Anomalous Hall Effect and Magnetoresistance of $SrFe_{1-x}Co_xO_{3-\delta}$

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Abstract

To investigate possible effects of non-trivial spin structures or spin chiral order on the Hall resistivity ρ_H, transport and magnetic studies have been carried out on polycrystalline samples of $SrFe_{1-x}Co_xO_{3-\delta}$. Although neutron diffraction studies have not found the long range ordered state of non-trivial spin structure, results of the magnetization(M) measurements indicate that the local structure is non-trivial. It is also found that the systems have a transition to the reentrant spin glass state. Unusual behavior of the magnetic field(H)- and temperature(T)-dependences of ρ_H indicates the existence of effects of the non-trivial spin structure on ρ_H in the reentrant spin glass systems.

Key words: $SrFe_{1-x}Co_xO_{3-\delta}$; anomalous Hall resistivity; spin chiral order; reentrant spin glass

$SrFe_{1-x}Co_xO_{3-\delta}$ with distorted perovskite structure exhibits the helical spin ordering in the region of $x < 0.2$ [1]. The modulation vector $\boldsymbol{k}$ is along the [111] direction and has the absolute value of $\sim 0.112\ |\boldsymbol{a}^*|$ [2], where $\boldsymbol{a}^*$ is the reciprocal lattice unit vector. For $x \geq 0.2$, the system has the ferromagnetic moment [1,3]. The electrical resistivity ρ decreases with increasing x and depends on the amount of the oxygen deficiency δ. The metallic state can be realized by synthesizing samples under the high oxygen pressure [1].

Polycrystalline samples of $SrFe_{1-x}Co_xO_{3-\delta}$ have been synthesized at 1100 °C and annealed at 320 °C under the oxygen pressure of 60 atm for 2 days, and the temperature(T)- and magnetic field(H)-dependences of ρ, Hall resistivities ρ_H and magnetizations M have been measured to clarify, first, if the spin structure in the ferromagnetic state is collinear or non-trivial one, and then, to search, if it is non-trivial, possible effects of such kind of structure (or effects of the order of the spin chirality χ, where χ is defined as $\chi \equiv S_1 \cdot (S_2 \times S_3)$ for three spins S_1, S_2 and S_3) on ρ_H, which are often argued [4,5] since the observation of the very striking T- and H-dependences of ρ_H of $Nd_2Mo_2O_7$ [6–8]. The

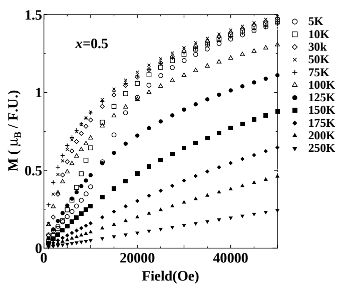

Fig. 1. M-H curves of $SrFe_{1-x}Co_xO_{3-\delta}$ taken at various temperatures.

amount of the oxygen deficiency δ were determined by the thermogravimetry. It changes from 0.06 for $x = 0$ to 0.2 for $x = 0.8$. Data of ρ and ρ_H were measured by the standard four probe methods. The magnetizations M were measured by a SQUID magnetometer. In the measurements of ρ_H and M, the same samples were used to avoid the ambiguity introduced by the demagnetization effects. T and H were changed in the same order in both measurements to avoid the ambiguity introduced by the hysteretic effects. Neutron diffraction data were taken with the T1-1 triple axis spectrometer at JRR-3M at Tokai.

The resistivities ρ of the samples with $x < 0.2$ exhibit

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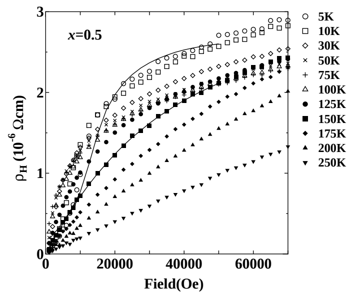

Fig. 2. H-dependence of $\rho_{\rm H}$ of $SrFe_{1-x}Co_xO_{3-\delta}$ at various T values. Solid lines are the results of the fittings at 5K and 150K.

