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PB-Th-93 (LT2173)

Determination of Current Profiles in Flat Superconductors Using Hall Probe Array

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Abstract: The current profiles in YBa$_2$Cu$_3$O$_7$ films when the magnetic field is perpendicular to the surfaces are studied. The current profiles are calculated from the field profiles, which are measured using a micro Hall-probe array. In this work we utilize a model, which has a spatial distribution of local current density. According to the model, the specimen is divided in two regions. One region, in which flux penetrates, has a constant current. The other is flux free and has a current distribution. This distribution is determined by one parameter “$J_c$”. Analyzing the measurement results using this model, the field profiles are reproduced well, in particular, at low external field.
Experiments

Sample: YBa$_2$Cu$_3$O$_7$
c-axis oriented epitaxial films
$T_c = 90$K
size 600x3800x0.8 $\mu$m$^3$.

Micro Hall probe array:
Si doped GaAs
10 elements
10x10 $\mu$m$^2$ active area

The sample is placed on the Hall probe array directly and the surface field is measured.
Measurements in increasing external field

The sample is cooled to 30 K at zero field and applied a dc field $H$. Fig. 3 and 4 show surface field measurements in increasing external field. The solid curves show calculated $B$.

Fig. 3 Profiles of flux-density $B$ at $T = 30$ K. External field is increased from 0 Oe to 3080 Oe. The solid curves show calculated $B$ at 20 $\mu$m distance from the sample surface.

Fig. 4 Profiles of flux-density $B$ at low external field.
Critical state model to determine screening currents

We utilize a critical state model* having a spatial distribution of local current. In case: a thin strip has width $2a$ along $x$ axis and $\Box$ along $y$ axis in an external field $H_a$, the sheet current $J(x)$ is

$$H_c = J_c / \pi$$

$$b = a / \cosh(H_a / H_c),$$

$$c \equiv (a^2 - b^2)^{1/2} / a = \tanh(H_a / H_c),$$

$$J(y) = \begin{cases} 
\frac{2J_c}{\pi} \arctan \frac{cy}{(b^2 - y^2)^{1/2}} & |y| < b \\
J_c y / |y| & b < |y| < a, 
\end{cases}$$

(1)

$J_c$ is the only fitting parameter.

In $|x| < b$, there is no flux.

Measurements in decreasing external field

After keeping the external field at the maximum for one hour, it is decreased from 3040 Oe to 2320 Oe [Fig. 6].

Fig. 6 Profiles of flux-density $B$ in decreasing external field. Closed circles show the experimental data for every 80 Oe. The solid curve shows calculated $B$. 
Current density $J$ in decreasing the external field

Fig. 7 shows estimated current profiles used for the calculation of Fig. 6. These current profiles are calculated by adding the initial current profile* to the profile derived from Eq. (1).

Fig. 7 Profiles of calculated current density $J$ in decreasing the external field.

*The initial field profile, before decreasing the external field, cannot be reproduced by the uniform current profile. Therefore we adopt a model which $J_c (B)$ decays exponentially with $B$ and then calculate the initial current profile.
In order to clarify the meaning of Fig. 7, we replot it after subtracting the initial local field from a present local field [Fig. 8]. These subtracted fields are reproduced quite well by the current profile derived from Eq. (1).

**Conclusion**

The current profile model, proposed by E. H. Brandt *et al.*, explains the experimentally obtained field profiles for both field-increasing and field-decreasing branches. This implicates the appropriateness of the model.