Mixed-state Properties of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{1.85}\text{Ce}_{0.15}\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{0.5}\text{Pr}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_y$ Multilayers

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The longitudinal, ρ_{xx} , and transverse, ρ_{xy} , resistivities of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{1.85}\text{Ce}_{0.15}\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{0.5}\text{Pr}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_y$ multilayers in mixed states were measured at different temperature ranges near T_c to investigate the effect of flux pinning on the mixed state Hall coefficient. The ρ_{xx} shows thermally activated behavior under magnetic fields parallel to the crystal c-axis. The negative Hall coefficient in mixed state depends on the pinning ability of the multilayers.

One interesting feature in the mixed state properties of high- T_c superconductors is the scaling behavior [1–5] $\rho_{xy} \sim \rho_{xx}^\beta$ in mixed state Hall coefficients, where ρ_{xx} and ρ_{xy} are the longitudinal and transverse Hall resistivities. Luo et al [1] observed $\beta = 1.7$ in YBCO film in the temperature range close to the onset of sign reversal. This observation has attracted much attention and various idea have been proposed to explain the scaling behavior [2–5]. In this work, we investigated the effect of flux pinning on the power law behavior of ρ_{xy} and ρ_{xx} and negative Hall coefficients on $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{1.85}\text{Ce}_{0.15}\text{CuO}_4$ (YBCO/NCCO) and $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Y}_{0.5}\text{Pr}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_y$ (YBCO/YPBCO) multilayers in mixed states

The YBCO/NCCO and YBCO/YPBCO multilayers were grown in-situ in an off-axis rf magnetron sputtering system.⁶ YBCO, NCCO and YPBCO films were grown at about $\sim 750^\circ\text{C}$ and the sputtering gas was a mixture of Ar and O_2 (3:7). In the Hall coefficient and resistivity measurements, the samples were patterned to a 5-leads Hall geometry.

The resistivity, ρ_{xx} , under magnetic fields shows thermal activated behavior and can be described by the formula: $\rho_{xx} = \rho_0 \exp(-U_c/k_B T)$ for YBCO/PYBCO and YBCO/NCCO multilayers. In figure 1 we show $\ln(|\rho_{xy}|)$ versus ρ_{xx} under magnetic fields $H = 2, 3, 4$ and 5 T for YBCO/YPBCO ($120\text{ \AA}/180\text{ \AA}$)₆ and YBCO/NCCO ($120\text{ \AA}/180\text{ \AA}$)₆ multilayers. The subscript refers to the number of modulation layer in multilayers. The YBCO/YPBCO ($120\text{ \AA}/180\text{ \AA}$)₆ sample shows the power law behavior, $\rho_{xy} = A\rho_{xx}^\beta$, with exponent $\beta = 1.7 \pm 0.1$ while the YBCO/NCCO

Figure 1. $\ln(|\rho_{xy}|)$ versus ρ_{xx} for (a) YBCO/YPBCO ($120\text{ \AA}/180\text{ \AA}$)₆ and (b) YBCO/NCCO ($120\text{ \AA}/180\text{ \AA}$)₆ multilayers.

Figure 2 Negative Hall coefficient as a function of temperatures for YBCO/YPBCO (120 Å/180 Å)₆ and YBCO/NCCO (120 Å/180 Å)₆ multilayers. The applied magnetic fields were 2, 3, 4 and 5 Tesla.

multilayer shows a power law with $\beta = 3.1, 2.9, 2.3$ and 2.0 respectively for $H = 2, 3, 4$ and 5 T. The pinning force of YBCO/YPBCO (120 Å/180 Å)₆ is stronger than that of YBCO/NCCO (120 Å/180 Å)₆. For (YBCO/YPBCO) (120 Å/180 Å)₆ sample with strong pinning force, β is nearly independent of magnetic field whereas for YBCO/NCCO (120 Å/180 Å)₆ sample with weak pinning force, β is magnetic field dependent.

The scaling law of $\rho_{xy} \propto \rho_{xx}^\beta$ in high- T_c superconductor as reported by Luo et al. [1] has been argued to be a consequence of vortex-glass transition with the influence of disorder. It was proposed by Dorsey and Fisher [2] that scaling behavior occurs near the vortex-glass transition in which the specially

introduced particle-hole symmetry has to be adjusted to obtain $\beta = 1.7$. An alternative model for $\beta = 2$ recently has been suggested by Vinokour et al. [3] Experimental support for their proposal derives from the observation of scaling $\rho_{xy} \propto \rho_{xx}^\beta$ with $\beta = 2$ by Samoilov [7] in BSCCO films. Recently Wang, Dong and Ting [5] have developed a unified theory by taking into account both back flow effect and thermal fluctuation. The obtained scaling behavior and the reversal of sign have been demonstrated.

In figure 2 we show negative Hall coefficient in mixed state as a function of temperatures for YBCO/YPBCO (120 Å/180 Å)₆ and YBCO/NCCO (120 Å/180 Å)₆ multilayers. Negative Hall coefficient was observed in YBCO/YPBCO (120 Å/180 Å)₆ sample while that of YBCO/NCCO multilayer diminished. The YBCO/YPBCO multilayer which has a stronger pinning force reveals negative Hall coefficients while YBCO/NCCO multilayer which has a weaker pinning force the negative Hall coefficients diminished. The data suggest that the negative Hall coefficient depends on the pinning ability of the multilayers. Systematic investigation of the mixed state Hall coefficient in YBa₂Cu₃O_y/PrBa₂Cu₃O_y superlattices has been reported in literature [8,9].

In summary, we investigated the longitudinal and transverse Hall resistivities of YBCO/YPBCO and YBCO/NCCO multilayers in mixed states. The power law, $\rho_{xy} = A\rho_{xx}^\beta$, persists in both YBCO/NCCO multilayers and YBCO/YPBCO superlattices. The negative Hall coefficient depends on the pinning ability of the multilayers.

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