Hall effect in the mixed state of $\text{YBa}_2\text{Cu}_3\text{O}_y$ films

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Hall coefficients and resistivities of high- T_c $\text{YBa}_2\text{Cu}_3\text{O}_y$ (YBCO) films in the mixed state have been measured in the temperature ranges below T_c to explore the correlation between the negative Hall coefficient and the flux flow resistivities. The negative Hall coefficient in the mixed state of YBCO films shows a local minimum; which corresponds to the flux flow regime in the resistivity data. The negative Hall coefficients is explained in terms of the charge accumulation due to the induced electric fields $E_{xy,ind}$, where $E_{xy,ind}$ is the component of induced electric field E_{ind} along a direction perpendicular to the transport current j_s .

Hall effects in the superconducting mixed state is a subject of strong current interest [1-4]. For a range of fields and temperatures, the longitudinal resistivity, ρ_{xx} , shows strongly thermal activated and flux flow behaviors, and the Hall electric field, E_{xy} , shows a sign reversal. In this work we investigate the flux flow resistivity and the Hall effect of high- T_c superconducting thin $\text{YBa}_2\text{Cu}_3\text{O}_y$ (YBCO) films in the mixed states.

The YBCO films were prepared by an off-axis rf magnetron sputtering. A detailed description of the sample preparation and characterization of YBCO films has been described in reference [5]. The as grown YBCO films shows preferred orientation with the crystal c axis perpendicular to the plane of $\text{SrTiO}_3(001)$.

Figure 1(a) shows the Hall coefficients as a function of temperature in the mixed states for YBCO films (24 nm thick) measured in 1, 2, 3 and 6.5 T. The resistivity of the as grown YBCO films at 300 K was 350 $\mu\Omega\text{cm}$ and the zero resistance temperature was at 83 K. YBCO films of 24 nm thick was used in this study because thin YBCO films show a weak pinning [5]; which is suitable for the investigation of the flux motion. The resistance as a function of temperature in the same magnetic fields was shown in Figure 1(b). The Hall measurements were performed in a superconducting cryostat. Several features were observed in the temperature dependence of Hall coefficients: (1). The Hall coefficient, R_H in the mixed state changes from positive values to negative values as one decreases the temperature and R_H has a local minimum in applied fields; (2). The temperature at the

local minimum of the Hall coefficients decreases as the applied field is increased, and (3). The Hall coefficients remain positive in a high magnetic field of 6.5 T.

In the regime where the Lorentz force is greater than the pinning forces, the flux flow occurs and energy is dissipated. An important theory of the flux flow was proposed by Bardeen and Stephen. [6] In

Figure 1. (a) Hall Coefficient as a function of temperature in the superconducting mixed state of YBCO films, (b) Resistance as a function of temperature for YBCO films in 1, 2, 3, and 6.5 T.

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that work that work the flux flow resistivity can be written as $\rho_{ff} = \rho_0 H/H_{c2}$, where H is the applied field and H_{c2} is the upper critical field and ρ_0 is the normal state resistance. It is useful to plot the flux flow resistivity along with the resistivity in magnetic fields as shown in Figure 1(b). The temperature-dependent $H_{c2}(T)$ is determined from the 10 % resistive transition and is extrapolated to low temperatures. It is clear that the negative Hall coefficient occurs in the flux flow regime.

To explain the occurrence of the negative Hall coefficient, we consider the motion of the vortex take up when the Lorentz force is greater than the pinning force in the mixed state. The applied magnetic field is perpendicular to the plane of the page. It is important to note that when the cores are in motion, the magnitude and the direction of the forces acting on them are different from when they are in pinned in the materials. So the velocity v_L of vortices make an angle θ with j_s as shown in Figure 2.

Figure 2. The transport current j_s , the resultant velocity v_L of flux-vortex and the induced electric field $E_{ind} = B \times v_L/c$ due to the flux-vortex motion.

Flux-vortex motion at a velocity v_L in a type II superconductors generates an induced electric field [6,7], $E_{ind} = B \times v_L/c$, as shown in Figure 2. The y-component of E_{ind} will exert an force on the charge carriers (holes in YBCO films). Because holes can not move out of the y direction, so they

will accumulate on one side of the YBCO films. In the steady state, the accumulated charges will generate an electric field $E_{xy,acc}$. The direction of $E_{xy,acc}$ is opposite to that of the Hall electric field E_{xy} in the normal state. If $E_{xy,acc} > E_{xy}$ then negative Hall coefficients will occur. There is an induced electric field $E_{xx,ind}$ along the direction of the transport current and the corresponding induced voltage is just the resistive voltage due to the passage of the transport current density j_s .

There has been many suggestions that the negative Hall coefficients may result from two type of carriers [8], the drag forces [9], and the back flow current due to pinnings, [10] etc.. We feel that they are unlikely. Our present explanation of the negative Hall coefficient is in terms of the charge accumulation along the y direction caused by the induced electric field $E_{xy,ind}$.

In summary, we measure the Hall coefficient of YBCO films in the mixed state. The sign reversal of the Hall coefficient is explained in terms of the charge accumulation by the induced electric field $E_{xy,ind}$ due to flux-vortex motion.

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