Field dependence of current density in strong pinning YBCO single crystals with different microstructure

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Proceedings of the 2.nd European Conference on Applied Superconductivity, EUCAS 95,
Jul. 3-6 1995, Edinburgh, Scotland, Inst. Phys. Conf. Ser. No 148 (1995) 315-318

Field Dependence of Current Density in Strong Pinning YBCO Single Crystals with Different Microstructure

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Abstract. $YBa_2Cu_3O_{7-\delta}$ single crystals with high critical current densities and different microstructure of the twin pattern were studied by means of torque magnetometry. Pinning contributions due to random point pinning and to correlated disorder as well as the influence of thermal oscillations of the fluxlines within the pinning barriers are discussed. Different collective pinning regimes of the fluxline lattice which are characterized by different power law behaviour of the form $j(B_z) \sim B_z^{p-1}$ could be identified.

1. Introduction

High current densities are necessary suppositions for power applications of high-T_c superconducting materials. However serious restrictions arise due to the influence of thermal fluctuations on pinning properties by (i) thermally activated jumps between different metastable states of the flux line lattice which leads to significant fluxcreep effects, and (ii) thermal fluctuations of the fluxlines within the pinning barriers which smear out the elementary pinning potential [1]. Concerning the second point we report in this paper on experimental investigations of $YBa_2Cu_3O_{7-\delta}$ single crystals with different microstructure by means of torque magnetometry.

2. Experimental

The microstructure of the twin pattern of several $YBa_2Cu_3O_{7-\delta}$ single crystals which were grown under similar conditions [2] was characterized by polarization microscopy. The samples were investigated by means of torque magnetometry (e.g. [3]). The angular dependence of the torque hysteresis ΔG measured for stationary rotation of the external magnetic field H was used to derive the irreversible part of the magnetization M_{irr}, the current density j , and the pinning force volume density F_p according to

$$M_{irr} = \Delta G/(\mu_o H V \sin(\Theta)) \quad (1a) \qquad j = k\, M_{irr}/d \quad (1b) \qquad F_p = j\, B_z \quad (1c)$$

(V = sample volume, Θ = magnetic field direction with respect to the c-axis, d = sample width, k = geometry dependent factor), which is valid under the assumption that there is only a magnetization component parallel to the c-axis [3]. From torque data measured at a temperature of 77.4K the dependence of current density on the component B_z of the flux density parallel to the c-axis direction ([001] direction) was calculated. All torque measurements were performed under a fixed voltage criterion of $E \approx 2.5\ 10^{-8}$ V/cm.

3. Results

In Fig. 1 the dependence of the pinning force volume density on B_z is shown for a $YBa_2Cu_3O_{7-\delta}$ single crystal with only one twin domain. Here we find a transition of the

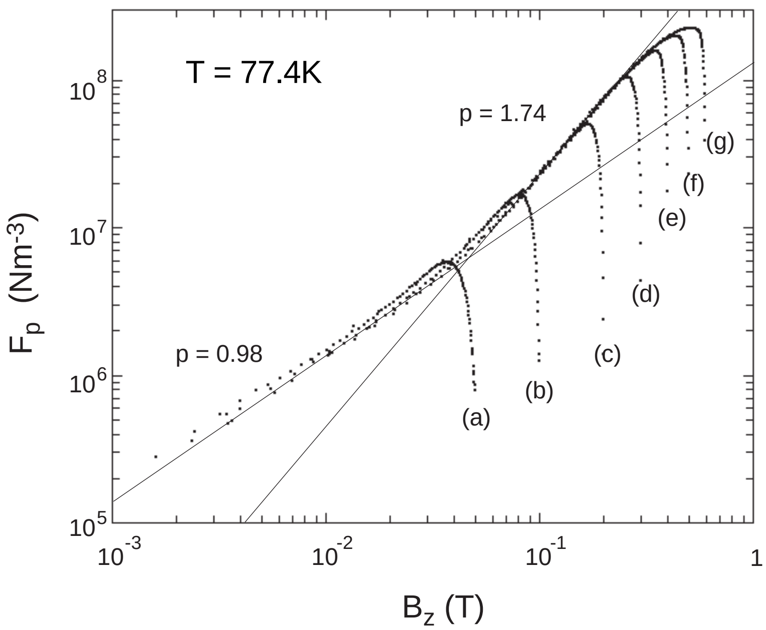

Fig.1 Pinning force volume density in dependence on B_z for different values of the external magnetic field of 40kA/m (a), 80kA/m (b), 160kA/m (c), 240kA/m (d), 320kA/m (e), 400kA/m (f), and 480kA/m (g). (Ignore the rapid drop of the F_p data for different H at high B_z which is caused by the minorloop characteristics of the torque magnetometry sweeps.)

