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Hall effect and flux pinning of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ multilayers

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Abstract

Hall coefficients of superconducting $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ (YBCO/NSMO) multilayers were measured to investigate the effect of flux pinning on the Hall behavior. The lower pinning ability accompanying a diminishing sign reversal of Hall coefficient is due to a decrease of flux pinning in YBCO/NSMO multilayers. The volume pinning force, $F_p = -J_c \times H$, of YBCO/NSMO multilayers can be represented as $F_p \propto (H/H_{c2})^{0.5}(1 - H/H_{c2})^2$. This suggests the existence of two-dimensional pinning centers in measured samples. The Hall coefficient and pinning force of (YBCO/NSMO) multilayers are compared with data of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{PrBa}_2\text{Cu}_3\text{O}_y$ superlattices. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In recent years, studies of the mixed-state Hall effect in high- T_c superconductors have been a subject of great interest. Hall measurements on certain high- T_c superconductors have shown an anomalous sign-reversal of Hall resistivity [1–7]. It is generally agreed that the sign reversal of Hall coefficient is related to the flux dynamics and the flux pinning [7]. The study of alternately stacked layers [8–10] is of considerable interest because we can alter the pinning ability in the mixed state by varying the layer thickness. Here, we report a systematic investigation of the correlation between Hall coefficients and flux pinning of $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{Nd}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ (YBCO/NSMO) multilayers. The results are compared with data of YBCO films and $\text{YBa}_2\text{Cu}_3\text{O}_y/\text{PrBa}_2\text{Cu}_3\text{O}_y$ (YBCO/PBCO) superlattices.

2. Experiment

High-quality YBCO/NSMO multilayers thin films have been deposited onto $\text{SrTiO}_3(100)$ substrates by the off-axis magnetron sputtering technique. The growth conditions of YBCO films, YBCO/PBCO superlattices and YBCO/NSMO multilayer have been described elsewhere [11,12]. For transport measurements, films were photolithographically patterned to a 2 mm long by 500 μm wide bridge containing Hall leads. Hall voltages were taken with a DC current density of $J \sim 10^3 \text{ A/cm}^2$ up to a magnetic field of 5 T.

3. Results and discussion

In Fig. 1, we show the longitudinal resistivities and Hall coefficients as a function of temperature for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times$ 16, and YBCO/NSMO (240 Å/38.5 Å) $\times$ 4 multilayers in magnetic fields, respectively. The resistivity under magnetic field shows a broadening behavior as shown in Fig. 1(a). The critical temperatures T_c defined by the temperature of the 50%

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Fig. 1. (a) Temperature dependence of the longitudinal resistivity ρ_{xx} for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers. (b) Temperature dependence of the Hall coefficient for the corresponding samples.

resistive transition in zero magnetic field are 90, 78, and 68 K for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers, respectively. The YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayer shows a lower critical temperature even when it is stacked with thicker YBCO layers and thinner NSMO layers. The lower T_c in YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers implies a strong suppression of superconductivity caused by ferromagnetic NSMO layers. In Fig. 1(b) the mixed-state Hall coefficient versus temperature for a YBCO film shows a sign change in fields of 1, 3, and 5 T while

Fig. 2. Volume pinning force as a function of applied field for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers. The solid curves are fitting data obtained from Eq. (1).

a diminishing of sign reversal were observed for both YBCO/PBCO (60 Å/144 Å) $\times 16$ and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers. The depinning behavior observed in YBCO/PBCO and YBCO/NSMO multilayers corresponds to the diminishing of the sign reversal of Hall coefficient observed in the mixed state. We obtained the activation energy, U , of the investigated samples from the slope of the straight line in the $\log \rho_{xx}$ versus $1/T$ plot using low resistivity data. The value of U of YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$ and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers is 50 563, 1 823, and 1 007 K, respectively in a magnetic field of 1 T.

Fig. 2 shows the field dependence of the volume pinning force F_p which is derived from $\vec{F}_p = -\vec{J}_c \times \vec{H}$ for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers. The critical current density, J_c , was measured at temperatures of 86, 70 and 62 K which corresponds to a T/T_c ratio of 0.95, 0.90, and 0.91, respectively for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers. It can be seen that the F_p of multilayers is smaller than that of YBCO films even when the YBCO film is at higher temperature. It was also found that the F_p can be represented as

$$F_p \propto (H/H_{c2})^{0.5}(1 - H/H_{c2})^2 \quad (1)$$

for investigated samples except a slight deviation for the YBCO film. The H_{c2} is 2.0, 2.6, and 1.8 T for YBCO (1500 Å), YBCO/PBCO (60 Å/144 Å) $\times 16$, and YBCO/NSMO (240 Å/38.5 Å) $\times 4$ multilayers, respectively. The

relation, $F_p \propto (H/H_{c2})^{0.5}(1 - H/H_{c2})^2$ for two-dimensional pinning has been derived by Dew-Hughes [13]. Our data suggest the existence of two-dimensional pinning centers in measured multilayers. The slight derivation for the YBCO film suggests a quasi-three-dimensional pinning instead of two-dimensional pinning. The depinning behavior observed in YBCO/PBCO and YBCO/NSMO multilayers corresponds to the diminishing sign reversal of the mixed state Hall coefficient.

4. Conclusion

In conclusion, we have measured the activation energies and the volume pinning forces for YBCO/NSMO multilayers. The lower pinning ability accompanying a diminishing sign reversal of Hall coefficient of YBCO/NSMO multilayers is due to a decrease of flux pinning. The strong suppression of T_c and pinning in YBCO/NSMO multilayers are attributed to the proximity induced ferromagnetic pair breaking in decoupled YBCO layers. The relation, $F_p \propto (H/H_{c2})^{0.5}(1 - H/H_{c2})^2$, observed for multilayers suggests the existence of two-dimensional pinning centers in our measured samples.

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