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Hall effect in electron-doped $Sr_{0.9}La_{0.1}CuO_2$ superconductors

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전자가 도핑된 $Sr_{0.9}La_{0.1}CuO_2$ 초전도체의 홀 효과

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Abstract

We have measured the Hall effect in infinite-layer $Sr_{0.9}La_{0.1}CuO_2$ thin films grown by molecular beam epitaxy. We do not observe T^2 dependence of the cotangent of Hall angle, which is commonly observed in other cuprate High-Tc superconductors. Therefore, this result cannot be interpreted within two different scattering mechanism based on chargespin separation theory. The mixed-state Hall effect shows no sign anomaly, implying that the hydrodynamic contribution of vortex core is negligibly small.

Keywords : Hall effect, infinite-layer, thin film

I. Introduction

Sigrist *et al.* synthesized an infinite-layer compound in 1988 [1]. This is known as one of two types of the electron-doped cuprate superconductors [2,3], which are T$'$-phase compounds and infinite-layer compounds.

The electron-doped infinite-layer $Sr_{1-x}Ln_xCuO_2$ (Ln=La, Nd, Sm, Pr and Ge) has the maximum $T_c \sim$ 43 K [4,5] and the simplest structure in the copper-oxide superconductors [6]. In spite of such merits, these have been much less studied than the T$'$-phase compounds, $Ln_{2-x}Ce_xCuO_4$ (Ln=La, Pr, Nd, Sm, and Eu) due to the difficulty of synthesis by using high pressure [3].

In high-temperature superconductors (HTSs) the Hall effect has played an important role in revealing the mechanism of high T_c superconductivity. In particular, it probes the charge-carrier densities and scattering mechanisms. Moreover it has become the center of attention in HTSs because there are some unusual behaviors such as temperature dependence of the Hall voltage observed in the normal state [7,8]. The mechanism that can explain the origin of such anomalous behavior has not been established yet.

In normal state, remarkable Hall effect is the existence of a temperature-squared dependence in the $\cot\Theta_H$ where Θ_H is the Hall angle. The $\cot\Theta_H$ is the ratio of longitudinal resistivity (ρ_{xx}) with transverse

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resistivity (ρ_{xy}), i.e., ρ_{xx}/ρ_{xy}. Anderson [9] has proposed that the two relaxation rates are determined by those of holons and spinons of quasiparticles. For HTSs most experimental results have supported this theory [10-14], and in general it is accepted that $\cot\Theta_H \sim T^2$ law is universal over a wide temperature range.

In the mixed state, the Hall effect as a probe of superconductivity shows the anomalous sign change near T_c as a function of the T and the magnetic field, and its origin has remained an unsolved subject for a long time. The sign anomaly has been observed not only in some conventional superconductors [15] but in most HTSs [15-17]. However, sign anomaly has not been found in clean superconductors, such as Nb, V, and 2H-$NbSe_2$ [15].

In this paper, we reported a measurement of the in-plane Hall effect for the electron-doped infinite-layer superconductors of $Sr_{0.9}La_{0.1}CuO_2$ thin films. We found that the sign of the Hall resistivity was negative, which is different from the behaviors of HTSs. And we do not observe T^2 dependence of the cotangent of Hall angle. The Hall effect in the mixed state showed no sign anomaly for magnetic field up to 5 T.

