Dimensionality of flux pinning in various superconducting YBCO/PYBCO superlattices

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Angular dependent of critical current densities $J_c(\theta)$ for a 960 Å-thick pure $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ thin film (denoted by sample A) and the $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}/\text{Pr}_{0.5}\text{Y}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-y}$ superlattices with 960 Å total thickness of $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ layers (denoted by samples B, C and D) under the magnetic field $H = 0.1$ T at the reduced temperature $t = 0.92$ was measured to investigate the dimensionality of the flux pinning. Samples B, C and D in our study are $(120\text{Å}/24\text{Å}) \times 8$, $(60\text{Å}/24\text{Å}) \times 16$ and $(48\text{Å}/24\text{Å}) \times 20$ respectively. In this report, it is found that the dimensionality of the flux pinning deviates from 2D for the sample A whereas it shows a 2D behavior for the sample B. Moreover, the dimensionality of the flux pinning deviates from 2D gradually for samples C and D. The cause will be discussed.

1. INTRODUCTION

The dimensionality of flux pinning for high- T_c superconductors still attracts a lot of attention. Tachiki et al. proposed a 3D model[1]. However, Kes and Clem suggested that the dimensionality of flux pinning should be 2D and only the pancake vortices exist[2,3]. And also, the dimensionality of flux pinning for $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ thin film or superlattices depends on many other factors, such as temperature and the applied magnetic field[4–6]. In this report, the thickness of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ layer of samples was varied to investigate its influence on the dimensionality of flux pinning.

2. EXPERIMENTAL DETAILS

In order to obtain the various thicknesses of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ layer, 24 Å-thick $\text{Pr}_{0.5}\text{Y}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-y}$ layers are inserted into the 960 Å-thick $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ films with 8, 16 or 20 periods to form the various $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}/\text{Pr}_{0.5}\text{Y}_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-y}$ (YBCO/PYBCO) superlattices. The configurations and the critical temperatures $T_{c, \text{zero}}$ of the samples used in this experiment are listed in Table 1. The methods for the deposition and patterning of the pure YBCO thin film and YBCO/PYBCO superlattices were reported in our previous study[4]. The critical current densities J_c were measured by the conventional four-probe method, and the criterion voltage for J_c is 5 $\mu\text{V}/\text{mm}$. To measure the angular dependent critical

current densities $J_c(\theta)$, where θ denotes the angle between the c axis of the film and the applied magnetic field $\mathbf{H}$, the films were mounted on a rotatable sample holder with the rotation axis(y axis) laid on the film surface along the applied current density $\mathbf{J}$, as shown by the inset in figure 1(b). The applied magnetic field was perpendicular to $\mathbf{J}$, thus the ab -plane and c -axis components of Lorentz force are $F_{L,ab} = (1/c)JH\cos\theta$ and $F_{L,c} = (1/c)JH\sin\theta$, respectively.

3. RESULTS AND DISCUSSION

The $J_c(\theta)$ curves under $H = 0.1$ T at the reduced temperature $t \equiv T/T_{c, \text{zero}} = 0.92$ are shown in figure 1. These data were fitted to a 2D scaling law which was represented by the solid lines. In figure 1(a), it is observed that the $J_c(\theta)$ curve for the sample A deviates from the 2D scaling law. This can be interpreted by the following reasons. First, the c -axis GL coherence length ξ_c is longer than the distance between the CuO_2 planes d in two neighboring unit cells at $t = 0.92$, and hence the Cooper pairs can couple with each other and tunnel along the c axis to form the string vortices. Second, the pancake and string vortices were moved by $F_{L,ab}$ and $F_{L,c}$, respectively. However, the $J_c(\theta)$ for the sample B can be fitted to the 2D scaling law very well. This fact is owing to the reduction in the coupling along the c axis caused by the PYBCO layers in sample B.

Table 1.

Film configurations and $T_{c,zero}$ for the pure YBCO thin film and YBCO/PYBCO superlattices with 960 Å total thickness of $YBa_2Cu_3O_{7-y}$ layers.

Sample no.	A	B	C	D
Sample	YBCO	YBCO/PYBCO	YBCO/PYBCO	YBCO/PYBCO
Film Configuration	960Å	(120Å/24Å)×8	(60Å/24Å)×16	(48Å/24Å)×20
$T_{c,zero}(K)$	87.5	80.2	78.5	76.5

Figure 1. Critical current densities $J_c(\theta)$ versus angle θ for (a) sample A, (b) sample B, (c) sample C and (d) sample D under $H = 0.1$ T at $t = 0.92$. The data are fitted to the 2D scaling law which was represented by the solid lines. The inset in (a) is the layer-structure of YBCO, where d denotes the distance between the CuO_2 planes in the neighboring unit cells and c denotes the lattice constant along the z axis.

By remaining the thickness of each PYBCO layer and decreasing that of each YBCO layer from sample B to samples C and D, the $J_c(\theta)$ curves deviate from the 2D scaling law gradually, as shown in figures 1(c) and 1(d). This implies that the dimensionality of flux pinning departs further from the 2D behavior when

the YBCO layers become thinner. In this case, although the coupling along the c axis is reduced by the PYBCO layers such as the results observed in sample B, meanwhile, the coupling along the ab plane is weaker as reducing the thickness of each YBCO layer. Therefore, it is suggested that the coupling of the Cooper pairs along ab plane is strong enough to exhibit a 2D behavior and hence remains highly anisotropic for sample B. However, for samples C and D with the thinner YBCO layers, the coupling of Cooper pairs along the ab plane turns out weaker and comparable with that along the c -axis direction, thus the behavior of the dimensionality of flux pinning deviated from a 2D behavior.

4. SUMMARY

In conclusion, the thickness of the each YBCO layer in YBCO/PYBCO superlattices was found to be able to change the coupling of the Cooper pairs along the ab plane. By reducing this thickness, the coupling of the Cooper pairs along the ab plane will be more comparable to that along the c axis and closer to a 3D behavior.

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