Magnetotransport properties and lattice effects of Cr-doped $Nd_{0.45}Sr_{0.55}MnO_3$ perovskite

Jun Takeuchi [1], Norihiko Yamane, Seitaro Hirahara, Kiyotaka Miyoshi, Kenji Fujiwara

Department of Material Science, Shimane University, Matsue 690-8504, Japan

Abstract

The effect of Cr-doping on the Mn site in the perovskite $Nd_{0.45}Sr_{0.55}MnO_3$ has been studied by using the magnetization, magnetoresistance, thermal expansion and magnetostriction measurements. Mother material changes from paramagnetic semiconducting state (PMS) to antiferromagnetic metallic one (AFM) at $T_{N(M)}$=230 K. 5 at.% Cr-doped material changes from PMS to ferromagnetic metallic state (FMM) at T_C=250 K and then to antiferromagnetic insulating one (AFMI) at $T_{N(I)}$=140 K. Either the application of 7T magnetic field or additional 5 at.% Cr-doping on this material completely suppresses the AFMI keeping the FMM down to the lowest temperature (10K) measured. Observed characteristic anomalies near $T_{N(M)}$, T_C and $T_{N(I)}$ indicate strong correlation between d-electron e_g state and lattice state.

Key words: metal-insulator transition; doping effect; colossal magnetoresistance;

There has been renewed interest in physical properties of hole-doped perovskite manganites $Ln_{1-x}A_xMnO_3$, since these materials show exotic electronic transport and magnetic properties [1,2]. Double exchange (DE) interactions between Mn^{3+}/Mn^{4+} pairs and the lattice distortion are believed to play an important role for the properties of these materials. Recently, it has been revealed that a small amount of Cr-doping on the Mn site in $Ln_{0.5}Ca_{0.5}MnO_3$ has a strong influence on the magnetic and electronic properties [3–6]. In this work, we have undertaken a study of the effect of Cr-doping in $Nd_{0.45}Sr_{0.55}Mn_{1-x}Cr_xO_3$ single crystals grown by the floating-zone method having been useful for doped single crystals $Nd_{0.67}Sr_{0.33}Mn_{1-x}M_xO_3$ and $Nd_{0.5}Sr_{0.5}Mn_{1-x}M_xO_3$ (M=Fe, Cr) [7,8].

Upper panel of Fig. 1 shows Cr-concentration determined by EPMA analysis on about 10 points per each grown crystal $Nd_{0.45}Sr_{0.55}Mn_{1-x}Cr_xO_3$ as a function of nominal concentration x. Well-defined linear relationship evidences the good homogeneity of the samples.

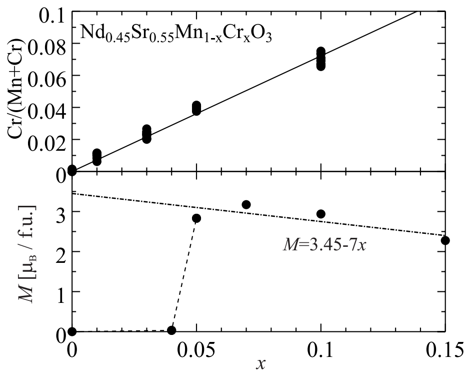

Fig. 1. Cr-concentration determined by EPMA analysis (upper panel) and average magnetic moment per TM site (lower panel) as a function of x.

The temperature dependence of the magnetization measured by the SQUID magnetometer is shown in the upper panel of Fig. 2. The mother material (x=0) shows an antiferromagnetic transition at $T_{N(M)}$=230

[1] Corresponding author.
E-mail: jun-tak@riko.shimane-u.ac.jp

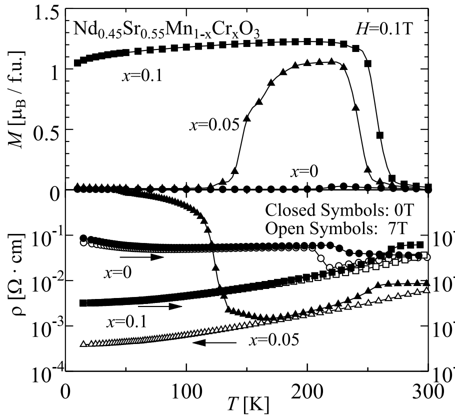

Fig. 2. Temperature dependence of the magnetization (upper panel) and the resistivity (lower panel) for $Nd_{0.45}Sr_{0.55}Mn_{1-x}Cr_xO_3$.

