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Dendritic and homogeneous regimes of flux penetration into YBCO films

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Abstract

Dendritic flux patterns in superconducting YBCO films are studied on a nanosecond time-scale. It is found that dendrites only develop for certain values of the external field and temperature.

Keywords: $YBa_2Cu_3O_7$; Flux propagation; Flux front instability; Flux dendrites

It is well-known that superconductors carrying high critical current densities tend to develop instabilities in their magnetic flux patterns which manifest themselves as macroscopic flux jumps [1]. A combination of magneto-optics and pulsed laser irradiation can be used to investigate the flux propagation with high spatial and temporal resolution in the micrometer and nanosecond range. Using this technique it was found that for thin superconducting films the flux jump instability can give rise to dendritic magnetic flux avalanches propagating with tip velocities as high as 50 km/s [2,3].

In this work we report on a systematic magneto-optic study of various types of dynamic flux patterns in thin films. Depending on temperature T and magnetic field B we observe two completely different regimes of flux penetration: either in the form of a smooth flux front, or as a dendritic flux avalanche.

In our experiments we used YBCO films with thicknesses 100, 200, 330, and 690 nm, grown on a $SrTiO_3$ substrate by thermal reactive co-evaporation (the c-axis is perpendicular to the substrate) [3]. The superconducting transition temperatures are between 86 and 90 K and critical current densities are between 2×10^6 and 4×10^6 A/m^2 at 77 K.

To visualize the magnetic c-component of the field a Bi-doped yttrium iron garnet (YIG) film on gadolinium gallium garnet with in-plane anisotropy is used as magneto-optic layer [4], which is mounted on top of the superconductor [5]. In order to distinguish between positive and negative direction of the field the polarizer and analyzer in our polarization microscope were not crossed completely and fields between −50 and +180 mT could be observed. The YIG film allows to obtain a time resolution of about 200 ps (see [6]).

Each experiment is done as follows. The sample is zero field cooled below T_c. After reaching a stable temperature a magnetic field B_a perpendicular to the sample surface is applied, and then the laser pulse is triggered. The thin film geometry enhances the field at the edges and the magnetic flux penetrates into the superconducting film from there. The first part of the laser pulse is now used to change the local magnetic field. This is done by focusing the laser pulse with a cylindrical lens onto the film from the substrate side of the sample. A stripe of 50 μm width is heated above T_c, dividing the quadratic sample into two regions of equal size. Magnetic flux fills the non-superconducting stripe and the

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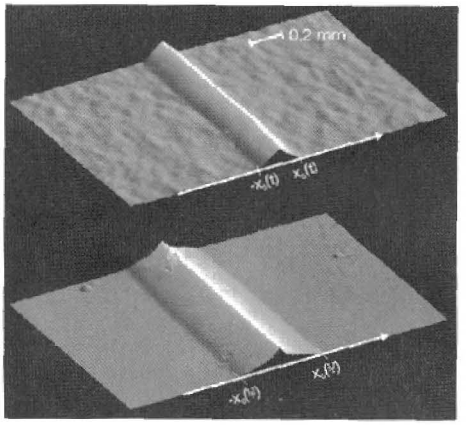

Fig. 1. Magnetic flux profiles after a time delay of 67.8 ns and of the final state (T = 30 K, B_a = 15.2 mT).

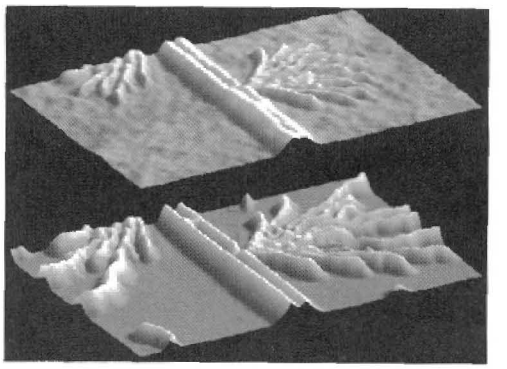

Fig. 3. 3D magneto-optical images of the flux density distribution after 50 ns and of the final state at 10 K with an applied field of 30 mT. The size of the area shown is 2.28 × 1.52 mm^2 and the maximal magnetic field density is 95 mT.

flux density is increased up to a constant value. This method allows to apply magnetic field very rapidly (10^8 T/s). Now the magnetic flux starts to penetrate perpendicular to the stripe into the superconductor. Fig. 1 shows the flux profile at 30 K after a time delay of 67.8 ns (top) and the final state (bottom).

We found that this homogeneous flux penetration is restricted to a region in the T/T_c versus B_a/J_c diagram as shown in Fig. 2. Above a certain magnetic field which depends on temperature the dendrite-type flux penetration develops. A snapshot of the flux distribution in this dendritic regime is depicted in Fig. 3. Moreover, above a certain "critical" temperature no dendrites are formed even if one goes to high magnetic fields. This observation is in good agreement with other experiments where instead of a local heating with a laser an external perpendicular magnetic field was swept to nucleate the dendrites [7,8]. The speed of the dendrite tips is in the beginning on the order of $\approx 10^5$ m/s and decreases thereafter to $\approx 10^4$ m/s.

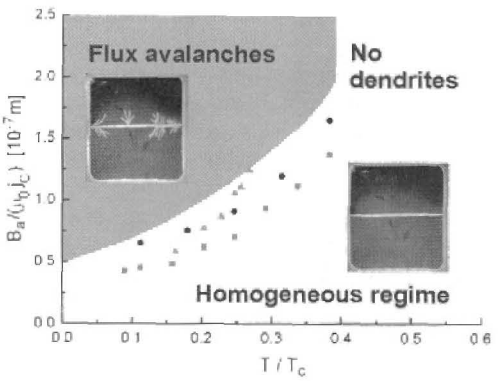

Fig. 2. Shown here is a diagram which separates the two distinct regions of flux dynamics. The squares and circles are values for YBCO samples with thickness 500 and 300 nm respectively. The triangles represent data for MgB_2 from Johansen et al. [8] (taken from the graphs). For j_c the temperature dependent values were used. j_c varies roughly by a factor of two in the regime where dendrites are observed.

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