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Formation of the central peak in magnetization loops of type-II superconductors

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Based on magneto-optical observations of flux distributions on high-T_c single crystals and thin films around $B = 0$ T at various temperatures, possible origins for the formation of the central peak commonly found in magnetization loops of hard type-II superconductors are discussed. The appearence of the central peak is closely related to the the full-penetration field, H^*. It is shown that a reduction of the sample thickness influences the value of H^*, thus leading to a narrower field range for the rearrangement of the vortices when passing $B = 0$ T. The role of pinning in the formation of the central peak and the role of the central peak in the formation of the fishtail effect is also discussed.

Recently, the formation of the central peak found in magnetization loops of hard type-II superconductors is vividly discussed in literature [1]. The position of the central peak, H_{p0}, in a magnetization loop (MHL) is mostly located at negative fields [2] in decreasing external field, and at positive fields in increasing external field. H_{p0} shifts with increasing temperature towards $\mu_0 H_a = 0$ T. In Ref. [1], it was shown that the shape of the central peak depends on sample geometry. Samples with large thickness should have a peak close to 0 T, and thin samples (with a large self field) a pronounced peak on the negative side. The experiments, however, demonstrated that the peak position H_{p0} for thick samples is shifted towards negative fields, whereas thin samples have the peak close to 0 T. All features of the central peak observed can be explained within the framework of the critical state models [3], if the critical current density depends explicitly on the internal field, B_i. For interpretation of the MHLs it is therefore necessary to consider the *local* field distribution in the sample during the field sweep through zero field.

Magneto-optical observations of flux distributions [4] have shown that remanent states of *thin* superconductors in perpendicular geometry consist of pinned flux lines in the sample centre, and of a thin rim of flux lines of opposite polarity along the edges (fig. 1). In between these two zones, the flux density is vastly reduced and an annihilation zone with $B_i = 0$ T can be detected [5]. The appearance of negative flux lines *during* reduction of the external field to 0 T is a pure demagnetization effect. Large self fields will generate flux lines of opposite sign already at large remaining fields when sweeping the applied field towards 0 T. With increasing sample thickness, this effect disappears. Additionally, high pinning forces are required to stabilize such a field pattern. After

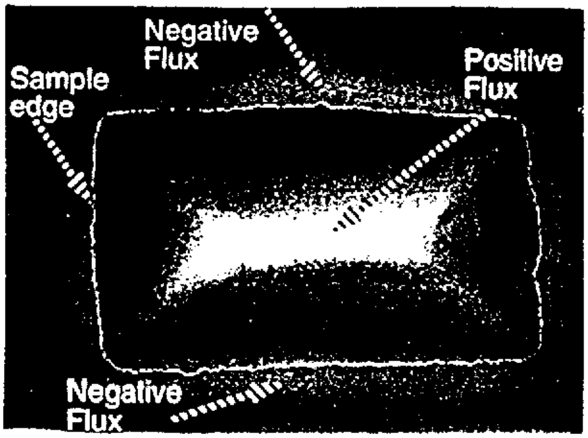

Figure 1: Magneto-optical image of a remanent state in a $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal, obtained after applying 1 T (see Ref.[4]. Both polarities of vortices appear as bright domains. B_i is vastly reduced in a large area of the crystal.

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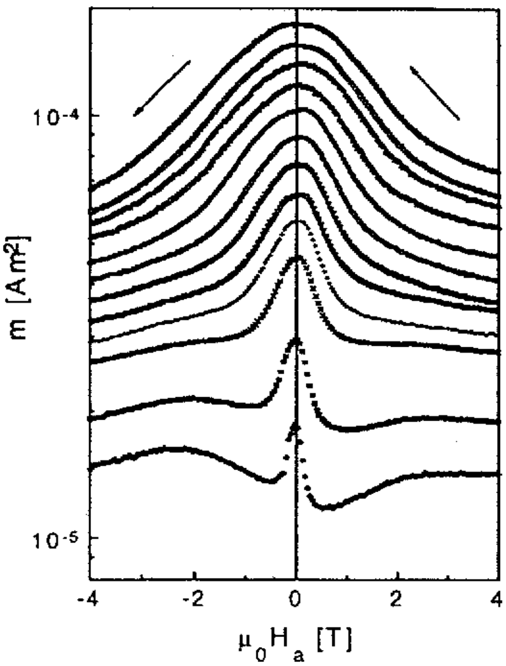

Figure 2: Temperature dependence of the central peak in a MHL, measured on a $YBa_2Cu_3O_{7-\delta}$ single crystal. Temperatures are T = 4.2, 5.5, 7, 8.5, 10, 12.5, 15, 17.5, 20, 25, 30, 35, 40, 50, 60, 70 and 77 K (from top to bottom).

reversal of the applied field, H_a, more flux lines of opposite polarity will enter the sample, thus causing a compression of the remaining pinned vortices. In this way, the total internal field will have a minimum which correponds to the central peak of a MHL. This remagnetization process takes place faster for thin samples due to the penetration of large self fields at larger H_a. Therefore, at a given temperature the central peak of thin samples will occur close to $\mu_0 H_a =$ 0 T, and shift towards negative values with increasing sample thickness (see figs. 2 and 3). In fig. 2, MHLs measured on a $YBa_2Cu_3O_{7-\delta}$ single crystal with a thickness d = 80 μm are presented for various temperatures. The height and the width of the central peak are exponentially decreasing with increasing T. The peak position at low temperatures is located at very small negative H_a. In contrast to this, a much thicker sample shows $H_{p0} = -0.3$ T at 10 K, and a large shift of the peak position towards 0 T with increasing temperature. The width of the central peak is in both cases similar to the value of the full penetration field, H^*. Calculations for thin (thickness $d \ll \lambda_L$) superconductors in perpendicular geometry [6], but allowing for a field dependence of the currents of the form $j_c(H) = j_0/(H_0 + |H|)^n$ demonstrate clearly that a central peak is generated in the MHL. Considering only creep rate effects is not sufficient to produce a peak in the MHL [7]. It is important to point out that the width and height of the central peak are determined by the critical current at a minimum of the local fields B_i.

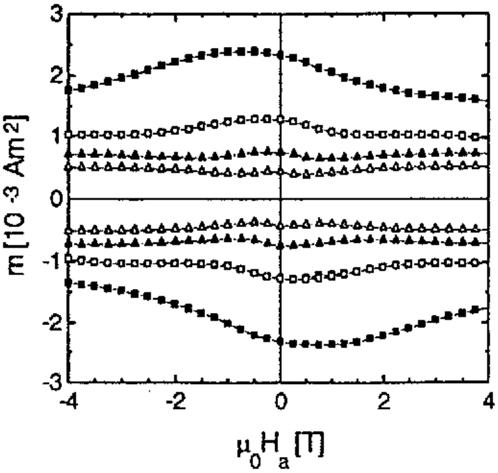

Figure 3: Temperature dependence of the central peak, measured on a $YBa_2Cu_3O_{7-\delta}$ single crystal with a thickness d = 500 μm.

Recently, it was shown [8] that the central peak of a MHL plays also an important role in the formation of the fishtail effect. The shrinking of the central peak, which is dominant in the MHL at low temperature, gives raise to the observation of other peaks in the MHL.

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