ON THE PENETRATION AND TRAPPING OF THE MAGNETIC FLUX IN Bi-2223 SUPERCONDUCTORS

SOBRE LA PENETRACIÓN Y ATRAPAMIENTO DEL FLUJO MAGNÉTICO EN SUPERCONDUCTORES DE Bi-2223

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Characterizing different coexisting superconducting levels in granular samples continues to be an important experimental task in fundamental and applied studies of superconductivity. The measurement of lower critical fields is one of the main aspects of this characterization. Some authors have reported measurements of lower critical fields at different temperature in Bi-2223/Ag tapes. They found that the intergranular lower critical field in perpendicular direction to the *c* axis is approximately 8 Oe at 77 K [1]. On the other hand, measurements in Bi-2223 powder samples reveal values of the lower critical field between 80 and 100 Oe at the same temperature [2,3]. In this case, the estimation of the lower critical field was performed following a graphic method. For this purpose, the deviation of the magnetization curve as a function of the applied magnetic field, $M(H_a)$, from its quasi-linear behavior was considered. Fittings of this curve by using the Bean model [4] have also been reported with similar results [3].

In this paper we compare the results obtained from the normalized $dM(H_a)/dH_a$ curve of a powder sample with those related to the transport flux-trapping curve [5] measured in a pellet sample of the same material compacted at low pressure (< 300 MPa) before the last sintering. A close relationship between both processes, penetration and trapping of the magnetic flux, has been observed even when these occur in powder and pellet samples, respectively.

Samples of Bi-2223 were elaborated following the preparation route described elsewhere [3]. The starting composition was $Bi_{1.35}Pb_{0.35}Sr_2Ca_{2.5}Cu_{3.5}O_y$ and the final compacting pressure 298 MPa. From the same pellet two types of samples were extracted: powder and slab for the measurements of $M(H_a)$ and flux- trapping curves, respectively. A piece of pellet was manually milled during 15 minutes to obtain the powder sample. X-ray diffraction patterns revealed the presence of a small percentage of the 2212 phase (<10%). The critical temperature of this phase resulted to be < 70 K. It was determined by the peak observed in the first derivative of the magnetization versus temperature curve, $M(T)$, measured in the powder sample.

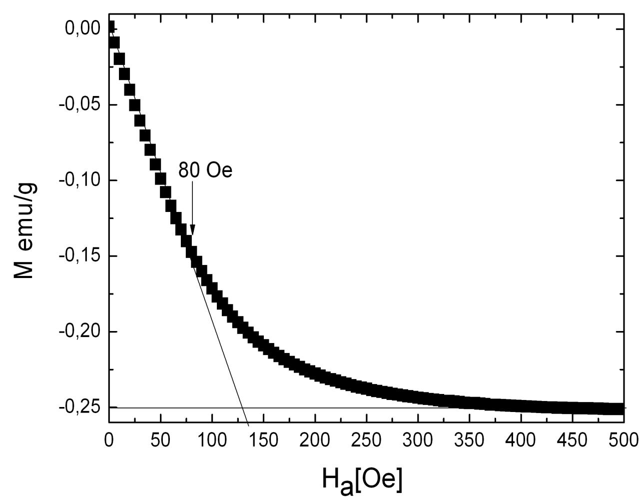

Figure 1. $M(H_a)$ curve of the powder sample. The continuous lines visualize saturation and quasi-linear regions.

Magnetization measurements under low applied magnetic fields were performed by using a commercial Quantum Design SQUID magnetometer. In this experiment the powder sample was cooled in zero applied magnetic field, from room temperature down to 77 K. After that, the applied magnetic field, H_a, was then increased from 0 to 500 Oe, in steps of 5 Oe and the magnetization was measured for each value of H_a. On the other hand, measurements of the critical current density as a function of the maximum applied magnetic field, $J_c(0,H_{am})$, were performed using the standard dc four-probe technique in a slab with typical dimensions of d = 0.5 mm (thickness), w = 2 mm (width) and l = 10 mm (length). The sample was cooled in the same conditions as described above. Afterwards, a certain value of maximum magnetic field, H_{am}, was applied to the sample for approximately 30 s, after which it was reduced to zero again, and the critical current density was determined by using the criterion of 1 μV. Finally, the sample was warmed up to temperatures higher than the superconducting critical temperature in order to erase its magnetic "memory" and then cooled down again to 77 K in zero applied magnetic field. By repeating these steps for different values of H_{am}, the flux-trapping curve, $J_c(0, H_{am})$, was built [5].

In Fig. 1 the $M(H_a)$ curve of the powder sample is shown. It reveals a quasi-linear behavior in the interval $0 < H_a < 80$ Oe apparently related to the Meissner state of the grains in the powder sample. The curve exhibits also a Bean-like behavior [4] within the range of applied magnetic field. In order to analyze in details the flux penetration process of the grains we have also plotted the normalized $dM(H_a)/dH_a$ curve. The derivative at a point is computed by taking the average of the slopes between the point and its two closest neighbors. The result is shown in Fig. 2(a).

