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In-Plane Rotational Magnetic Losses in a Laser Deposited $YBa_2Cu_3O_{7-x}$ Film

By

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One of the most remarkable features of the high-T_c superconducting materials is their large anisotropy of the crystal lattice and, consequently, of the superconducting properties, too. It was shown recently that torque magnetometry is a useful method for investigations of anisotropic magnetic properties of high-T_c superconducting single crystals /1, 2/. Moreover, the method is also well suited for investigations of superconducting films as shall be demonstrated for the special case that the external field is slowly rotating in the film plane. In this way we tried to check the result of Roas et al. /3/ who found in-plane isotropy of the critical current density j_c in contrast to the large j_c anisotropy perpendicular to the film plane.

$YBa_2Cu_3O_{7-x}$ films on (100) $SrTiO_3$ substrates were prepared by laser ablation using an excimer laser. The deposition system is described elsewhere /4/. The films grow highly textured with the c-axes perpendicular to the mirror-like surface. For the X-ray rocking curve of the (005) film reflex we measured a width at half maximum of 0.75^o. For torque measurements the film was carefully oriented with its plane, i.e. the CuO planes, parallel to the field-rotation plane (angle deviation $< 0.15^o$). Measurements were carried out in external fields of 16 kA/m < H < 400 kA/m at T = 79 K.

Typical torque curves are shown in Fig. 1. The measured torque is nearly independent of the angle ϕ. The small remaining anisotropy in Fig. 1 can quantitatively be explained by the residual misorientation. Remarkably, the sharp torque extrema due to vortex pinning at twin boundaries reported previously for single crystals /5/ are missing for the present film. The losses derived by subtracting the forward and backward branches of the torque curves /2/ are nearly isotropic. Since, according to Fruchter et al. /6/, the critical current density is proportional to the losses the result of Roas et al. is confirmed by our present experiments.

In order to estimate the pinning force acting on the vortices, we assumed a homogeneous distribution of defects and straight vortex lines. Then, the mean

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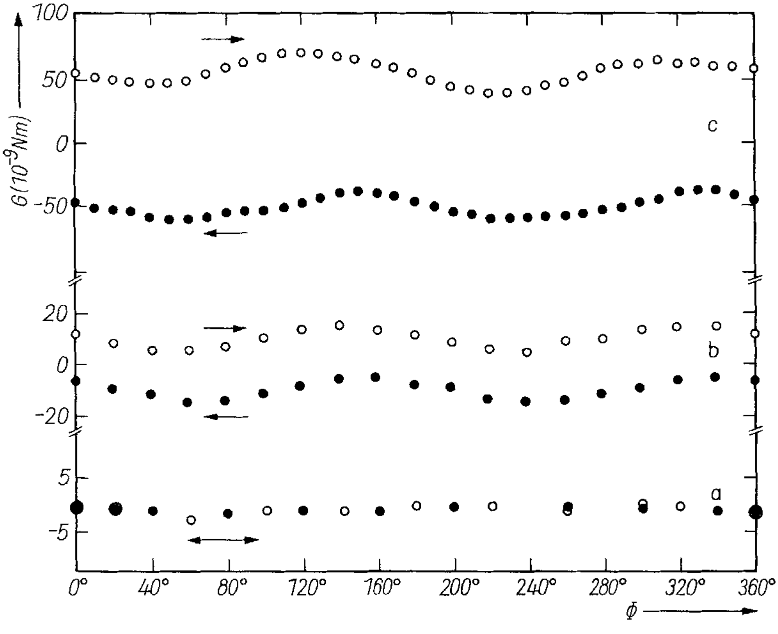

Fig. 1. Torque G as a function of the angle ϕ between external field H and an arbitrary direction in the film plane. The symbols (o) and (●) mean forward ($\vec{G}$) and backward ($\overleftarrow{G}$) rotation of H, respectively. Field strength is 16 (a), 96 (b), and 400 kA/m (c)

pinning force per unit length is, according to a formula given by Fuhrmans and Heiden /7/,

$$f_p = 3\pi\Delta G\Phi_o/(8BVR) \ , \qquad (1)$$

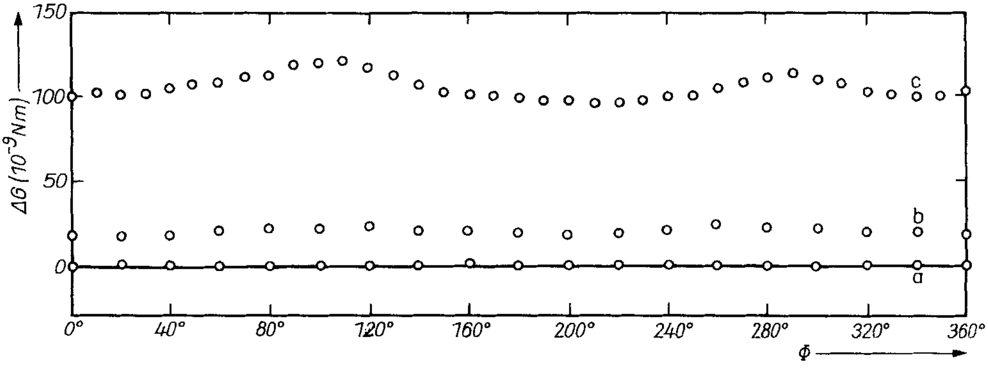

Fig. 2. Losses $\Delta G(\phi) = \vec{G}(\phi) - \overleftarrow{G}(\phi)$ derived from Fig. 1 for the field strength 16 (a), 96 (b), and 400 kA/m (c)

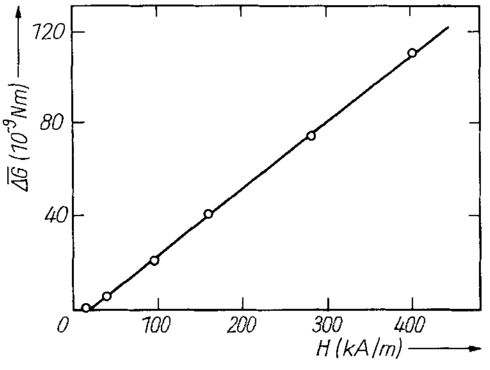

Fig. 3. Mean value of $\Delta G(\phi)$ averaged over $\phi = 0$ to 360° as a function of the external field H

where B, V, and R mean the induction, the volume, and the radius of the film, respectively. Φ_0 is the flux quantum. ΔG can be taken from Fig. 3. For R = 0.5 cm and a film thickness of 600 nm we obtain a pinning force f_p montonously increasing from 6×10^{-10} (B = 0.05 T) to 1.5×10^{-9} N/m (B = 0.5 T).

As shown in Fig. 3 the losses appear beyond a certain threshold field H_c and increase linearly with the field. In recent investigations /2/ of single crystals we identified H_c with the lower critical field H_{c1}. In this way we obtain for the present film H_{c1} = 20 kA/m which is one order of magnitude higher than the single-crystal value for the ab plane. The difference is probably caused by the small film thickness which is at 79 K in the order of the London penetration depth or less.

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