Temperature dependence of the Hall angle in disordered $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films

K. Makise [a], Y. Yadoguchi [a], F. Ichikawa [b,1], T. Fukami [c], T. Aomine [a], Z. Hao [d], B. Zhu [d], B. Xu [d], B.R. Zhao [d], T. Nishizaki [e], N. Kobayashi [e]

[a] *Department of Physics, Kyushu University, Fukuoka 812-8581, Japan*

[b] *Department of Physics, Kumamoto University, Kumamoto 860-8555, Japan*

[c] *Department of Material Science & Engineering, Himeji Institute of Technology, Himeji 671-2201, Japan*

[d] *National Laboratory for Superconductivity, Institute of Physics & Center for Condensed Matter Physics, Chinese Academy of Sciences, Beijing 100080, China*

[e] *Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan*

Abstract

We have studied the behavior of carriers near the field-induced superconductor-insulator transition for different disordered $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films. The measurement of longitudinal and Hall resistivities has been carried out in the magnetic fields. For the lower disordered film the superconducting transition appeared even at 10 T, while, the insulating behavior was observed for the higher disordered film. Also the temperature dependence and values of Hall angle $\cot\theta_{\rm H}$ are related to the disorder. We discuss the behavior of carriers on the viewpoint of the electronic state.

Key words: Superconductor-Insulator transition; Hall angle; $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films

1. Introduction

The superconductor-insulator transition (SIT) driven by the disorder or the magnetic field has been actively studied in various superconducting materials such as quench-condensed metals, composite materials and high-critical temperature T_c superconductors [1]. It is expected that the SIT critical field B_c for the superconductor with high T_c is much higher than the available magnetic field ($B \sim 10$ T). Therefore strongly underdoped sample whose T_c is low is desirable for the purpose of studying the SIT of high-T_c superconductors. In this study we use $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films whose T_c decreases with increasing Pr concentration x [2].

An electronic state of the strongly underdoped sample differs remarkably from that of the optimally doped sample for the normal state in the magnetic field. This paper shows the transport measurement for strongly underdoped $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films under the magnetic fields. We discuss the relations between the disorder and the field-induced SIT from the results of Hall angles.

2. Experimental

The c-axis oriented $Y_{0.5}Pr_{0.5}Ba_2Cu_3O_{7-\delta}$ thin films were fabricated by dc magnetron sputtering method on (100) $SrTiO_3$ substrates. In order to measure the longitudinal and Hall resistivities, the samples were patterned to a six-leads Hall geometry by the photolithographic method. The size of the sample is 130 μm wide, 530 μm length and 100 nm thick. The magnetic field was applied up to 10 T by the superconducting magnet.

[1] E-mail:ichikawa@kumamoto-u.ac.jp

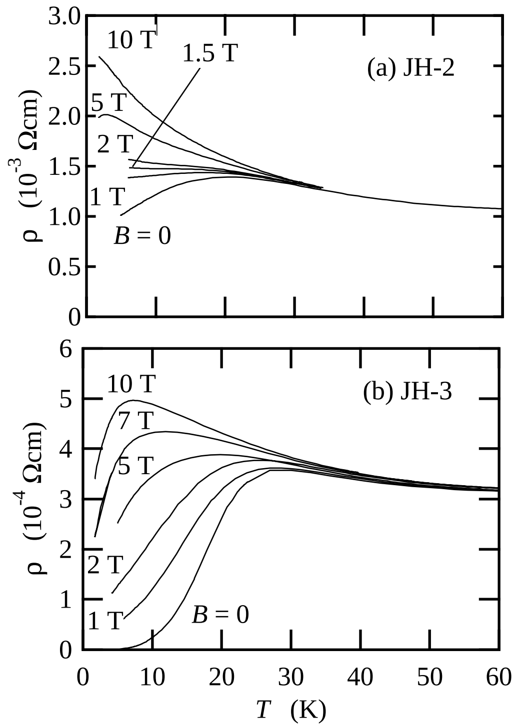

Fig. 1. T dependence of ρ under the magnetic field which was applied in the direction perpendicular to the film surface for (a) JH-2 and (b) JH-3.

3. Results and discussion

Figure 1(a) and 1(b) show the temperature T dependence of resistivity ρ under the magnetic field B for two films JH-2 and JH-3, respectively. Though the origin of the sample dependence is not clear in detail, we think that JH-2 is more disordered than JH-3 from the absolute value and the T dependence of ρ.

