Electrical and Magnetic Properties of (Sr$_{1-x}$R$_x$F)FeAs ($R = \text{La, Nd}$)

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Abstract. We have investigated the electrical and magnetic properties of (Sr$_{1-x}$R$_x$F)FeAs ($R = \text{La, Nd}$). (Sr$_{1-x}$La$_x$F)FeAs shows superconductivity. The superconducting transition temperature $T_c$ and the transition width $\Delta T_c$ of (Sr$_{0.6}$La$_{0.4}$F)FeAs are 26.1 K and 2.1 K, respectively. The value of the temperature derivative of the upper critical magnetic field ($\partial H_{c2}/\partial T$) at $T_c$ is $\sim -1.4$ T/K and the estimated value of $H_{c2}$ at 0 K exceeds 26 T. On the other hand, (Sr$_{1-x}$Nd$_x$F)FeAs is not superconducting but shows a metallic conductivity. Although all compounds show a weak ferromagnetism, the origin of this ferromagnetism is considered to be due to tiny Fe impurities.

1. Introduction
Since the discovery of high $T_c$ superconductivity in (LaO$_{1-x}$F$_x$)FeAs [1], many researches on the iron-based superconductors have been carried out. The new superconducting compound (Sr$_{1-x}$La$_x$F)FeAs with $x = 0.4$ is found, and its superconducting transition temperature $T_c$ is 29 K [2]. The crystal structure of the parent compound (SrF)FeAs is as same as that of (LaO)FeP. It belongs to the space group $P4/nmm$. The SrF and FeAs layers are stacked along the c axis, and Fe and F atoms are surrounded tetrahedrally by As and Sr atoms, respectively. Recently, it is reported that (Sr$_{0.5}$Sm$_{0.5}$F)FeAs is a superconductor with $T_c$ of 56 K [3]. However, superconducting properties of them have not been clarified now.

Then, in this study, we have prepared (Sr$_{1-x}$R$_x$F)FeAs ($R = \text{La, Nd}$) and investigated their electric and magnetic properties.

2. Experimental
Stoichiometric amounts of Sr (99 %) pieces and La (99.9 %), Nd (99.9 %), Fe (99.9%), SrF$_2$ (99.9%) and As (99.9%) powders were weighed and mixed in Ar atmosphere. They were sealed in evacuated quartz tubes, and were heated at 500 °C for 12 h, and at 950 °C for 60 h. Then, they were mixed and pressed into bars in Ar atmosphere. Pressed bars were sealed in evacuated quartz tubes again, and were heated at 500 °C for 12 h and at 1150 °C for 72 h.

The powder X-ray diffraction (XRD) measurement was carried out by Rigaku RINT 1100. The electrical resistivity and magnetization measurements were carried out by Quantum Design PPMS system.

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3. Results and Discussion

Figure 1 shows XRD patterns of (SrF)FeAs and (Sr_{0.6}R_{0.4}F)FeAs (R=La, Nd). The crystal structure is as same as that of (LaO)FeP. The SrF_2 and unknown impurities are observed in all samples. Unreacted Nd impurity is observed in (Sr_{0.6}Nd_{0.4}F)FeAs. Figure 2 shows the x dependence of the lattice parameters of (Sr_{1-x}Nd_xF)FeAs (R = La, Nd). Lattice parameters a and c increase with x in both cases.

Figure 3 (a) shows the temperature dependence of the electrical resistivity (\rho-T curve) of (Sr_{1-x}La_xF)FeAs. The anomaly due to the SDW transition is observed at 170 K in (SrF)FeAs. This anomaly decreases with x. The absolute value of the electrical resistivity firstly decreases and then increases with x. The superconducting transition temperature \( T_c \) and the transition width \( \Delta T_c \) of (Sr_{0.6}La_{0.4}F)FeAs are 26.1 K and 2.1 K, respectively. This value of \( T_c \) is lower than that of previous report [2]. Figure 3 (b) shows \( \rho-T \) curves measured at various magnetic fields. The value of the temperature derivative of the upper critical magnetic field (\( \partial H_{c2}/\partial T \)) at \( T_c \) is -1.4 T/K and the estimated value of \( H_{c2} \) at 0 K becomes 26 T, assuming the parabolic approximation.

Figure 4 shows \( \rho-T \) curves of (Sr_{1-x}Nd_xF)FeAs. All compounds do not show superconductivity above 3 K, but show a metallic conductivity. The absolute value of the electrical resistivity firstly decreases and gradually increases with x. This behavior is similar to that of (Sr_{1-x}La_xF)FeAs.

Figure 1. The XRD patterns; (a) (SrF)FeAs, (b) (Sr_{0.6}La_{0.4}F)FeAs, and (c) (Sr_{0.6}Nd_{0.4}F)FeAs

Figure 2. The \( x \) dependence of the lattice parameters; (a) (Sr_{1-x}La_xF)FeAs, and (b) (Sr_{1-x}Nd_xF)FeAs.
Figure 3. (a) Temperature dependence of the electrical resistivity of (Sr$_{1-x}$La$_x$F)FeAs, and (b) that of (Sr$_{0.6}$La$_{0.4}$F)FeAs measured at various magnetic fields. Horizontal line indicates the midpoint of the electrical resistivity, and vertical lines indicate the midpoint temperatures.

Figure 4. Temperature dependence of the electrical resistivity of (Sr$_{1-x}$Nd$_x$F)FeAs.

The anomaly at 170 K due to the SDW transition is not observed in $x = 0.2$ and emerges again in $x \geq 0.3$. In (Sr$_{0.6}$Nd$_{0.4}$F)FeAs, the electrical resistivity increases slightly below 20 K.

Figure 5 shows the temperature dependence of the field cooled (FC) magnetization of (Sr$_{0.6}$R$_{0.4}$F)FeAs (R = La, Nd) measured at $H = 1$ T. All compounds show a ferromagnetic behavior. It cannot be easily concluded whether the ferromagnetism is intrinsic or extrinsic. However, as the Curie temperatures exceed the room temperature, the origin of this ferromagnetism may be tiny amounts of Fe impurities which are not observed in XRD measurement. The value of the magnetization, $0.2 \times 10^3$ emu/mol observed in (SrF)FeAs corresponds to $\sim 2\%$ Fe impurities. The increase of the magnetization with $x$ in (Sr$_{1-x}$R$_x$F)FeAs (R = La, Nd) may be also due to the increase of Fe impurities.

Figure 6 shows the temperature dependence of the FC and zero field cooled (ZFC) magnetic susceptibilities of (Sr$_{0.6}$La$_{0.4}$F)FeAs measured at $H = 0.01$ T. The superconducting transition is observed at 26 K, which agrees with $\rho-T$ curve, and the superconducting volume fraction is $\sim 25\%$. This volume fraction is rather large compared with the previous report for (Sr$_{0.5}$Sm$_{0.5}$F)FeAs [3].

4. Conclusion
We have prepared (Sr$_{1-x}$R$_x$F)FeAs ($0 \leq x \leq 0.4$) (R = La, Nd). Lattice parameters increase with $x$ in both cases. (Sr$_{0.6}$La$_{0.4}$F)FeAs shows a superconductivity with $T_c$ of 26
K. The upper magnetic critical field $H_{c2}$ at 0 K is estimated to exceed 26 T. On the other hand, $(\text{Sr}_{1-x}\text{Nd}_x\text{F})\text{FeAs}$ does not show a superconductivity, but shows a metallic conductivity. Although all compounds show a ferromagnetism, the origin of the ferromagnetism is considered to be due to Fe impurities.

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