power p in the power law $F_p(B_z) \propto B_z^p$ from $p = 1$ (i.e. j = const) to $p = 1.75$ (i.e. $j \propto B_z^{3/4}$) which can be interpreted in the frame of the collective pinning theory as a transition from the single vortex pinning regime to the regime of collective pinning of small flux bundles at low depinning temperatures $T_L^* << T$ and is discussed elsewhere [4,5]. In the case of very strong pinning $YBa_2Cu_3O_{7-\delta}$ single crystals with a dense twin pattern and crossing twin boundaries a transition from the single vortex pinning regime (p =1) towards a fishtail behaviour which is characterized by $p = 2$ (i.e. $j \propto B_z$) can be observed (c.f. Fig. 2). For samples with crossing twin boundaries but only medium pinning strength a transition from a $j \propto B_z^{-1/4}$ behaviour towards a linear increase of j with B_z was found which is shown in Fig.3. The current density in this sample is more than one order of magnitude smaller than in the sample of Fig.2.

4. Conclusions

Besides the “fishtail”-effect with $p = 1.75$ which is caused by collective pinning of small flux

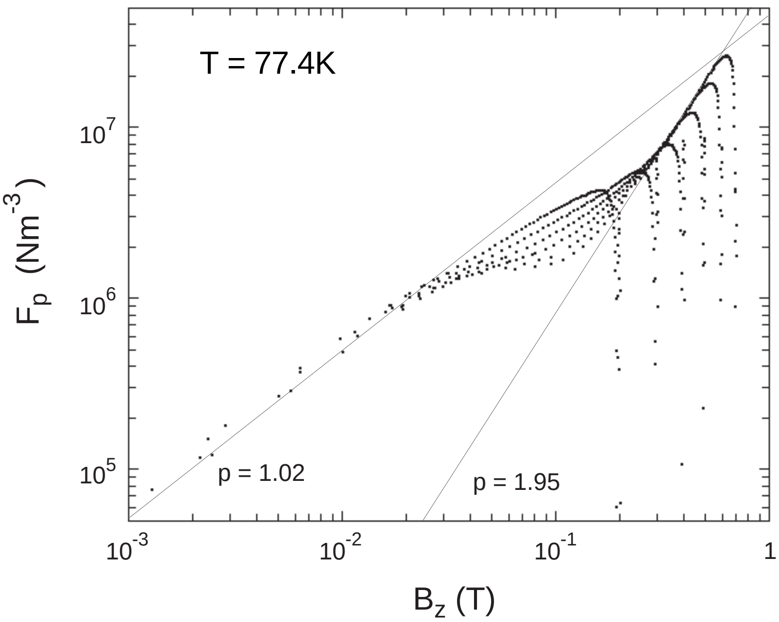

Fig.2 Transition from $p = 1$ to $p = 2$ in the pinning force volume density of a $YBa_2Cu_3O_{7-\delta}$ single crystal with high pinning strength and many crossing twin boundaries.

