Apparent non-scaling of pinning force data of Bi-based HTSC

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Abstract

The scaling of the normalized volume pinning forces, $F_\mathrm{p}/F_\mathrm{p,max}$, versus a reduced field $h = H_\mathrm{a}/H_\mathrm{scale}$ has proven to be a very informative tool to study the origin of the flux pinning in superconductors. Remarkably, on $(Pb,Bi)_2Sr_2$-$Ca_2Cu_3O_{10+\delta}$ (Bi-2223) and $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) data were mostly analyzed only in a narrow temperature range around 77 K). Here, we present a study of the pinning forces in various Bi-2223 samples at temperatures between 18 K and 80 K. The measurements clearly reveal that there is an apparent non-scaling of the pinning force data; instead, two different temperature regimes can be recognized, which are in direct relation to the second step in the $m(T)$ curves as reported earlier.

Key words: Bi-based HTSC, flux pinning, scaling

The scaling of the normalized volume pinning forces, $F_\mathrm{p}/F_\mathrm{p,max}$, versus a reduced field $h = H_\mathrm{a}/H_\mathrm{scale}$ has proven to be a very informative tool to study the origin of the flux pinning in superconductors [1–4]. In the case of the high-T_c superconductors, the appropriate scaling field is not the upper critical field H_c2, but instead the irreversibility field, H_irr, which denotes the upper limit of strong flux pinning. Such a pinning analysis was performed on a variety of high-T_c superconductors in literature [3,5,6] but on $(Pb,Bi)_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi-2223) and $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) data were mostly analyzed only in a narrow temperature range (typically around 77 K).

In this contribution, we present a study of the pinning forces in Bi-2223 (intact tapes, extracted individual filaments and bulk samples) at temperatures between 18 K and 80 K. The measurements clearly reveal that there is an apparent non-scaling of the pinning force data; instead, two different temperature regimes can be recognized, which are in direct relation to the second step in the $m(T)$ curves as reported earlier [7].

Details of the sample preparation are given elsewhere; the Bi-2223 tapes were prepared by the standard powder-in-tube method as mono- and multifilaments with up to 55 filaments. Individual filaments were extracted from the tapes by means of an etching procedure. Bulk samples of Bi-2223 were prepared using a melt-quenching technique. A total of 20 different samples was investigated in order to obtain a clear trend. Measurements of $m(T)$ were performed in various magnetometers (SQUID, VSM) allowing to perform measurements with different sweep rates of the external magnetic field. For the scaling of F_p in Bi-2223, there is an useful relation, as the law $H_\mathrm{irr}(T) \sim (1 - T/T_c)^3$ holds [8] over a wide temperature range for the tapes and bulk samples as observed by various authors. Therefore, there is no free parameter to improve the scaling behaviour, and furthermore, H_irr can be predicted reasonably well for cases where the available magnetic field is too small for a direct determination of H_irr. H_irr was determined using a criterion of 10^4 A/cm^2. The linear behaviour in the temperature range 20 – 77 K was found to hold well for all samples investigated here.

Fig. 1 (a) presents the scaling of the pinning forces for one selected sample. In the temperature range around 77 K, the scaling is reasonably good, and a peak position, $h_0 \approx 0.18$ is obtained. In strong contrast to this,

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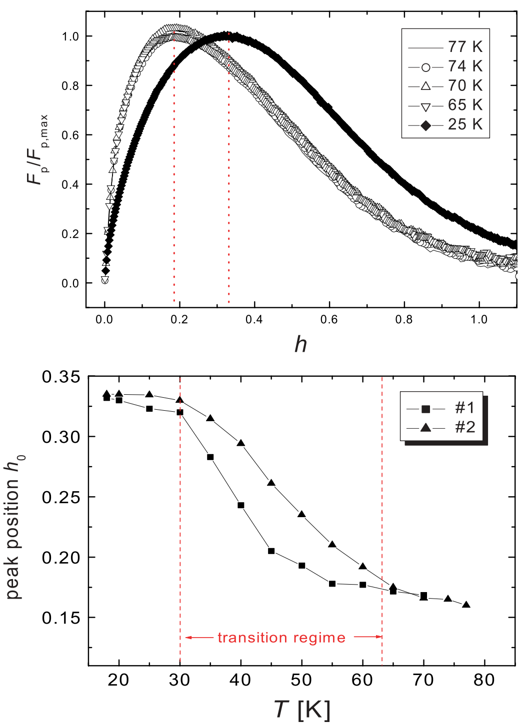

Fig. 1. (a): Plots of the scaled volume pinning forces, $F_\mathrm{p}/F_{\mathrm{p,max}}$, versus the reduced field, $h = H_a/H_{\mathrm{irr}}$, for extracted filaments from a Bi-2223 tape. (b): The peak position of the pinning foce scaling, h_0, as a function of temperature for two selected samples; sample "1" is an extracted filament from a multifilamentary tape, "2" is a monofilamentary tape. The lines are guidelines to the eye.

the scaling of the data at 15, 20 and 25 K is also reasonably good, but h_0 is shifted to ≈ 0.32. Data lower than 18 K do not reach h_0 anymore within the available field range. The inset presents scaled data measured at two different sweep rates of the external magnetic field; clearly indicating that h_0 does *not* depend on the sweep rate. Therefore, h_0 is an important parameter to discuss the underlying microscopic pinning mechanism. The other samples studied exhibited essentially the same behaviour. Fig. 1 (b) shows the determination of h_0 as function of temperature for two samples "1" and "2". Sample "1" is an extracted filament of a multifilamentary tape with 55 filaments, sample "2" is a monofilamentary tape. Both samples exhibit an identical beaviour at high and low temperatures, only the intermediate part is different. This is a clear indication of the microscopic differences in the pinning landscape of the two samples; it is remarkable that the monofilament tape "2" shows the best pinning properties in the intermediate temperature range from all samples studied here. The peak position $h_0 = 0.33$ implies according to Ref. [1] a flux pinning at small ($v \sim \xi^3$) normal-conducting or insulating particles. However, $h_0 \approx 0.18$ indicates a dominant flux pinning of a two-dimensional type like e.g. grain boundaries or dislocations. If there is an effect of some added non-superconducting particles [9] to be observed, then it must be in the intermediate temperature range between 30 and 70 K, i.e. the peak position at $h_0 = 0.33$ should be maintained at higher temperatures.

This drastic change of the dominating pinning mechanism in the Bi-2223 samples is also directly linked to our earlier observation that there is a second step in the $m(T)$ curves at high applied magnetic fields. This step is seen in Bi-2212 single crystals [7] as well as in Bi-2212 bulks and Bi-2223 tapes [10]. This step indicates the breakdown of the Josephson-coupling between superconducting clusters, due to the presence of Bi-2201 with a T_c of ≈ 20 K. This implies that even the best single crystals of Bi-2212 are spatially inhomogeneous. Such intergrowths were observed by TEM in all Bi-based systems. Therefore, the goal for the further development of the Bi-2223 superconductors must be to maintain the pinning force scaling at $h_0 = 0.33$.

To conclude, we have found that the pinning force scaling in Bi-2223 works well in two narrow temperature regimes around 70 K and below 20 K. In the intermediate temperature range, the peak position shifts towards 0.18 on increasing T, manifesting a change in the basic pinning mechanism.

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