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Electrical and Magnetic Properties of Neodymium Monoxide Thin Film

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Abstract

NdO (001) epitaxial thin film was fabricated on $YAlO_3$ (110) substrate by pulsed laser deposition method for the first time. According to electrical conductivity and magnetic susceptibility measurements, ferromagnetic ordering seemingly coexists with antiferromagnetic ordering below 20 K.

1. Introduction

Rare earth compounds show unique electrical and magnetic properties due to the interaction between localized electrons in 4f orbital and itinerant electrons in 5d band. Especially, rare earth monochalcogenides *REX* (*RE* = rare earth element, *X* = S, Se, Te) have been widely investigated as model rare earth compounds, because of their simple rock-salt structure. For example, neodymium monochalcogenides Nd*X*, are known to exhibit antiferromagnetism, plausibly as a result of superexchange interaction of Nd-*X*-Nd bond in analogy with Eu monochalcogenides [1]. While NdTe and NdSe have a [111] oriented collinear spin configuration, NdS with the smallest lattice constant (a = 5.69 Å) showed tilted magnetic moments along [331] direction [2], probably caused by weak ferromagnetic interaction induced by the short distance between two neighboring Nd ions. Hence, it is expected that ferromagnetic exchange interaction is more dominant in NdO (a = 4.99 Å), whose lattice constant is smaller than that of NdS [3]. However, NdO is thermodynamically unstable and its physical properties have not been sufficiently investigated so far because of the poor crystallinity of polycrystalline powder specimens synthesized under high pressure [3]. In this study, we fabricated high quality NdO epitaxial thin films and investigated their electric and magnetic properties.

2. Experiment

Pulsed laser deposition method was used for thin film synthesis of NdO, because it has enabled to synthesize metastable YO and SmO epitaxial thin films with the aid of epitaxial stabilization [4,5]. Nd metal target was irradiated by KrF excimer laser (λ = 248 nm) in an ultrahigh vacuum chamber with various oxygen pressures. Thin films were grown on $YAlO_3$ (110) substrate (a = 5.22 Å) at 250 °C. After the deposition, the NdO films were *in situ* capped with an amorphous AlO_x layer for protection against oxidation [5]. Crystal structure of the thin films was analyzed with X-ray diffraction method (XRD). Electrical resistivity and carrier density were evaluated by the four-probe and Hall effect measurements by using Hall bar patterned samples. The electrical and magnetic measurements were performed by physical property measurement system (Quantum Design Model 6000) and superconducting quantum interference device magnetometer (Quantum Design, MPMS), respectively.

3. Result and Discussion

From the out-of-plane θ–2θ XRD pattern (Fig. 1a), only 00*n* diffractions of NdO thin film were seen. From the reciprocal space map, it was confirmed that the NdO (001) thin film were epitaxially grown. Full width at half maximum of the rocking curve around 002 peak was 1.764 degree, indicating a relatively good crystallinity in spite of the metastable phase. The in-plane and out-of-plane lattice constants were 5.09 Å and 5.11 Å, respectively. The lattice constants were slightly larger than the lattice constants of polycrystalline specimens [3].

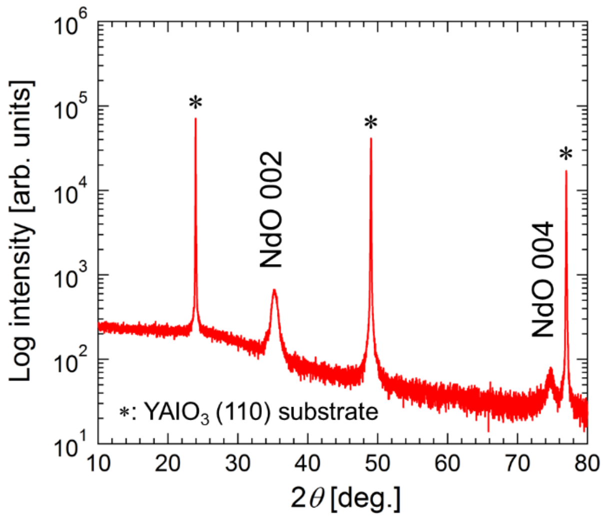

Fig. 1 Out-of-plane θ–2θ XRD pattern of NdO thin film on $YAlO_3$ substrate.

