Experimental report

30/07/2019

Proposal:	**5-54-288**	**Council:**	10/2018
Title:	Magnetisation and diffusion depth profiles in ultrathin epitaxial YIG/GGG(111) layers for low-relaxationspin wave applications		
Research area:	Materials		

This proposal is a new proposal

Main proposer: **Victor UKLEEV**

Experimental team: Alexander KOROVIN
Alexei VOROBIEV
Victor UKLEEV
Alexander SUKHANOV
Dmitry CHERNYSHOV

Local contacts: Alexei VOROBIEV

Samples: Y3Fe5O12/Gd3Ga5O12

Instrument	Requested days	Allocated days	From	To
SUPERADAM	7	3	14/06/2019	17/06/2019

Abstract:

Epitaxial growth of YIG / GGG (111) films exhibiting atomically flat step-and-terrace surface, sharp and flat interfaces, low coercivity, rectangular magnetization loops and low damping spin wave propagation has been achieved by means of pulsed laser deposition. However, our recent ferromagnetic resonance (FMR) and polarized neutron reflectometry (PNR) experiments have shown a 6 nm thick interface layer between YIG and GGG, suggesting migration of Ga atoms from the substrate across the interface. As seen from FMR, the thickness of this layer increases with the growth temperature indicating temperature-activated mechanism of migration. We propose to further elucidate this issue and explore the mechanisms of Gd and Ga migration by means of PNR. This knowledge is necessary to further optimize the YIG epitaxial growth technology aimed at creation of high-quality ultra-thin YIG layers for spintronics applications.

5-54-288 Experimental report

Magnetisation and diffusion depth profiles in ultrathin epitaxial YIG/GGG(111) layers for low-relaxationspin wave applications

An advanced pulsed laser deposition (PLD) approach to grow ultrathin epitaxial $Y_3Fe_5O_{12}$ (YIG) / $Gd_3Ga_5O_{12}$ (GGG) (111) layers of high crystalline quality has been recently developed in Ioffe Institute [1-4]. The films exhibit atomically flat step-and-terrace surface, sharp and flat low roughness interfaces, low coercivity rectangular magnetization loops and low damping spin wave propagation [4]. In our previous work by the powerful combination of the experimental techniques, including preliminary polarized neutron reflectometry (PNR) measured at SuperADAM (ILL) instrument, we have shown the high-temperature growth results to the thermal diffusion of the Ga ions from the GGG substrate into the YIG film, resulting in the broadening of the ferromagnetic resonance spectra and damping of interfacial magnetization [4]. Present study was aimed to further explore the structural and magnetic features at the YIG/GGG interface and optimize the epitaxial growth technology aimed at creation of high-quality ultra-thin YIG layers for spintronics applications.

The experiment has been performed at the polarized monochromatic instrument SuperADAM without polarization analysis. Standard 0.8 T vertical field electromagnet and rotatable sample holder for room=temperature experiments were employed. Neutrons with wavelengths $\lambda = 5.21$ were used. Polarization of the direct beam was measured by analyzer prior to the experiment. Flipping ratio of 250 was found at applied magnetic field of 70 Oe. Further the experiment was performed without polarization analysis, i.e. R^+ and R^- components of reflectivity were acquired. Reflected beam was detected by two-dimensional position-sensitive detector. PNR experiment has been performed for layer-resolved measurement of magnetization distribution inside the YIG/GGG epitaxial heterostructures grown at two $T = 700^o$ C and subsequently annealed during 1 and 3 hours at $T = 880^o$ C, respectively. To be assured about the identical structure of the annealed and un-annealed samples, as-grown films were cut into two pieces prior to the annealing. Therefore, the size of the resulted PLD-grown samples for PNR measurement was only 3-4x7 mm^2. Nevertheless, SuperADAM, being the low-background instrument provided us with the reasonable PNR datasets. Four samples in total have been measured during the 3 days of the allocated beamtime.

