Frequency Dependence of the Depinning and Irreversibility Lines in BSCCO

Hüseyin Sözeri [a,1], Lev Dorosinskii [a],

[a] *TUBITAK-UME, National Metrology Institute, P.O. Box 54, 41470 Gebze-Kocaeli, Turkey*

Abstract

Penetration of AC magnetic field in $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals was studied using the magnetooptic technique. It was found that the apparent depinning line shifts towards higher (H, T) values with increasing field frequency. At higher frequencies irreversibility in magnetization is controlled by pinning but not by the geometrical or surface barrier. Comparison with the melting line has shown that the depinning line lies completely in the vortex liquid region. Moreover, at least in low DC fields, the vortex liquid does not become unpinned up to the critical temperature of superconductor. Therefore, contrary to general understanding, we show that pinning is the main reason of irreversibility in magnetization at higher frequencies. It was also shown that the reason why this pinning is not observed at lower frequencies (i.e., using slow measurement technique) is the giant flux creep in BSCCO.

Key words: Depinning and irreversibility lines; magneto-optics; AC susceptibility measurements; geometrical barrier

1. Introduction

There are three main sources of irreversibility in magnetization of superconductors: pinning, Bean-Livingston surface barrier and geometrical barrier. In global measurements it is difficult to separate these effects. However, they can be separated by polishing samples into a prism shape thus eliminating the effect of the geometrical barrier [1]. In this way, it was shown in [1]that the geometrical barrier is the main source of irreversibility in $Bi_2Sr_2CaCu_2O_\delta$ at high temperatures. It was also reported in [1] that depinning line crosses the flux-line-lattice (FLL) melting line, so that in low fields the vortex liquid is unpinned everywhere down to the melting temperature, and even there is a region of unpinned vortex solid in a region of the H-T phase diagram just below melting line. Thus, [1] corrected the previously accepted notion that the depinning line coincides with the FLL melting line. However, most of the works on irreversible properties of BSCCO, were done using slow measurement techniques. This may lead to wrong conclusions because of the giant flux creep, which is especially strong in BSCCO samples at elevated temperatures. In order to study the flux pinning, the experimental time window should be smaller than the characteristic time of magnetization relaxation. This achieved by studying the penetration of AC field, then the effective time window will be equal to the inverse frequency of the field. In the present work we measured profiles of the amplitude of AC field in BSCCO single crystals using the magnetooptic (MO) technique. From the slope of the profiles we could estimate the critical current in the sample, and from the amplitude jump at the sample edge the magnitude of the surface or geometrical barrier could be estimated. Thus, the depinning line and the line, where the barrier vanishes, were plotted on the H-T phase diagram.

[1] Corresponding author. Present addressTUBITAK-UME, National Metrology Institute, P.O. Box 54, 41470 Gebze-Kocaeli, Turkey :E-mail:hbocuk@ume.tubitak.gov.tr

2. Results and Discussion

High-quality BSCCO crystals with $T_c \approx 91$ - 92 K and grown by the self-flux method [2] were used. Observations and measurements of the field penetration in superconductors were done using yttrium-iron garnet indicator films with in-plane anisotropy [3]. The main advantage of this technique is its locality with high spatial resolution ≈ 1 μm. This allows one to separate different factors contributing to the irreversibility of a superconductor. Vortex pinning, for example, results in a slope of Bean-like profiles of local field (or field amplitude in the case of AC field). Surface barrier manifests itself in a jump of the field (or amplitude) value at the sample edge. Another advantage of MO method is its fast dynamic response (≈ 10 MHz). An example profile of the AC field amplitude in a BSCCO sample is shown in Fig. 1. The AC field frequency is 500 Hz and the amplitude is 5 Oe. Two contributions to the flux screening can be easily distinguished.

