Magnetism and structure of ε-Fe_2O_3 films grown on GaN and MgO buffer layer

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1. Introduction

Hybridization of semiconducting and magnetic materials into a single heterostructure is believed to provide opportunities for designing novel functional spintronic devices. The iron oxides form a big family of magnetic materials exhibiting a rich variety of outstanding physical properties. The metastable ε-Fe_2O_3 is known to be the most intriguing ferrimagnetic and multiferroic iron oxide phase exhibiting a bunch of exciting physical properties both below and above room temperature [1]. The feasibility to grow the exotic ε-Fe_2O_3 phase along with three other iron oxide phases (Fe_3O_4, α-Fe_2O_3 and γ-Fe_2O_3) has been demonstrated [2]. Placing the iron oxide film having controllable spontaneous magnetization / polarization next to the active zone of the GaN-based semiconductor devices is expected to add magnetic related functionality to these devices and to present interest from the point of view of potential use in novel designs for (opto-) electronic and spintronic applications.

1. Gich, M. et al., Advanced Materials, 26, 4645–4652 (2014).
2. Suturin, S. et al., arXiv 1712.05632 [cond-mat.mtrl-sci] 1712.05632 (2017).
3. Ukleev, V., et al., Scientific reports, 8,1, 8741 (2018).

2. Experiment

Polarized neutron reflectometry (PNR) experiment has been performed at SHARAKU time-of-flight instrument. The temperature and magnetic field at the instrument were controlled by 4T horizontal field cryomagnet. Polarization of the direct beam was measured by analyzer for each value of magnetic field used in the experiment. The amplitudes of PNR curves were corrected for polarization efficiency.

4. Results

PNR experiment has been performed for layer-resolved measurement of magnetization distribution inside the heterostructure. PNR curves $R(Q_z)$ measured at temperatures T = 5 K are shown in Fig 1. Note, that all the curves measured at high field B = 3 T are shifted along vertical axis for clarity. The splitting of $R^+(Q_z)$ and $R^-(Q_z)$ is proportional to the net magnetization of the film along the field direction. PNR data was fitted assuming the model consisted of GaN, transition layer (interface) and ε-Fe_2O_3 layer, consequently. The initial model contained the table values of scattering lengths and densities and nominal thickness of iron oxide layer, then the densities and thicknesses of Fe_2O_3 and interface layer were allowed to vary freely in the fitting routine. Iron oxide density is consistent compared to the calculated value. The minimum of the fitting algorithm corresponds to the model containing an interface layer with thickness of 80-90 Å and roughness 30 Å between iron oxide and GaN buffer. In contrast to our previous result [3], the nuclear SLD of the transition layer is much lower than one of Fe_2O_3, GaN and $GaFeO_3$ (Fig. 2). Moreover, the interface layer becomes non-magnetic (right panel in Fig. 2 corresponds to the magnetic SLD).

