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Bean–Livingston barriers

A new source for magnetic irreversibility in $YBa_2Cu_3O_7$ crystals ☆

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We present new measurements of the field distribution in untwinned single crystal of $YBa_2Cu_3O_7$, using an ultra-sensitive local Hall-probe technique. In the temperature range 75 K to T_c (92.5 K), there is no field gradient along the sample when the external field is reduced. This indicates that Bean–Livingston surface barriers are the main source of magnetic irreversibility in this temperature range.

Traditionally, the irreversible magnetization curves of type-II superconductors have been treated within the framework of the Bean model [1] which presumes strong bulk pinning. This model has also been used extensively during the last four years to explain irreversible magnetization data for high-temperature superconductors (HTSC). Only recently it has become apparent that surface barriers, which were first described decades ago by Bean and Livingston [2] (BL), contribute significantly to magnetic irreversible features of HTSC. First claims for the existence of surface barriers in HTSC were given in refs. [3] and [4] based on the anomalous up-turn which is found at low temperatures in the temperature dependence of the lower critical field H_{c1}. More direct evidence for the existence of BL barriers is presented in ref. [5] which describes measurements of the first field for flux penetration in an untwinned Y–Ba–Cu–O (YBCO) crystal at high temperature, in the vicinity of T_c. One of the main observations of ref. [5] is the "asymmetry" in the magnetization curves, namely that for decreasing applied fields the measured magnetization is virtually zero. This observation, which is confirmed over a wide range of temperatures, is in sharp contrast to the behavior expected from a type-II superconductor with strong bulk pinning [1]. On the other hand, exactly such behavior is one of the main fingerprints of BL barriers [6]. We have thus concluded that BL barriers play a major role in determining magnetic irreversible features in high quality HTSC crystals. The purpose of this article is to further support this conclusion with new experimental evidence.

Hall-probes are used to measure the local magnetic moment in an untwinned YBCO crystal. Electrical contacts are attached to a piece of InSb ($2000 \times 100 \times 80\ \mu m^3$) to form *two* active Hall-probes separated by approximately 1 mm. The crystal (sample 1b of ref. [5]) is placed above the InSb slab in such a way that one Hall-probe is located directly above the sample whereas the second one is outside (see fig. 1.)

This configuration allows for a simultaneous measurement of the magnetic induction B as a function of the applied external field H_a at the center and at the edge of the sample. Thus, it is possible to determine the local magnetization $\Delta H = B - H_a$ and the field gradients in the bulk of the sample.

Figures 2(a) and (b) present typical data which

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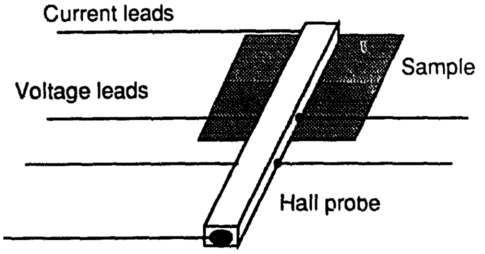

Fig. 1. Schematic description of experimental setup.

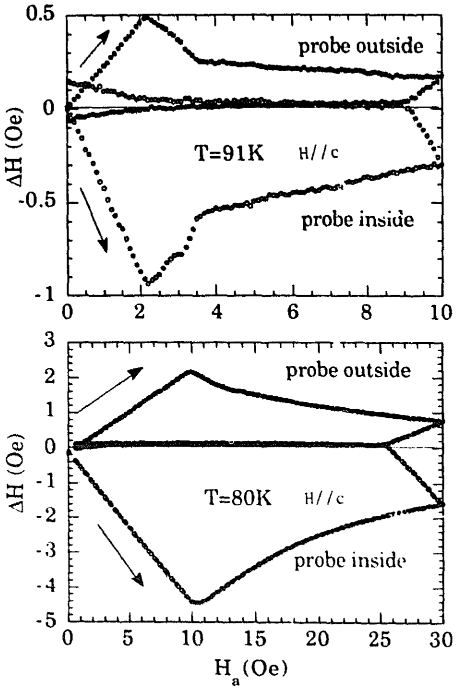

Fig. 2. Magnetization loops recorded at 91 K and at 80 K.

are obtained at 91 K and 80 K, respectively. The open symbols and the full ones represent data from the probes above ("inside") and outside of the sample, respectively. Note the change in the sign of the recorded magnetization which reflects the opposite directions of the field generated by the shielding currents, at the location of the two probes. Despite this sign change, all the qualitative features of the magnetization curves are preserved, demonstrating the fact that the actual location of the probe is insignificant in determining features such as first field for flux penetration [5].

The most intriguing feature in figs. 2(a) and (b) is the fact that the value of the magnetization is almost zero in the descending branch of the hysteresis loop. This is in sharp contrast with the expectations from the Bean model [1] which predicts a "symmetric" loop, namely that the value of the magnetization in the ascending and descending branches should be the same, but with opposite signs. On the other hand, as we have already stated above, zero magnetization in the descending branch is one of the main fingerprints of BL surface barriers. Figure 2 contributes significant information to this fact namely that the measured magnetization is zero independent of the location of the Hall-probe. This means that there is *no flux gradient* inside the sample when the field is decreasing; again in contradiction to the picture of bulk pinning and consistent with the model of surface barriers.

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