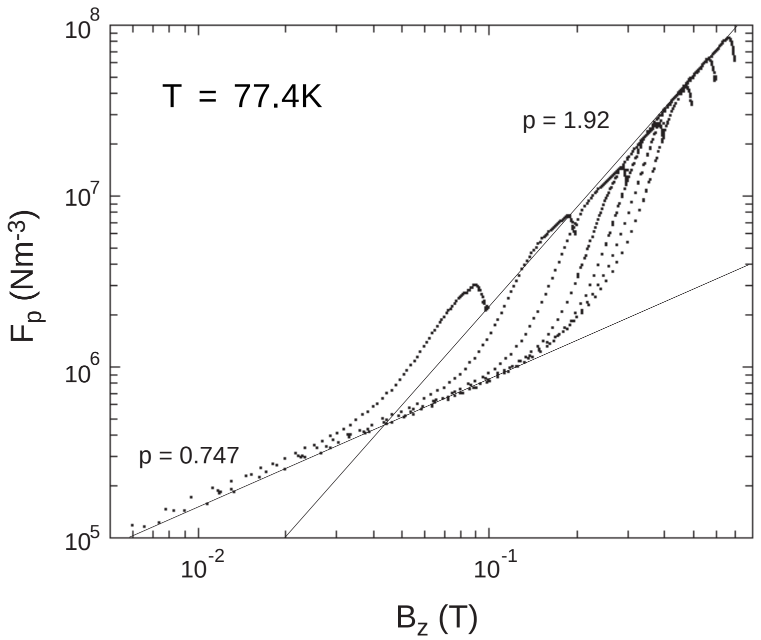

Fig.3 Transition from $p = 3/4$ to $p = 2$ in the pinning force volume density of a $YBa_2Cu_3O_{7-\delta}$ single crystal with crossing twin boundaries and only medium pinning strength. Note the bad scaling in the region of intermediate B_z values.

bundles at weak random point pinning centers, there exists a second type of “fishtail”-effect which is characterized by a linear increase of the current density with B_z. This linear increase of j can be explained by strong pinning of small flux bundles at $T < T_L*$. To proof this statement the data of $\ln(j/B_z)$ of a very strong pinning heavily twinned $YBa_2Cu_3O_{7-\delta}$ single crystal are plotted in Fig.4 together with the fit data of a nonlinear fit with Equ.(10) of reference [1]. In the field range beyond the fishtail-peak, there is a good agreement of the power of B_z in the

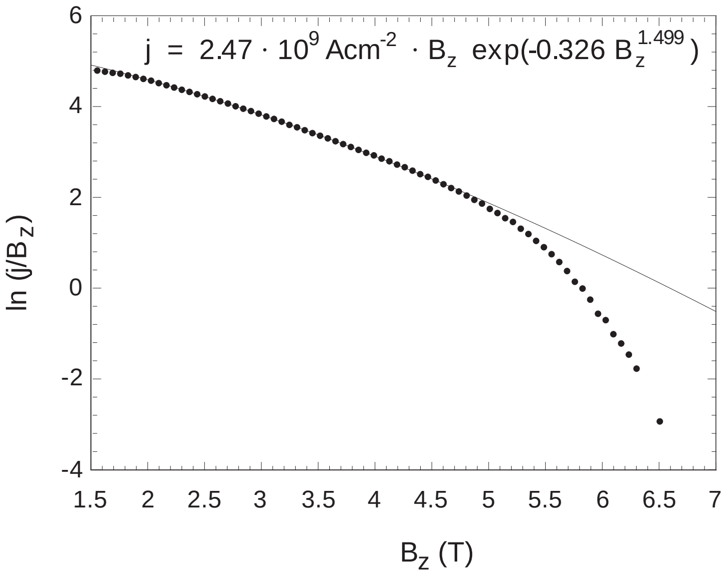

Fig.4 Nonlinear fit in the fieldrange between $B_z = 2.5$T and $B_z = 4.5$T of $\ln(j/B_z)$ data calculated from field sweep measurements [5] of a heavyly twinned $YBa_2Cu_3O_{7-\delta}$ single crystal. Note the good agreement of the power of B_z in the exponent (1.499) with the value 3/2 predicted by Equ.10 of reference [1]. {Ignore the rapid drop of the data at high B_z which is caused by the minorloop characteristics of the torque magnetometry sweeps.}

exponent with the value 3/2 which follows from Equ.(10) in reference [1] under the condition of $T_L{}^* > T$. In the case of the sample of Fig.3 the transition from the $j \propto B_z^{-1/4}$ regime at low B_z (at very low current densities) towards the "fishtail"-regime depends on the vortex orientation in the sample: For different values of H we find the inflection point of the $j(B_z)$ curve for the same angular orientation of the flux lines ($\theta \approx 52°$). This behaviour can be interpreted as a lock in of the flux lines in the linear defects which are given by the regions of high stress at crossing twin boundaries of different orientations [5]. As a consequence of this transition the pinning becomes stronger correlated and the influence of the thermal fluctuations of the flux lines within the pining centers is reduced which results in higher values of $T_L{}^*$

Acknowledgements

The authors greatly appreciate the opportunity to perform a part of the measurements in the Laboratory of Solid State Physics at the Free University of Amsterdam. This work was supported by the BMFT under contract No. 13N6100

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