Carrier density at 300 K was evaluated to be 3.31 × 10^{22} cm^{-3} from the Hall effect measurement, suggesting that each Nd ion provides approximately one itinerant electron with the electron configuration of $[Xe]4f^35d^1$ being consistent with the other Nd*X*. Electrical resistivity of NdO film showed a metallic temperature dependence with a characteristic kink structure at T^* = 20 K (Fig. 2). This kink was suppressed by applying external magnetic field.

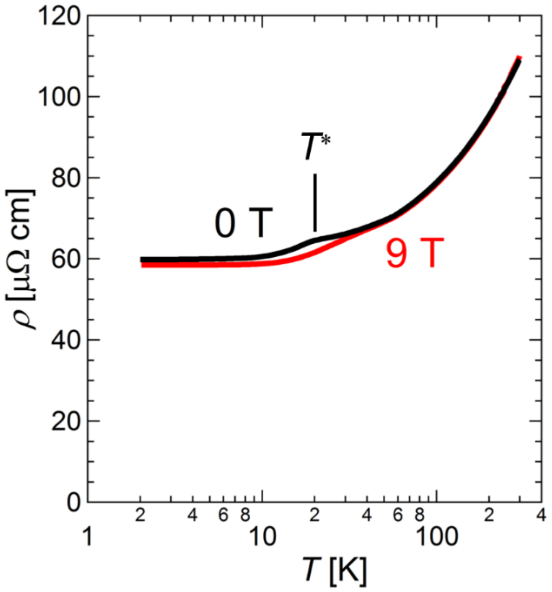

Fig. 2 Temperature dependence of electrical resistivity ρ of NdO thin film under magnetic field of 0 T (black) and 9 T (red) along out-of-plane.

Temperature dependence of magnetic susceptibility showed a drop at T^* in zero-field cooling, suggesting an antiferromagnetic ordering similar to the other Nd*X* members (Fig. 3). On the other hand, magnetic susceptibility in field cooling significantly increased with decreasing temperature, and nonnegligible hysteretic behavior was observed in the magnetization curve at 5 K (inset of Fig. 3), implying a competition between antiferromagnetic and ferromagnetic ordering. The ferromagnetic ordering was probably caused by significant direct exchange interaction between neighboring Nd ions, because of the small oxygen ions.

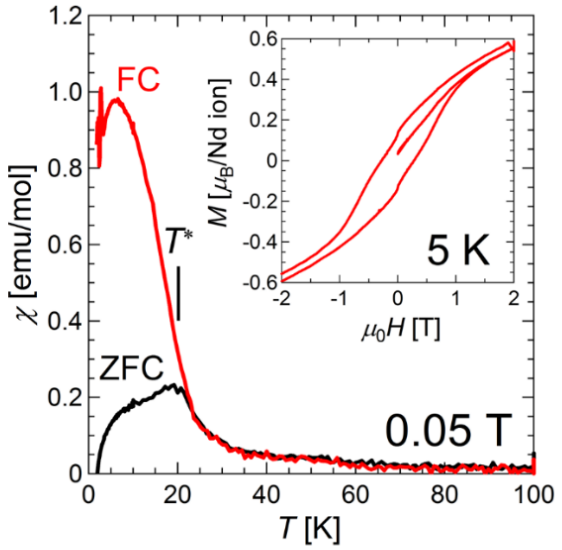

Fig. 3 Temperature dependence of magnetic susceptibility of NdO thin film in zero-field cooling (black) and field cooling (red) at 0.05 T along in-plane. Inset shows magnetization curve at 5 K.

3. Conclusions

We succeeded in fabrication of NdO epitaxial thin film for the first time and investigated its electrical and magnetic properties. Temperature dependence of electrical resistivity and magnetic susceptibility suggests a competition between antiferromagnetic and ferromagnetic ordering below $T^* = 20$ K, probably caused by the small lattice constants of NdO owing to the oxygen ions. Its simple rock-salt structure will be useful building block of magnetic heterostructure.

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