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Current-induced decoupling of vortices in $Bi_2Sr_2CaCu_2O_8$

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Abstract

Simultaneous transport and magnetization measurements in $Bi_2Sr_2CaCu_2O_8$ crystals are reported. The transport current is injected at the top surface, while Hall sensor arrays measure the local magnetic field across the crystals at the bottom. Surprisingly, at high-currents we find *finite* resistivity well *below* the magnetic irreversibility line, where the vortices are *pinned*. This resistivity is non-monotonic with temperature and highly non-linear. We interpret the new observation as a shear-induced decoupling, in which the vortices flow only in the top few layers and are decoupled from the pinned vortices in the rest of the crystal. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Decoupling; Bi-2212; Pancake vortices

The interpretation of the transport measurements in high-temperature superconductors is complicated due to their high anisotropy and layered structure. The corresponding resistivity tensor has two components, the in-plane ρ_{ab} and the out-of-plane ρ_c, with a typical ratio of $\rho_c/\rho_{ab} \simeq 10^4$ in the normal state of $Bi_2Sr_2CaCu_2O_8$ (BSCCO) crystals [1]. As a result, the measured resistance R is a function of sample geometry and contact configuration [1]. Yet it is generally assumed that ρ_{ab} and ρ_c are well defined functions of the applied current I_a [2]. In this paper we demonstrate that at elevated I_a an additional important element, the gradient of the in-plane current dj_{ab}/dz, which is not taken into account in conventional electrodynamic calculations, has a dominant effect.

The studies were carried out on several high quality BSCCO crystals ($T_c \simeq 90$ K). Four wires were attached to the top *ab* surfaces. The bottom surface of the crystals, free of electrical contacts, was attached to an array of 19 2DEG Hall sensors [3], $30 \times 30\ \mu m^2$ each, allowing *simultaneous* resistance and local magnetization measurements in the presence of transport current.

Fig. 1 shows the measured resistance $R(T)$ of BSCCO crystal at various $H_a \| c$-axis at elevated applied current $I_a = 30$ mA. At low currents $R(T)$ (shown by the dashed line) is monotonic and has a well-defined $T_R = 0$ at which $R(T)$ drops below our experimental resolution. However, when I_a is increased we find surprisingly a very pronounced highly non-linear non-monotonic reentrant behavior. $R(T)$ reaches a minimum at some characteristic T_{min}, but then increases again at lower T.

We have carried out simultaneous resistive and local magnetization measurements *in presence* of elevated I_a as shown in Fig. 2. The result seems to be completely paradoxical. Finite resistivity should be present only above the magnetically measured IL, which in Fig. 2 occurs above 1600 Oe. Below the IL R should be immeasurable in standard transport measurements. This is indeed the case at low I_a. However, at elevated currents, substantial resistance is measured concurrently with the hysteretic magnetization below the IL (Fig. 2). Since the transport and magnetization measurements are carried out simultaneously, heating effects are not responsible for the observed discrepancy.

We describe the observed phenomena in terms of shear-induced decoupling and shear-enhanced anisotropy. At elevated temperatures in the vortex-liquid phase

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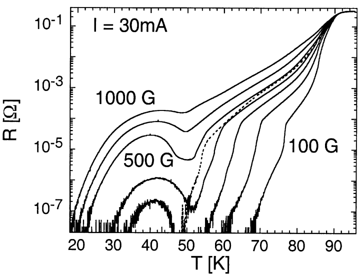

Fig. 1. Resistance (log scale) versus temperature at 100, 200, 300, 400, 500, 700, and 1000 Oe; $I_a = 30$ mA. Dashed line is for $I_a = 10$ mA at 500 Oe.

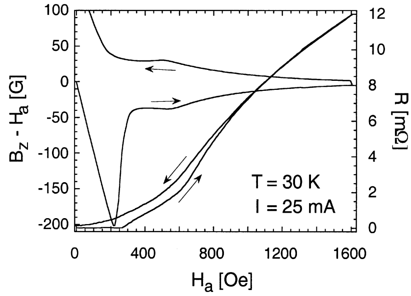

Fig. 2. Resistance (right axis) and hysteretic magnetization loop in the sample center (left axis) versus H_a at $T = 30$ K and $I_a = 25$ mA.

the in-plane current density $j_{ab}(z)$ decreases exponentially from the top surface to the bottom due to high anisotropy γ of BSCCO [1]. As T is decreased the current density at the bottom becomes lower than critical current density J_c. As a result, the vortices at the bottom stop moving, whereas the vortices at the top maintain their high velocity since the current density there is above J_c. The thickness of the vortex pinned layer grows as T is decreased resulting in progressively larger velocity gradients dv_{ab}/dz within the vortex mobile part at the top. The enhanced dv_{ab}/dz results, in turn, in shear-induced phase slippage between the adjacent CuO_2 planes, leading to decoupling of the planes [2,4]. As a result ρ_c and hence γ are increased significantly, resulting in non-monotonic $R(T)$ in Fig. 1. The large ρ_c prevents the lower vortex pinned region from effectively shunting the current. The shear-induced decoupling results in highly non-linear behavior and explains the apparent discrepancy between the transport and the magnetization data. The transport current confined to the top layers creates vortex flow in these layers, resulting in a measurable voltage drop below the IL, whereas the Hall sensors measure the hysteretic magnetization due to pinned vortices at the bottom part of the sample.

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