Magnetism of a HoN thin film

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Rare-earth monopnictides like HoN, DyN, or ErN are semiconductors with typical band gaps between 0.73 and 1.3 eV. The fact that they exhibit ferromagnetic ordering at low temperatures makes them possible candidates for spintronic applications requiring an intrinsically ferromagnetic semiconductor. We have conducted a temperature and field-dependent polarized neutron reflectometry study of a 15 nm HoN thin film using the D3 reflectometer at the Chalk River Laboratories, Canada. Polarized neutron reflectometry (PNR) allows deriving the magnetic depth profile of a ferromagnetic thin film with Angstrom resolution. By measuring the reflectivity for polarized neutrons at different temperatures and external fields, the magnetic properties of the HoN film were characterized.

Figure 1a) shows the R^+ and R^- reflectivity of the 15 nm HoN film in an external field of $\mu_0 H_{ext}$ = 3 T at a temperature of T = 5 K. The sample shows a clear splitting between R^+ and R^- unambiguously proving that the HoN thin film exhibits a magnetic polarization at this field and temperature. To derive quantitative information, these measurements were fitted and the best result is shown in the figure as green and blue lines. The quality of the fit is very good reproducing all features of the reflectivity. The resulting scattering length density which is equivalent to the magnetic and chemical depth profile is shown in Figure 1b). The HoN film has a magnetic polarization of 3.3 μ_B/f.u. at T = 5 K and in an external magnetic field of $\mu_0 H_{ext}$ = +3 T. The magnetic moment is three times smaller than in HoN powder which could either be related to the polycrystalline structure of the film or to a quenching of the orbital magnetic moment due to crystal field effects. The PNR clearly shows that the bulk of the 16 nm HoN film is homogeneously magnetic and only the region close to the upper interface exhibits a slightly altered magnetic (M = 3.3 → 2.9 μ_B/f.u.) and chemical (ρ = 10.1 → 9.9 g/cm³) SLD which is very likely due to a small off stoichiometry close to the YSZ capping layer.

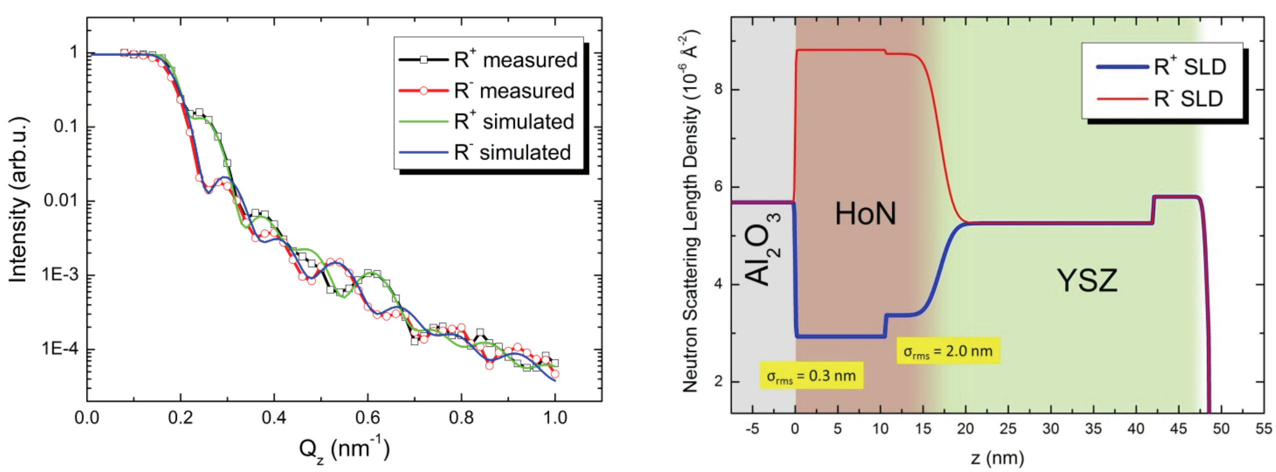

Fig. 1 a) Polarized neutron reflectometry at T = 5K for parallel (R^+) and antiparallel (R^-) alignment of neutron spin and external magnetic field. The external magnetic field is $\mu_0 H_{ext}$ = +3T and the sample was field cooled prior to measuring. The data was fitted using a simulation to derive the scattering length density and the best fitting result is shown as green and blue line in subfigure 1a). Subfigure 1b) shows the resulting scattering length density for the sample.

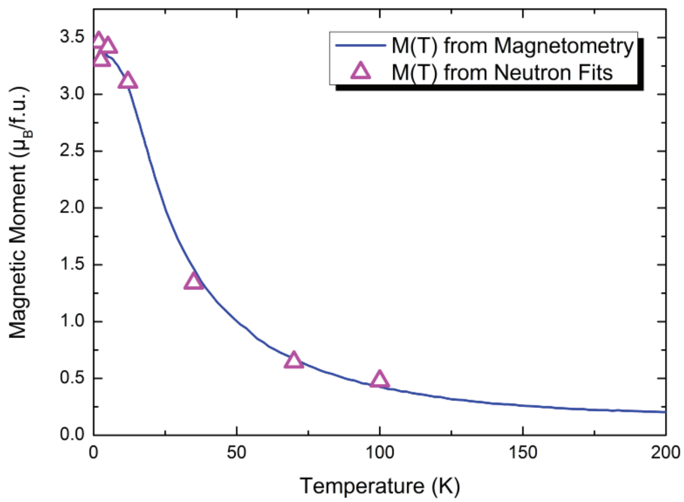

Fig. 2 Temperature dependence of the magnetic moment of the film derived from PNR and SQUID magnetometry. The measurements prove that the film magnetization is homogeneous and that the reduced moment is not the result of a magnetically dead layer.

The measurements were then repeated for temperatures ranging from T = 2 K to T = 300 K to characterize the temperature evolution of the magnetism and to confirm that the whole layer shows the same temperature trends and thereby magnetic properties. Figure 2 shows the magnetic moment of HoN derived from magnetometry and PNR. Both complementary measurements are in good agreement. The most notable feature of both curves is that the magnetic moment settles for temperatures below 5 K. This is a clear indication of ferromagnetic ordering in the film. The measurements prove that the film magnetization is homogeneous and that the reduced moment is not the result of a magnetically dead layer.