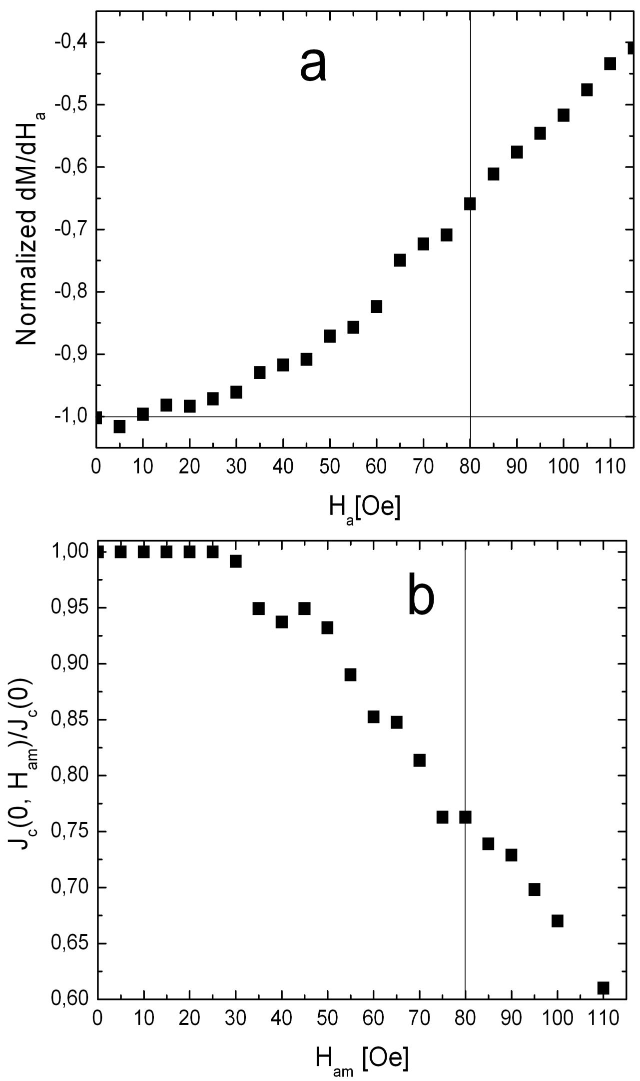

Figure 2. a) Normalized dM/dH_a as a function of applied magnetic field of the powder sample. For the interval $0 < H_a < 90$ Oe the experimental error does not exceed 5%. b) Flux-trapping curve of the pellet sample. The continuous horizontal and vertical lines visualize the value of normalized dM/dH_a at B_a=0 and the value of the applied magnetic field of 80 Oe, respectively.

Notice that for $30 < H_a < 80$ Oe the dependence shows several steps, but its increase is more uniform for $H_a > 80$ Oe. A similar behavior is observed in the flux-trapping curve, which is displayed in Fig. 2(b). These results show that the penetration and trapping flux processes in powder and pellet samples respectively are closely related. Thus, the main cause of the $J_c(0, H_{am})$ dependence must be linked to the intragranular trapped flux, contrary to the concept of cluster described elsewhere [2, 3]. In addition to that, the experimental results of Fig. 2 can be summarized as follows:

1. For $H_a < 30$ Oe the magnetic flux effects in both curves of Fig. 2, can be disregarded.

2. For $30 < H_a < 80$ Oe two processes may occur: a) the grains are penetrated in defects located in the boundaries between two crystals of the same grain [6], b) the existence of different demagnetization factors and orientation angles of the grains in the magnetic field is reflected in the normalized $dM(H_a)/dH_a$ curve as a distribution of the lower critical fields of the sample.

3. For $H_a > 80$ Oe most of the grains start to be penetrated inside the crystals.

The discontinuing growth of the normalized $dM(H_a)/dH_a$ curve in the second interval may suggest the penetration of the magnetic flux into planar defects of the grains. For certain values of applied magnetic field these defects are penetrated depending on their misorientation angles [6] and their orientations respect to the intergranular magnetic field. Such a penetration provokes a jump in normalized $dM(H_a)/dH_a$ dependence. It happens because in the planar defects the magnetic flux penetration is confined into the defect area of order $2\lambda L$. Here, L and λ represent the length of the planar defect and the London penetration depth, respectively. For higher values of H_a, the magnetic flux penetrates into the crystals, the $M(H_a)$ curve follows the Bean model and the increase of its slope is continuous as can be observed in both curves for $H_a > 80$ Oe.

This hypothesis might be experimentally verified observing the microstructure of the powder particles or studying the $M(H_a)$ dependence at different temperatures. A detailed study of the grain size distribution in both, powder and pellet samples, could also contribute to the understanding of this phenomenon. Since the demagnetization factors of the grains are involved in the process, their estimation is also important to determine which one of the two elements considered in the second aspect of our process description has more influence in the behavior of the samples.

To summarize, we suggest the existence of a significant link between the magnetic flux penetration in a powder sample of Bi-2223 and the transport flux-trapping curve measured in a pellet of the same material. This result reveals that the magnetic flux trapping in ceramic samples compacted at low pressures is essentially an intragranular phenomenon. Although the tentative explanation on the penetration and trapping of the magnetic flux is based on the experimental results obtained in two samples of the same material, we have repeated these experiments for several Bi-2223 samples and the results have been similar for pellets compacted at low pressure. To determine the true nature of the trapped magnetic flux in the range of applied magnetic field of $30 < H_a < 80$ *Oe* and also evaluate the anisotropic magnetic behavior of the Bi-2223 grains, more experiments are necessary.

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