Characteristic Charge Transport in Oxygen-Deficiency-Controlled $LnFeAsO_{1-y}$ ($Ln = La$ and Nd)

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Abstract

We have investigated the transport properties of $LnFeAsO_{1-y}$ ($Ln = La, Nd$) over a wide range of doping. When we compare the exponent n of resistivity $\rho(T) \sim T^n$, a marked difference is found between La and Nd system. In the La system with lower T_C , $\rho(T)$ is always dominated by a T^2 term at low temperatures, showing relatively large magnetoresistance. On the other hand, in the Nd system with higher T_C , $\rho(T)$ is linear on T with a small magnetoresistance. These results indicate that the carriers are subject to stronger scattering in $NdFeAsO_{1-y}$, which might be linked to the higher T_C .

Key words: iron-based superconductors, resistivity, magnetoresistance

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1. Introduction

The discovery of high- T_C superconductivity with $T_C = 26K$ in the iron-based oxypnictide $LaFeAsO_{1-x}F_x$ has attracted great attention [1]. In this system, T_C increases by replacing La by other Ln (Ln : lanthanide elements) with smaller ionic radius and exceeds 50K for $Ln = Nd, Sm, \dots, Dy$ [2, 3, 4, 5]. It is pointed out that T_C of $LnFeAsO$ system strongly correlates with the crystal structure and becomes maximum when the $FeAs_4$ forms nearly ideal tetrahedron [6]. However, it is not trivial why T_C so drastically changes in spite of slight modification of the crystal structure. To understand the difference of T_C , we focus on their transport properties in this study. Since single crystals are not available for a systematic study at present, we investigate the transport properties of polycrystalline oxygen-deficient oxypnictides, $LaFeAsO_{1-y}$ and $NdFeAsO_{1-y}$.

2. Experimental procedures

Polycrystalline samples of $LnFeAsO_{1-y}$ were prepared by high-pressure synthesis technique using a cubic-anvil-type apparatus (Riken CAP-07) [7]. Well-sintered samples of high density, sufficient for transport measurements, were obtained by application of pressure of 2GPa during the synthesis and we found no difference in the sample quality between $Ln = La$ and Nd . There was no trace of impurity phases in the X-ray diffraction patterns. The actual amount of oxygen deficiency y was slightly smaller than that of the nominal composition because some of the starting materials are quite reactive to oxygen and

we could not avoid them from being oxidized in the synthesis procedure. We estimated y values based on the lattice constants of each sample in reference to the Rietveld analysis of the neutron powder diffraction patterns [6]. In order to make the distribution of oxygen deficiency homogeneous, the samples were annealed in air at 450°C. The introduction of oxygen deficiency is considered to work as the electron doping, which seems equivalent to the substitution of fluorine for oxygen [5, 6]. A standard four-terminal method was used for the resistivity measurements. Since the anisotropy ratio ρ_c/ρ_{ab} is estimated to be ~ 25 or larger [8, 9], it is reasonable to assume that the transport properties of the polycrystalline samples mainly reflect the in-plane ones. The transverse magnetoresistance have been measured in a cryostat equipped with a superconducting magnet (PPMS, Quantum Design Inc.) with the magnetic field normal to the widest plane.

3. Results and discussion

Figure 1 shows the temperature dependence of resistivity for $LaFeAsO_{1-y}$ (left panel) and $NdFeAsO_{1-y}$ (right panel) in the log-log scale after subtracting the residual resistivity ρ_0 from the raw resistivity $\rho(T)$. Here T_C of the samples are determined from zero-resistivity. We can determine the exponent n of $\rho(T) \sim T^n$ from the slope in the low temperature region in Fig. 1. We plot n as a function of T_C in Fig. 2. It is clear that $NdFeAsO_{1-y}$ belongs to a class distinct from $LaFeAsO_{1-y}$. In the La system with maximum $T_C = 28K$, the low-temperature resistivity is dominated by a T^2 term at any doping level (i.e. $n \sim 2$).

Figure 1: $\log(\rho(T) - \rho_0)$ vs $\log T$ plots for LaFeAsO_{1-y} (left panel) and NdFeAsO_{1-y} (right panel) at various doping levels, where ρ_0 is the residual component of resistivity. The solid lines correspond to $\rho(T) \sim T$ and T^2 , respectively.

This suggests the dominance of electron-electron scattering for the carriers in the most conductive channel. On the other hand, in the Nd system with T_C exceeding 40K, the normal-state resistivity shows predominantly T -linear dependence. The inset of Fig. 2 shows the magnetic-field dependence of transverse magnetoresistance (MR), $\Delta\rho(H)/\rho(0)$ ($= [\rho(H) - \rho(0)]/\rho(0)$), for LaFeAsO_{1-y} ($y = 0.14$) and NdFeAsO_{1-y} ($y = 0.15$) up to 6T. In the case of LaFeAsO_{1-y} sizable MR is observed, while it is remarkably suppressed in NdFeAsO_{1-y} , although these samples are at almost the same doping level. According to the simple two-carrier analysis, the large MR would arise when one type of carriers has relatively smaller density and higher mobility. Then, in La system, there might be carriers with high mobility which dominating the transport properties. Such carriers might not exist or their mobility might be lower in Nd system. Together with the T -dependence of resistivity, these results indicate that the carriers in NdFeAsO_{1-y} are subject to stronger scattering than in LaFeAsO_{1-y} .

4. Summary

We have shown an intimate correlation between normal-state resistivity $\rho(T)$ and transition temperature T_C in the oxypnictide superconductors. It is found that high- T_C superconductivity with T_C exceeding 50K is seen when $\rho(T) \sim T$ in the normal state. In the case of LaFeAsO_{1-y} whose maximum T_C is $\sim 28\text{K}$, $\rho(T)$ is dominated by a T^2 -term at any doping level. Such marked contrast suggests that the strong carrier scattering giving rise to T -linear resistivity is characteristic of high- T_C superconductivity in iron-based compounds and might be linked to the pairing interaction.

Figure 2: Relationship between T_C and the exponent n of $\rho(T) \sim T^n$ determined based on Fig. 1 for LaFeAsO_{1-y} and NdFeAsO_{1-y} . The inset shows the magnetic-field dependence of transverse magnetoresistance.

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