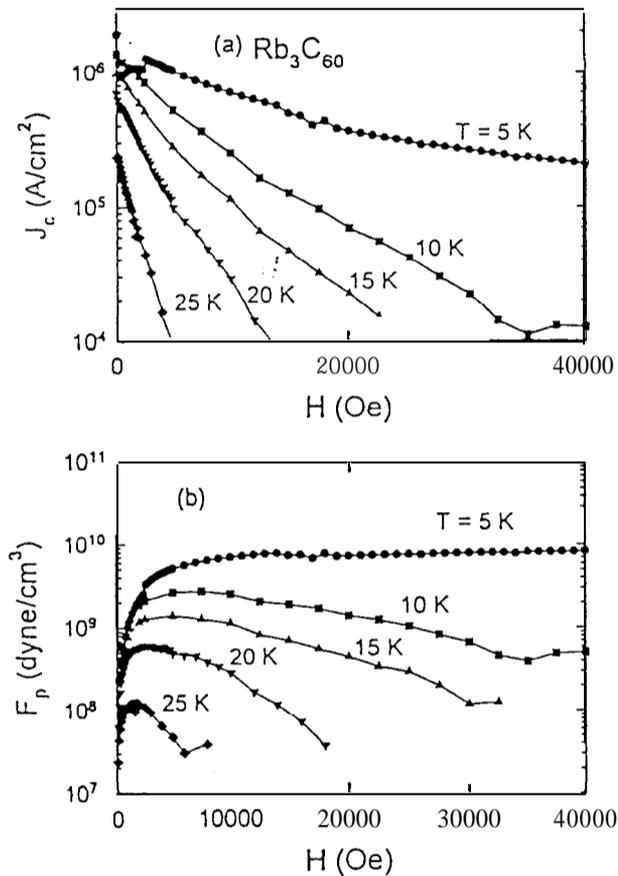


FIG. 1. (a) magnetic critical-current density J_c and (b) volume pinning-force density F_p as a function of external field at various temperatures.

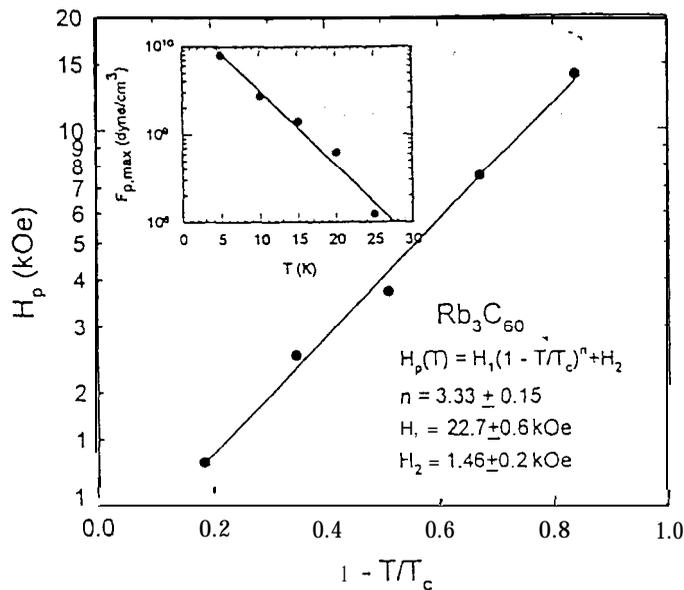


FIG. 2. H_p , at where has a maximum F_p , as a function of temperature. Insert: temperature dependence of $F_{p,max}$.

The volume pinning-force density can be calculated by the definition of $F_p = J_c \times H$. Although J_c decreases monotonically with increasing field, the cross product of J_c and H reveals more complex features and variation on field. Fig. 1(b) shows F_p of Rb_3C_{60} fullerene as a function of applied field at different temperatures. For $T = 5$ K, F_p at first increases rapidly from 0 to 5×10^9 dyne/cm³ when H increases from 0 to 0.5 T. Then it levels off between 0.5 and 1.4 T. Finally, F_p reaches at saturation of 9×10^9 dyne/cm³ as H continues to increase to our maximum available field. For $T > 5$ K, F_p is also increases rapidly from 0 to a maximum value, $F_{p,max}$, when H increases from 0 to H_p . From there an F_p gradually decreases. Both J_c and F_p eventually vanish when H reaches at the irreversibility field, H_{irr} [1,2]. Within the field region available, H_{irr} can only be obtained for $T \geq 15$ K. For $T \leq 10$ K, H_{irr} are larger than 5.5 T [2].

As shown in Fig. 2, both H_p and $F_{p,max}$ decrease with increasing temperature, that seems to follow a power law behavior. The temperature dependence of H_p is in fair agreement with the following expression: $H_p(T) = H_1(1 - T/T_c)^n + H_2$, where T_c is the superconducting transition temperature. Here, n , H_1 and H_2 are parameters which may be related to material characteristics, in particular, the type of pinning centers. The best fitting result of the experimental data of H_p to this equation is $n = 3.33 \pm 0.15$, $H_1 = 22.7 \pm 0.6$ kOe, and $H_2 = 1.46 \pm 0.2$ kOe.

The magnetic J_c and F_p as functions of temperature and field for powdered Rb_3C_{60} sample have been obtained by the magnetization curves. $F_p(H)$ shows a maximum $F_{p,max}$ at field H_p . Both $F_{p,max}$ and H_p appear to obey approximately a scaling behavior of $(1 - T/T_c)^n$.

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