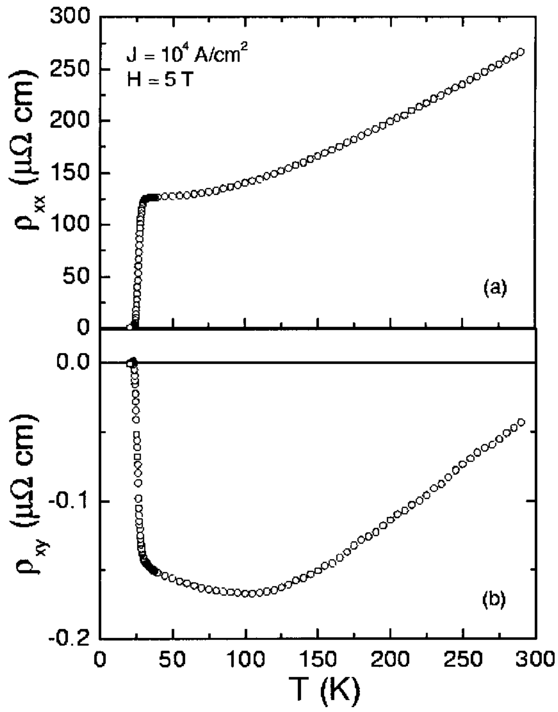

Fig. 1. For current density 10^4 A/cm^2 and applied magnetic field 5 T, temperature dependence of (a) the longitudinal resistivity (b) the Hall resistivity. The Hall resistivity has negative values.

II. Experiment

The $Sr_{0.9}La_{0.1}CuO_2$ thin film was grown on $KTaO_3$ substrate by using molecular-beam epitaxy (MBE) [18,19]. The dimension of the sample was 10 mm × 10 mm with a typical thickness of 500 Å.

To achieve good ohmic contacts (< 1 Ω), we coated an Au film on the contact pads after cleaning the sample surface by using Ar-ion milling. After installing a low-noise preamplifier prior to nanovoltmeter, we achieved a voltage resolution of below 1 nV. The magnetic field was applied perpendicular to the sample surface by using a superconducting magnet system, and the applied current density was 10^4 A/cm^2.

III. Results and discussion

Figure 1 shows the temperature dependence of (a) the longitudinal resistivity (ρ_{xx}) and (b) the Hall resistivity (ρ_{xx}) for a $Sr_{0.9}La_{0.1}CuO_2$ thin film at H = 5 T.

First of all, Fig. 1(a) shows the metallic behavior of the temperature dependence of longitudinal resistivity (ρ_{xy}) of the $Sr_{0.9}La_{0.1}CuO_2$ thin film in normal state. The current density (J) was applied 10^4 A/cm^2 in the magnetic field (H) of 5 T.

The temperature dependence of Hall resistivity (ρ_{xy}) of the same sample is shown in Fig. 1(b). The Hall voltage was taken as the average value, $V_{xy} = [V_{xy}(H)-V_{xy}(-H)]/2$ to eliminate all offset components associated with the small misalignment of the Hall electrodes for all data points. The value of ρ_{xy} was observed to be negative over the entire temperature range.

In Fig. 2, we show the temperature dependence of $\cot\Theta_H$ at 5 T. The $\cot\Theta_H \sim T^2$ low was not observed. According to the Anderson theory [9], which is based on charge-spin separation, charge transport is governed by two separate scattering rates with different temperature dependencies. The longitudinal conductivity (σ_{xx}) is proportional to the transport scattering time (τ_{tr}) whereas the Hall (transverse) conductivity (σ_{xy}) is determined by $\tau_H\tau_{tr}$ where the Hall relaxation time (τ_H) is proportional to $1/T^2$. The τ_H is mainly governed by spinon-spinon interactions. Thus its temperature dependence is not affected by impurities. In consequence, the $\cot\Theta_H$ should follow a T^2 law. Most HTSs support this temperature dependence. But the electron-doped infinite-layer superconductor, which we measured above, data does not follow a T^2 law. Edwin *et al.* [20] studied Hall effect in infinite-layer thin film, $Sr_{0.9}Nd_{0.1}CuO_2$ and the temperature dependence of $\cot\Theta_H$ data behaves as a function of T^3. Our data were not fit to even T^3 as well as to T^2. Therefore, this result cannot be interpreted within two different scattering mechanism based on charge-spin separation theory. Our result suggests that an undiscovered scattering mechanism up to the present affects the electrical transport properties of this infinite-layer superconductor, $Sr_{0.9}La_{0.1}CuO_2$.