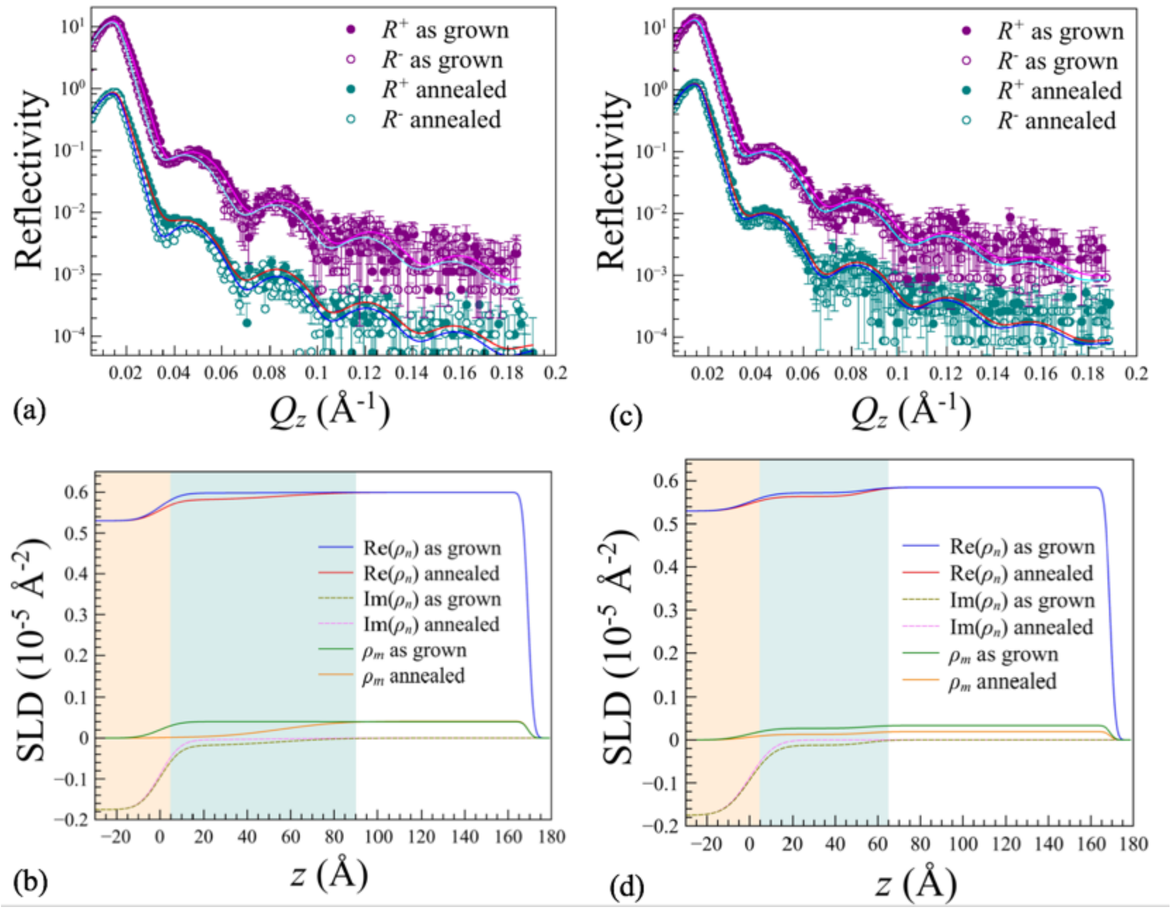

Figure 1 (a) PNR curves and (b) corresponding SLD profiles of the as-grown and 3 h annealed YIG/GGG sample. (c) PNR curves and (d) corresponding SLD profiles of the as-grown and 1 h annealed YIG/GGG sample.

PNR curves $R(Q_z)$ measured at T = 300 K at H = 70 Oe are shown in Fig. 1 are the main outcome of the work. Figs. 1a,b show the PNR data measured from as-grown and 3 hour-annealed YIG (20 nm)/GGG sample, and their scattering density profiles (SLD), respectively. The data was fitted via GenX software package [5] using minimal model containing two layers onto GGG substrate. The nuclear SLDs of the GGG substrate and main YIG layer were fixed to the values corresponding to the bulk densities. The interfacial (transition) layer was modeled by $Gd_xY_{3-x}Ga_yFe_{5-y}O_{12}$ chemical composition assuming the gradual substitution of Gd atoms by Y atoms and Ga atoms by Fe atoms. The depth-resolved structural and magnetic SLD profiles delivered by fitting are shown in Fig. 1b. The resultant nuclear and magnetic SLD profiles $\rho_n(z)$ and $\rho_m(z)$ of as-grown and annealed samples show drastically different behavior. The as-grown sample demonstrates sharp YIG/GGG interface without a signature of chemical mixing and magnetically homogeneous. However, the annealing results into reduction of nuclear SLD due to the thermal migration of the Ga atoms the YIG main layer. Correspondingly, the magnetic moment of the interfacial 8 nm-thick layer is sufficiently damped. Similar, but less pronounced behavior is has been also observed in the sample that has been annealed for 1 hour (Figs. 1c,d).

In conclusion, our experiment revealed significant degradation of the chemical and magnetic sharpness of the YIG/GGG interface after annealing. While the crystallinity of the main YIG layer can be improved by high-temperature treatment, the interfacial layer degradation occurs. Therefore, we conclude that the annealing procedure is extremely undesirable for the ultra-thin (<100 nm) YIG/GGG heterostructures due to the significant volume of the degraded part.

References

[1] N. S. Sokolov et al. Journal of Applied Physics, 119(2), 023903 (2016).

[2] L.V. Lutsev et al., Applied Physics Letters, 108(18), 182402 (2016).

[3] B. B. Krichevtsov et al, Sci. Technol. Adv. Mater., vol. 18, no. 1, pp. 351–363 (2017)

[4] S. Suturin, et al., Phys. Rev. Mat., 2.10, 104404 (2018).

[5] Björck, M. & Andersson, G., J. Appl. Crystallogr. 40, 1174–1178 (2007).