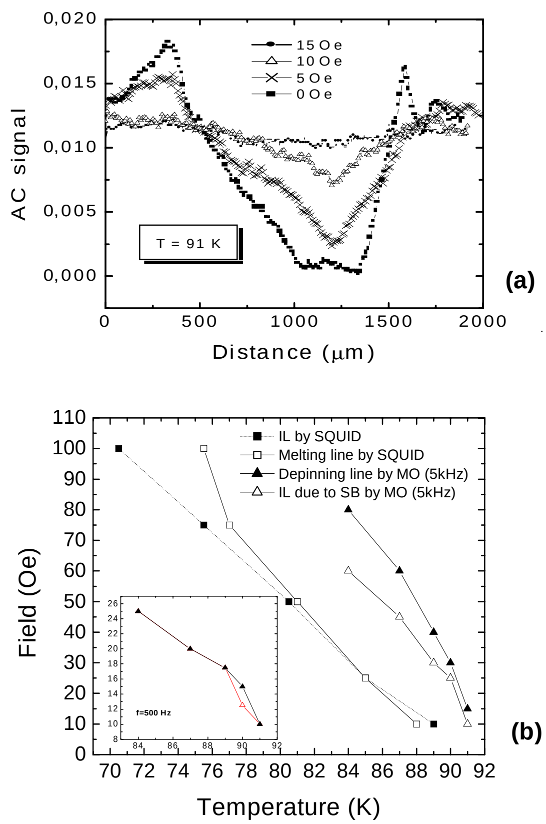

Fig. 1. Profiles of AC field amplitude across a BSCCO single crystal at f=5 kHz and at different values of external DC field. T_c= 92.3 K. Fig1b: H-T Phase diagram of BSCCO crystal. Inset: Open triangles- Irreversibility line due to surface barrier at 500 Hz, solid triangles - the depinning line at 500 Hz

With increasing the external DC field both the surface jump and the profile slope decrease gradually. As one can see from Fig. 1, surface jump vanish at DC field of 10 Oe while there is finite profile slope which is a sign of pinning. This contradicts to the results of [1], where it was concluded that above the depinning line there is still irreversibility caused by the geometrical barrier. The principal difference between our experiment and [1] is the experimental time window. As the time window increases, the apparent critical current measured in the experiment decreases because of the fast relaxation caused by creep. Therefore, for a slow measurement the sensitivity may simply become insufficient to detect the bulk irreversibility in the sample. This can be the reason why we detect bulk irreversibility in the area of the H-T diagram, which appears reversible in other measurements. We also measured AC profiles at various temperatures and for various values of the AC field frequency which were shown in Fig.2. It was observed that, at 5 kHz, irreversibility in magnetization is controlled by the bulk pinning but not by the geometrical barrier. However, both lines (i.e., depinning and irreversibility due to geometrical barrier) coincide at 500 Hz. Thus, our results have shown that the apparent depinning line is strongly frequency dependent. We have measured the irreversibility and melting lines using a Quantum Design MPMS-XL SQUID magnetometer. The H-T phase diagram thus built is shown in Fig. 2. At higher frequencies the depinning line lies completely in the vortex liquid region (notice that the irreversibility line measured in SQUID almost coincides with the melting line, like it is generally observed by global measurement techniques). Also, from Fig. 2 one can see that at lower frequencies this line coincides with the line where the geometrical barrier vanishes. But at higher frequencies the depinning line runs above all other lines on the phase diagram. Contrary to the common point of view, the depinning line lies entirely in the vortex liquid part of the phase diagram. This means that vortex liquid is pinned everywhere up to T_c.

In conclusion, position of the depinning line in BSCCO has to be corrected to take into account the flux creep effect. The real depinning line, which can be measured only at high frequencies, lies completely above the FLL melting line in the vortex liquid region. That is, at least in zero field, there is no region of unpinned vortex liquid, i.e. vortices are pinned even in the liquid phase up to the critical temperature.

References

[1] D. Majer et. al., Phys. Rev. Lett. **75**, (1995) 1166.

[2] S. Takekawa et al., J. Cryst. Growth **92**, (1988) 687.

[3] L.A.Dorosinskii et.al., Physica C **203**, (1992) 149.