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Sample size dependence of vortex penetration and the second magnetization peak in $Bi_2Sr_2CaCu_2O_{8+\delta}$

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Local magnetization measurements of $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals with various shape and size were performed using a local GaAs/AlGaAs Hall probe. The vortex penetration field is proportional to the -1/4 power of the sample area, independent of sample geometry. The second magnetization peak (SMP) is observed only below a size dependent temperature, which may not support the 2D-3D vortex solid transition as the intrinsic origin of the SMP.

1. INTRODUCTION

Magnetization measurements probe the vortex penetration field (H_p) and the vortex matter phase transitions in High-T_c superconductors. The penetration field for high Tc superconductors is governed by a geometric barrier [1], which relates H_p to the thickness d, the width w and the lower critical field H_{c1} of a long strip sample by $H_p= (d/w)^{1/2}H_{c1}$. For disk sample, the H_p is predicted to be $\tanh[(0.67d/2r)^{1/2}]H_{c1}$ [2], where d and r are the thickness and the radius of the disk, respectively. Our local magnetization measurements (Fig. 1) of various size $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) disks, squares and rectangles suggest a universal sample area dependence of H_p regardless of the sample geometry.

The second magnetization peak of BSCCO is thought to be indicative of a 2D-3D vortex solid transition. However, a recent measurement [3] suggests the vortex-jump instability as a possible alternative origin of the SMP. Our study of various size BSCCO samples suggests a sample size dependent temperature, above which the SMP is absent. The validity of the adiabatic critical state model for the vortex-jump instability [4] is also analyzed taking into account the anisotropy of BSCCO.

2. EXPERIMENTS

Single crystals of BSCCO were grown using the floating zone method. Disks and squares were fabricated from the same piece of 10 μm thick crystal using Argon Ion-milling. The disks had areas of $2.56\times10^4\ \mu m^2$, $0.42\times10^4\ \mu m^2$ and $0.04\times10^4\ \mu m^2$; the squares had areas of $0.81\times10^4\ \mu m^2$, $0.25\times10^4\ \mu m^2$ and $0.12\times10^4 \mu m^2$. The samples were slightly overdoped with a transition temperature of 87K. Local magnetization measurements were performed using a GaAs/AlGaAs Hall probe with an active area of 10 x 10 μm^2. The Hall probe was placed underneath the center of the samples.

3. RESULTS AND DISCUSSION

For a long BSCCO strip in a perpendicular field, the geometric barrier limits the vortex penetration field to $H_p=(d/w)^{1/2}H_{c1}$. For square and disk samples, the H_p is predicted to be $\approx \tanh[(0.36d/w)^{1/2}]H_{c1}$ and $\tanh[(0.67d/2r)^{1/2}]H_{c1}$, respectively. Our measurements of BSCCO squares and disks indicate that H_p only depends on the -1/4 power of the sample surface area as $H_p(\mathrm{Oe}) = 2560[A(\mu m^2)]^{-1/4}$, regardless of the sample geometry. In addition to squares and disks, the penetration fields of the rectangular samples also fall on the curve. Using d = μm and $H_{c1} \approx 150$ G [5] at 26K,

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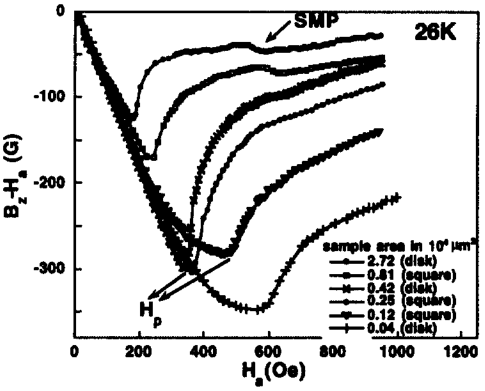

Figure 1. (B_z-H_a) vs. H_a of BSCCO at 26K. We define H_p as the peak in the (B_z-H_a) vs. H_a plot, which should agree with the deviation from linearity of (B_z-H_a) vs. H_a. We attribute the early deviation from linearity of the $0.12\times10^4 \mu m^2$ and $0.04\times10^4 \mu m^2$ samples to the comparable size of the sample to the sensor area.

$H_p(Oe) = 2560[A(\mu m^2)]^{-1/4}$ could be written as $H_p = C\ (d^{1/2}/A^{1/4})\ H_{c1}$ with the coefficient $C \approx 5.4$.

The vortex-jump instability, which is induced by catastrophic vortex entry due to adiabatic heating of the sample, has been suggested as a possible extrinsic origin of SMP in BSCCO [3]. Our study of the same thickness but different lateral size samples indicates that the SMP is present only below a sample-area-dependent temperature of $T_{SMP} = -22.4 + 15.6\log[A(\mu m^2)]$ (Fig. 3). Due to the large anisotropy of BSCCO, the thermal conductivity along the c axis is much smaller than that of the ab plane. Therefore, the vortex instability study by Swartz and Bean [4] for an infinite slab in a parallel field could be applied to flat BSCCO in a perpendicular field. A resulting SMP curve could separate the adiabatic critical state from the isothermal critical state, defining a region of thermal stability.

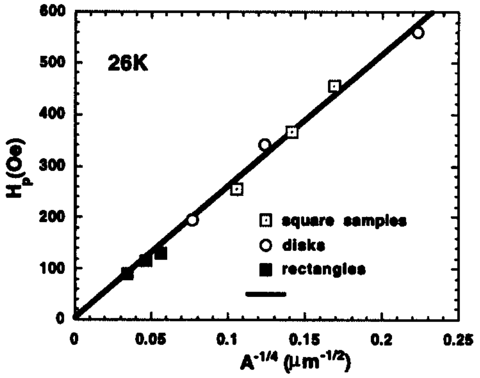

Figure 2. H_p vs. $A^{-1/4}$ for BSCCO squares, disks and rectangles. The data is fitted well by $H_p(Oe) = 2560[A(\mu m^2)]^{-1/4}$.

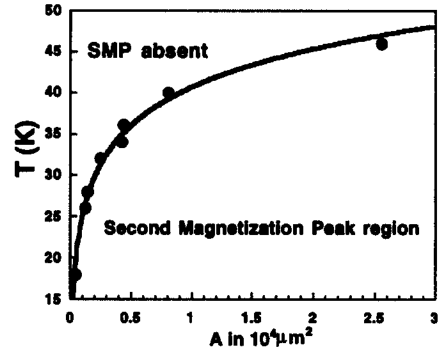

Figure 3. The onset temperature for the SMP increases with sample area as $T_{SMP} = -22.4 + 15.6\log[A(\mu m^2)]$.

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