

Magnetic instability in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films

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Abstract

Using a magneto-optic technique we have investigated the magnetic flux propagation into and out of superconducting thin $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films. After field cooling below T_c , the external magnetic field B_{ext} perpendicular to the film is changed which gives rise to shielding currents in the sample. The current distribution is disturbed momentarily by heating with a focused laser pulse near the sample edge. This triggers a magnetic instability, in which a magnetic flux avalanche starts to propagate. © 2000 Elsevier Science B.V. All rights reserved.

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Earlier experiments studied the magnetic flux pattern triggered by a magnetic instability into the Meissner state of a superconducting film [1]. We extended our investigation to study this flux pattern in different external magnetic fields. For this purpose we have used epitaxial *c*-axis oriented $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films deposited by pulsed-laser deposition on MgO with CeO_2 buffer layer [2]. The films had a thickness of 300 nm and a critical current density of j_c (77 K) = 1.3×10^6 A/cm². The experiments were carried out in a small continuous flow cryostat, which had two optical windows with a diameter of 25 mm. For detecting the magnetic field penetrating the superconductor we used a doped ferrimagnetic iron garnet layer grown onto gadolinium–gallium–garnet substrate by liquid-phase epitaxy with an additional aluminum layer [3]. This magneto-optical layer was placed just above the YBCO film. By using a home-built polarization microscope the local Faraday rotation of the linearly polarized light caused by the local magnetic field H_z in the magneto-optical layer was made visible with nearly crossed polarizer and analyzer as an intensity contrast and imaged with a 12-bit slow-scan CCD camera.

The YBCO film was zero-field-cooled down to 10 K. After reaching a stable temperature an external magnetic field B_{ext} perpendicular to the sample surface was ap-

plied. Magnetic flux penetrated into the superconducting film first from the edges and from defects which were in contact with the edges until a local equilibrium of the flux distribution due to the pinning force and the magnetic force was reached. This induces a current distribution in the superconducting film.

In order to disturb the equilibrium of this current distribution and to initiate a magnetic instability, a pulse of a frequency doubled Nd:YAG laser ($\lambda = 532$ nm, half-width $\tau = 7$ ns) was focused onto the film from the substrate side. The energy density in the laser spot (diameter 30 μm) was up to 30 mJ/cm². The sample temperature in the focus could not be measured directly, but we estimate that the temperature is well above the critical temperature.

If the perturbation is sufficiently strong, e.g. for energy densities of the laser pulse above 7 mJ/cm², this triggers a magnetic instability, in which a magnetic flux avalanche penetrates into the film. Fig. 1 shows a magneto-optical image of the resulting flux distribution after the laser pulse. Bright regions correspond to high magnetic flux density. In contrast to the more or less homogeneous flux fronts which propagate towards the sample center when the external field is gradually increased, this instability develops in the form of a dendritic pattern as already observed earlier [1]. The total area covered by the flux branches is found to increase linearly with the external magnetic field B_{ext} above a threshold ($B_{\text{ext}} = 7.5$ mT), whereas the width of the branches (0.1 mm) remains constant within our accuracy.

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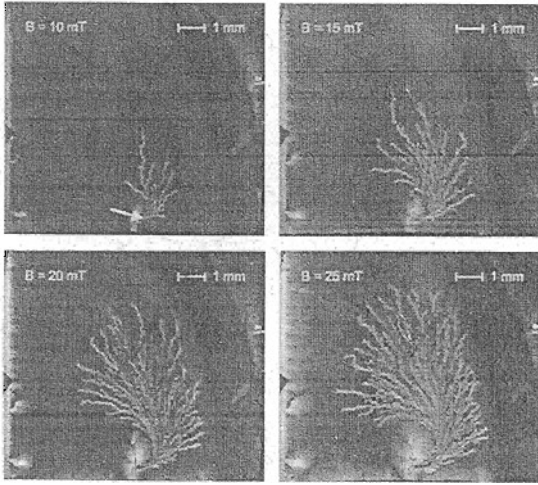


Fig. 1. Magneto-optical images of a YBCO film zero field cooled down to 10 K. The flux distribution after a $10 \text{ mJ}/\text{cm}^2$ laser pulse focused to a $30 \mu\text{m}$ spot close to the bottom edge of the image (arrow). The area of the pattern increases linearly with the before applied external magnetic field above a threshold ($B_{\text{ext}} = 7.5 \text{ mT}$).

In order to demonstrate that it is indeed the macroscopic shielding current – induced in the superconductor by a change in the external field – whose perturbation by the laser pulse leads to the observed instability we have also studied the effect of *decreasing* the external magnetic field. An example is shown in Fig. 2, where the superconductor was field cooled ($B_{\text{ext}} = 45 \text{ mT}$) down to 10 K, then the field was reduced to zero. Consequently, the flux leaves the sample at the edges but in the center remnant magnetization due to pinning is still observed, which is again connected with macroscopic currents. As seen in Fig. 2, the perturbation with the laser pulse now leads to a flux avalanche *leaving* the sample and hence to branches with a *reduced* flux density.

In summary, we have studied magnetic instabilities induced by a laser pulse in superconducting YBCO films

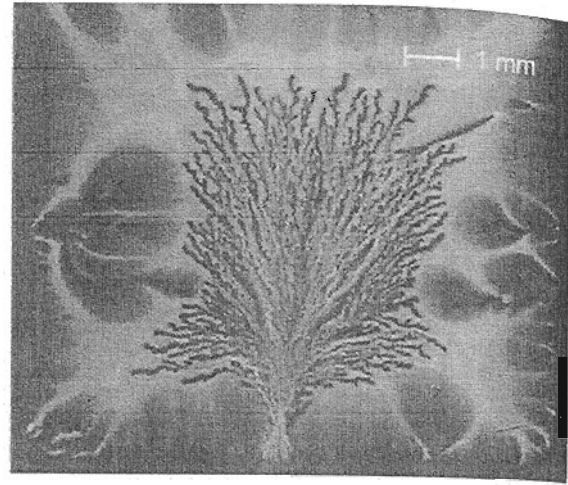


Fig. 2. MO image taken under similar conditions as in Fig. 1. Instead of increasing B_{ext} , the external field (here 45 mT) was switched off ($\Delta B_{\text{ext}} < 0$) before applying the laser pulse.

exposed to an external perpendicular magnetic field. The resulting flux distribution has a dendritic structure with a different flux density and their total area depends on the field. Inverse patterns are also observed.

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