The superconducting transition appeared even at 10 T for JH-3. The behavior of $\rho(T)$ is inconsistent with a scaling theory proposed by Fisher [3]. While, though the data of JH-2 seemed to follow the scaling law, the product of critical exponents $z_B\nu_B \sim 5$ and the critical sheet resistance $R_c = 220\ \Omega$ were different from the values expected from the theory. Details will be reported elsewhere.

In the normal state of high-T_c superconductors various quantities deviate from the conventional Fermi-liquid behaviors. The Hall angle $\theta_{\rm H}$ also shows an unusual behavior $\cot\theta_{\rm H} \propto T^2$ [4]. Different types of theories have explained this T dependence of $\theta_{\rm H}$, ex. the spin-charge separation in Luttinger liquid [5] and the spin-fluctuation theory [6]. We have studied the Hall angle in order to examine the different behaviors of carriers near the SIT.

Figure 2 shows the T dependence of Hall angle as

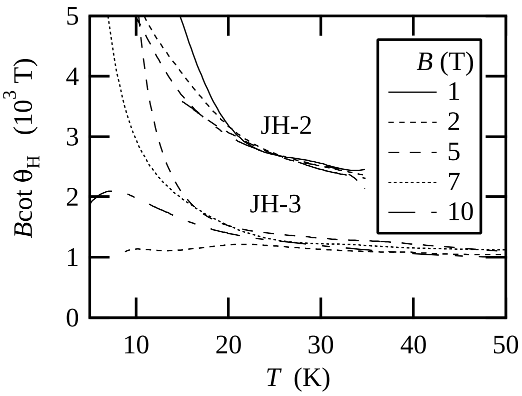

Fig. 2. T dependence of the Hall angle as $B\cot\theta_{\rm H}$ for JH-2 and JH-3.

$B\cot\theta_{\rm H} = \rho/R_{\rm H}$ for JH-2 and JH-3, where $R_{\rm H}$ is the Hall coefficient. $B\cot\theta_{\rm H}$ is almost independent of B above 20 K. The value of $B\cot\theta_{\rm H}$ for JH-2 is larger than that for JH-3. In the free electron model the Hall angle is proportional to a revolution between collisions, $B\cot\theta_{\rm H} \propto \tau^{-1}$, where τ is the relaxation time. Therefore it is understood that the difference of $B\cot\theta_{\rm H}$ is related to the difference of disorder.

In the high temperature region as not shown in the figure $B\cot\theta_{\rm H}$ of JH-3 increases with increasing T, while that of JH-2 is almost temperature independent. For the less disordered sample than JH-3 the behavior of $\cot\theta_{\rm H} \propto T^2$ was observed. Then, the T dependence of $\cot\theta_{\rm H}$ may be influenced by the disorder.

For both samples the values of $B\cot\theta_{\rm H}$ increase with decreasing T below about 20 K even in the insulating region though the T dependence of $B\cot\theta_{\rm H}$ is not systematic to the applied B. Recently Capan *et al.* proposed the existence of vortices in the normal state of SIT for underdoped $La_{2-x}Sr_xCuO_4$ [7]. Therefore, there is a possibility that the origin of $\rho(T)$ behavior of JH-2 is the same as that of JH-3. That is, the behavior of $\rho(T)$ may relate to the superconducting fluctuation in the insulating region of SIT.

References

[1] N. Marković *et al.*, Phys. Rev. B **60** (1999) 4320; S.Okuma *et al.*, Solid State Commun, **106** (1998) 529; S. Tanda *et al.*, Phys. Rev. Lett. **69** (1992) 530; F. Ichikawa *et al.*, Solid State Commun. **98** (1996) 139.

[2] Y. X. Jia *et al.*, Phys. Rev. B **46** (1992) 11745.

[3] M.P.A. Fisher, Phys. Rev. Lett. **65** (1990) 923.

[4] T.R. Chien *et al.*, Phys. Rev. Lett. **67** (1991) 2088.

[5] P.W. Anderson, The Theory of Superconductivity in the High-T_c Cuprates, Princeton university Press (1997).

[6] H. Kontani *et al.*, Phys. Rev. B **59** (1999) 14723.

[7] C. Capan *et al.*, Phys. Rev. Lett. **88** (2002) 056601.