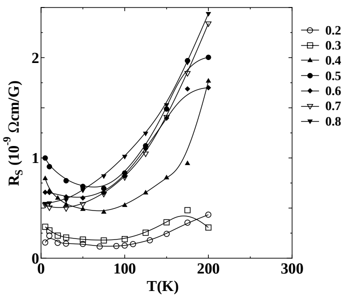

Fig. 3. Anomalous Hall coefficient $R_{\rm s}$ of $SrFe_{1-x}Co_xO_{3-\delta}$ obtained by the fittings is plotted against T.

the rapid increase with decreasing T, while the ρ values for $x \geq 0.2$ are of the order of $1 \sim 2$ mΩ·cm above 60 K and increase slightly as T is lowered down to 5 K. The magnetoresistance $\Delta\rho(H)/\rho$ have been analyzed by a model of the metallic grains connected with insulating barriers, where the barrier height for the conducting electrons depends on their spin directions relative to that of the magnetization of the barrier, and rather satisfactory explanation of the observe data has been obtained. However, here, we do not describe the details.

The M-H curves taken with increasing H after the zero field cooling are shown in Fig. 1 for the sample with $x = 0.5$, for example, for which $\delta = 0.14$ and the Curie point $T_{\rm C}$ is $\sim$ 100 K. We find that below $\sim$ 50 K, M in the relatively low field region decreases with decreasing T. Because the significant hysteresis of the M-T curves is observed below $\sim$ 70 K($<$ T$_{\rm C}$), when the temperature is varied up and then, down, we think that the behavior is the manifestation of the reentrant spin glass phase. The fact that the neutron magnetic reflection data observed around the nuclear Bragg points indicate that the reflection becomes diffuse-like with decreasing T, is one of the supports of the idea. We also find that M does not saturate up to the present maximum field H (= 5 T). Considering this and that the hysteretic behavior is observed even at the H value larger than 1 T, we think that the local spin structure is non-trivial one, which is derived by adding ferromagnetic component to the helical structure similar to that observed for $x = 0$. We also add here that the hysteretic behavior is most significant for $x = 0.4 \sim 0.6$.

In Fig. 2, the H-dependence of $\rho_{\rm H}$ is shown for $x = 0.5$, for example. The data have been fitted by the equation $\rho_{\rm H} = R_0 H + 4\pi R_{\rm s} M$, which is usually used for ordinary ferromagnets. Satisfactory fits have been obtained in the T-region where the hysteretic behavior of the M-T curves is not seen(See the fitted line at 150 K in Fig.2, for example.). In contrast, in the low T region where the hysteretic behavior is significant, we cannot obtain satisfactory fits(See the fitted line at 5 K in Fig.2, for example.). It is remarkable that the T- and H-regions where the fitted curves deviate from the data, coincides with those of the glassy behavior of the magnetizations M. In Fig. 3, the T-dependences of the $R_{\rm s}$ values obtained by the fittings are shown for various x values. In the relatively high T region, $R_{\rm s}$ decreases, as for ordinary ferromagnets, with decreasing T. However, for $x = 0.4 \sim 0.6$, where the glassy behavior is most significant, it increases with decreasing T, in the glassy phase.

As one of the candidate mechanisms of the observed deviation of $\rho_{\rm H}$, we note the possible coupling of the uniform magnetization M and the spin chirality χ proposed by Tatara and Kawamura [5]. They have pointed out that the coupling induces the uniform component of the spin chirality, which induces a new component of anomalous Hall conductivity or Hall resistivity in addition to those treated by the classical theories [9,10]. It is interesting to investigate further to clarify the role of the chirality in the determination on the Hall resistivity $\rho_{\rm H}$.

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