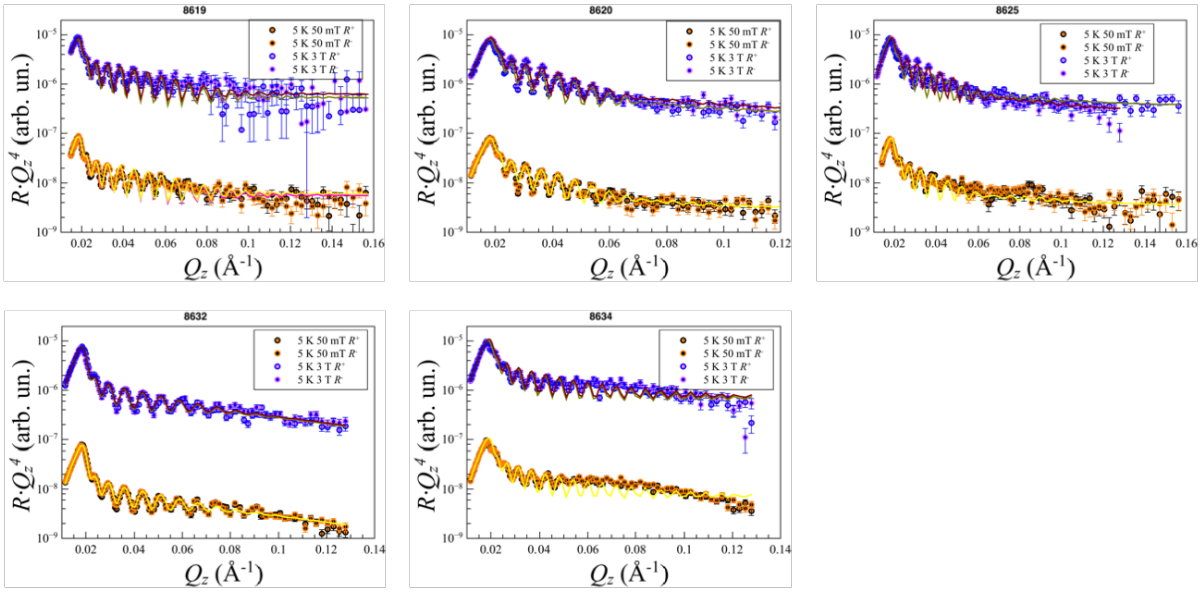

Figure 1 Low-temperature PNR curves measured from ε-Fe_2O_3/GaN samples grown at various conditions.

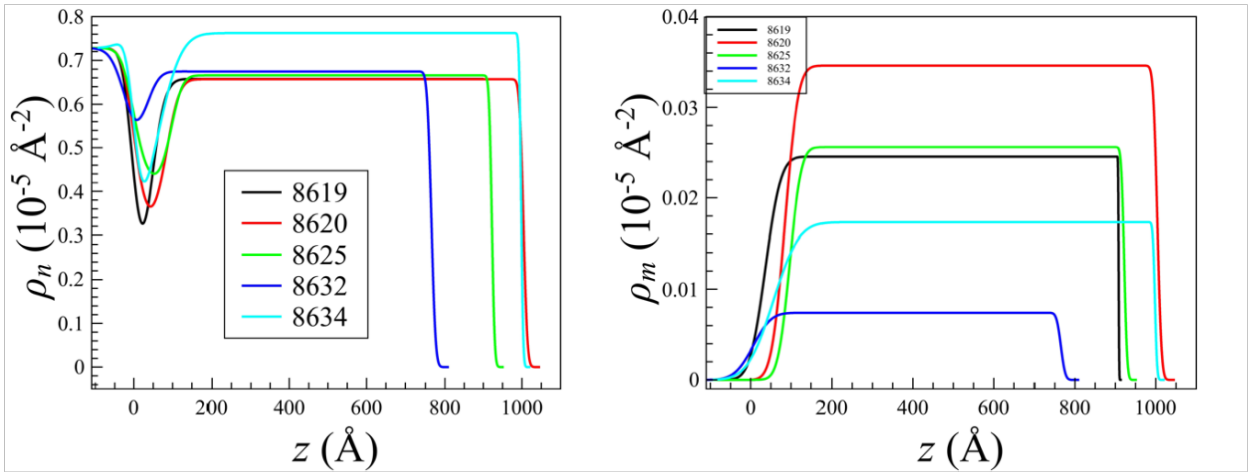

Figure 2 Nuclear and magnetic SLD profiles corresponding to the fitted PNR models.

4. Conclusion

The polarized neutron reflectometry data suggests that the composition and density of interface layer resembles non-magnetic Ga_2O and soft-magnetic $GaFeO_3$ depending on the growth conditions. While the in-depth density variation is in agreement with the transmission electron microscopy measurements, the layer-resolved magnetization profiles are qualitatively consistent with the unusual wasp-waist magnetization curves observed by SQUID [3]. A noticeable Ga diffusion into the ε-Fe_2O_3 films has been detected by providing a clue to the mechanisms guiding the nucleation of exotic metastable epsilon ferrite phase on GaN at high growth temperature and influencing the interfacial properties of the studied films [3]. The diffusion of Ga ions can be successfully blocked by growth of Ga_2O interlayer between GaN and iron oxide film.