In Fig. 3 we show the longitudinal resistivity and Hall resistivity versus temperature in the mixed state for various different fields. In Fig. 3(a), a broad superconducting transition is observed, which implies the existence of a relatively wide vortex-liquid phase in this compound. In Fig. 3(b), sign reversal of the Hall data was not observed for magnetic fields from 1 to 5 T. A puzzling sign reversal has been observed in the mixed-state Hall effect for most HTSs [17]. In conventional superconductors, this sign reversal of the Hall effect appears among moderately clean superconductor, but does not occurred in either the very clean or dirty limits [15]. Since the coherence length of cuprate superconductor is very small, HTSs is categorized in the clean-limit superconductor rather than dirty-limit one. Therefore, the absence of the sign anomaly suggests that the electron-doped infinite-layer $Sr_{0.9}La_{0.1}CuO_2$ superconductors belong to the clean-limit superconductors.

According to the treatments based on time-dependent Ginzburg-Landau theory, the mixed-state Hall conductivity in type-II superconductors is

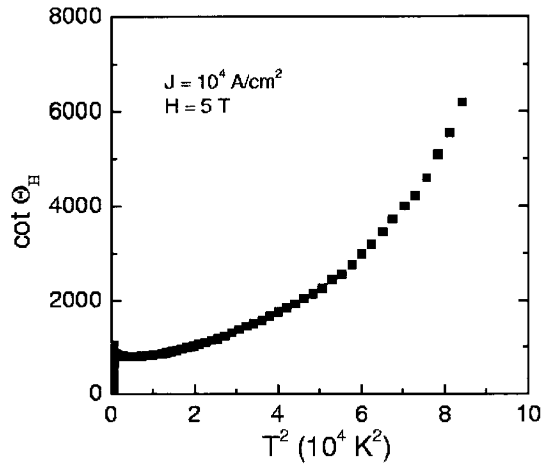

Fig. 2. The temperature-squared dependence of $\cot\Theta_H$ for applied magnetic field 5 T. T^2 low was not observed.

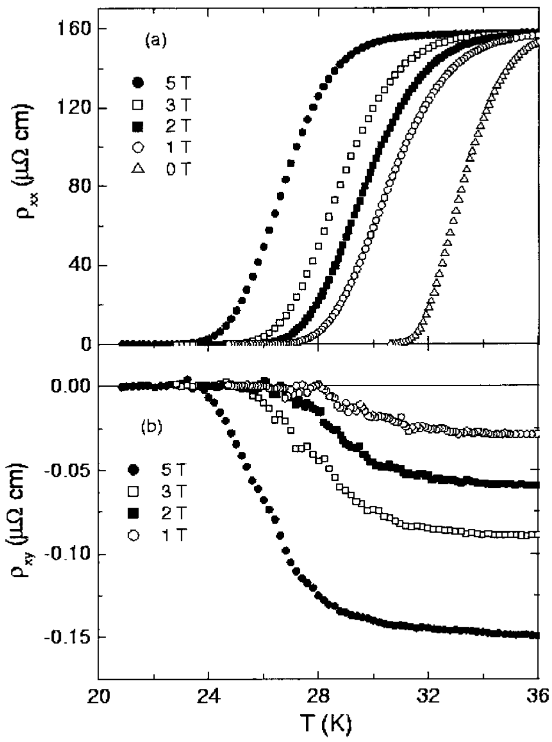

Fig. 3. Mixed-state temperature dependence of (a) longitudinal resistivity and (b) Hall resistivity at different fields. No sign anomaly of the Hall data was observed, which is different from the case of HTSs.

determined by the quasiparticle contribution and the hydrodynamic contribution of the vortex cores. Since the hydrodynamic contribution is determined by the energy derivative of the density of states [21,22], if that term is negative anomaly can appear. For the mixed-state Hall effect in the electron-doped infinite-layer superconductor, $Sr_{0.9}La_{0.1}CuO_2$, we may suggest that no sign anomaly of the Hall data implies that the hydrodynamic contribution of vortex core is negligibly small in this thin film.

In summary, we studied the Hall effect in the electron-doped infinite-layer superconductor thin film sample of $Sr_{0.9}La_{0.1}CuO_2$. The normal-state Hall resistivity was negative. We do not observe T^2 dependence of the cotangent of Hall angle, which is commonly observed in other cuprate High-T_c superconductors. Therefore, this result cannot be interpreted within two different scattering mechanism based on charge-spin separation theory. The mixed-state Hall effect shows no sign anomaly, implying that the hydrodynamic contribution of vortex core is negligibly small.

Acknowledgments

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