Magneto-optical Kerr effect characterisation of static and dynamic processes in a Thulium Iron Garnet thin film

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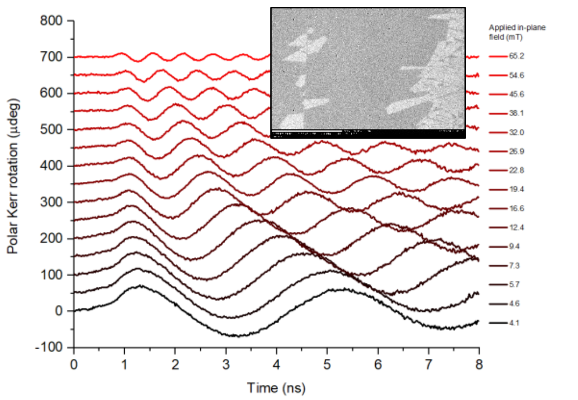
Thulium Iron Garnet (TmIG) films have recently shown promise for ultralow switching current density in spintronic applications[1] due to efficient spin transport at TmIG/Pt interfaces[2]. Understanding the TmIG equilibrium state and corresponding sub-nanosecond magnetization dynamics will allow further optimisation for spintronic devices. Here we use a combination of wide-field and time-resolved scanning Kerr microscopies to characterise the ferrimagnetic domain structure and magnetization dynamics of 6.4 nm thick TmIG grown by pulsed laser deposition on a (111)-oriented Gadolinium Gallium Garnet (GGG) substrate, as in [2]. The GGG substrate was not pre-annealed so that the effect of interface defects could be explored. Out-of-plane and in-plane magnetometry (hysteresis loops and domain imaging) was carried out for two principal wavelengths of 400 nm and 520 nm to identify the optimum magneto-optical contrast. The resonance frequency as a function of in-plane magnetic field was then extracted from time-resolved measurements at the optimum wavelength. Hysteresis loops showed an out-of-plane magnetic anisotropy with a low coercivity below 1 mT. However, the magnetization could be pulled in-plane with only moderate applied fields indicating that the perpendicular magnetic anisotropy was low. Furthermore, domain images reveal a combination of large area uniform magnetization domains punctuated with regions of finer labyrinth-type domains that are correlated with surface defects that may introduce local strain, for which TmIG has a significant dependence[1]. Such variations would not be readily detectable in bulk characterisation techniques. Time-resolved measurements of precession of the magnetization biased in-plane show an almost linear dependence on in-plane magnetic field, precession frequency into the sub-GHz regime, and long relaxation time as expected for the low damping of TmIG previously reported ~1×10^{-3} [1-3]. These results show that magneto-optical Kerr effect measurements will be a critical tool for the continued optimisation of such materials for spintronic applications.

Fig. 1. Time-resolved polar Kerr signals acquired over full range of time delay (8 ns) and magnetic field ~4 - 65 mT. The long relaxation of the precession signal indicates low damping. Relaxation time, precession frequency, and amplitude extracted from damped sinusoid fitting function will be presented. Inset, a wide field Kerr image (scale bar 200 µm) acquired during switching shows geometric domain patterns that are likely associated with GGG surface defects that may induce local strain on the TmIG film.



[1] C. N. Wu, et al. *High-quality thulium iron garnet films with tunable perpendicular magnetic anisotropy by off-axis sputtering – correlation between magnetic properties and film strain*. Sci Rep **8**, 11087 (2018).
[2] A. Quindeau *et al*. *$Tm_3Fe_5O_{12}$/Pt Heterostructures with Perpendicular Magnetic Anisotropy for Spintronic Applications*, Adv. Electron. Mater., **3**, 1600376 (2017);
[3] R. Timalsina *et al*. *Mapping of Spin-Wave Transport in Thulium Iron Garnet Thin Films Using Diamond Quantum Microscopy*, Adv. Electron. Mater., **10**, 2300648 (2024),