K, where a small peak appears in the magnetization. The doping of 5 at.% Cr^{3+} ions changes its magnetic state to have T_C=250 K and $T_{N(I)}$=140K. The doping of 10 at.% Cr^{3+} ions raises T_C to be 260 K, and keeps the ferromagnetic state to the lowest temperature (10K) measured. The temperature dependence of the resistivity is shown in the lower panel of this figure. The resistivity for mother material shows metallic behavior below $T_{N(M)}$, indicating that this material is antiferromagnetic metal (AFMM), though the resistivity increases slowly at lower temperatures. The resistivity for 5 at.% Cr-doped material shows metallic behavior below T_C and abrupt increase below $T_{N(I)}$ indicating that this material changes from ferromagnetic metal (FMM) to antiferromagnetic insulator (AFMI) through $T_{N(I)}$. The application of 7T magnetic field completely suppresses the AFMI keeping the FMM down to the lowest temperature. The resistivity for 10 at.% Cr-doped material shows metallic conduction below T_C keeping the FMM state even under zero magnetic field.

The average magnetic moment per TM site (Mn or Cr) determined by the magnetization at 10K under 7T is shown in lower panel of Fig. 1. The relation M=3.45-7x is well satisfied in the FMM region above x=0.07, which means Cr^{3+} spins are opposite to Mn^{3+} and Mn^{4+} spins. These results suggest the mechanism for Cr-induced FMM state. The antiferromagnetic interaction between Cr and Mn ions invokes the ferromagnetic DE interaction between Mn^{3+} and Mn^{4+}. The FMM state will be realized when DE interaction overcomes antiferromagnetic super-exchange (SE) interaction between Mn ions.

The applied magnetic field dependence of the magnetization and resistivity (upper panel) and magnetostriction measured by strain gauge method (lower panel) for $Nd_{0.45}Sr_{0.55}Mn_{0.95}Cr_{0.05}O_3$ at 10K is shown

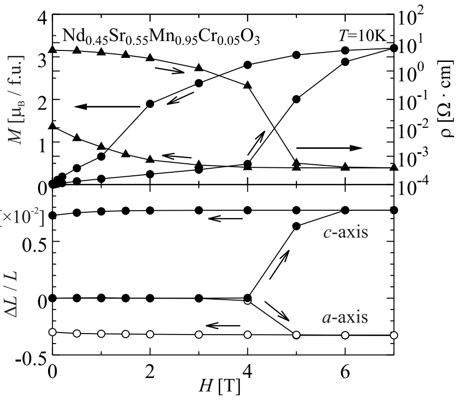

Fig. 3. Magnetization and resistivity (upper panel) and magnetostriction (lower panel) for $Nd_{0.45}Sr_{0.55}Mn_{0.95}Cr_{0.05}O_3$ as a function of applied field.

in Fig. 3. The magnetization increases abruptly above 4T field and the resistivity decreases abruptly by 4 order of magnitude above this field, which indicates that field-induced AFMI-FMM transition is realized. Not only electron state but also lattice state changes above 4T field, that is, c-axis length is expanded and a-axis is contracted. This result means strong correlation between d-electron e_g state, which carries magnetic and transport properties, and lattice state. Another characteristic is large hysteresis in the magnetization, resistivity and magnetostriction as shown in this figure, which is probably due to the field-induced domain in the competing ferromagnetic DE and antiferromagnetic SE interactions. No hysteresis is observed in well-defined AFMM state for mother material and in well-defined FMM state for 10 at.% Cr-doped material.

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