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High-Performance Thin-Film Garnet Materials for Magneto-Optic and Nanophotonic Applications

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Abstract: Since the 1960's, Magneto-optic (MO) garnet materials have been studied extensively. These materials can possess world-record MO performance characteristics in terms of Faraday rotation and optical quality. Among the rear-earth-doped garnets, the Bi-substituted iron garnet is the best candidate for use as a functional material in different integrated-optics, imaging/image processing applications and also in forward-looking applications e.g. the design of metamaterials with non-reciprocal properties. We have established a set of technologies for fabricating ferrimagnetic garnet films of type $(\text{BiDy})_3(\text{FeGa})_5\text{O}_{12}$ and also garnet-oxide nanocomposite $(\text{BiDy})_3(\text{FeGa})_5\text{O}_{12} : \text{Bi}_2\text{O}_3$ layers possessing record-high MO quality across the visible spectral range [1] using RF-magnetron sputtering and oven annealing. Our MO garnet films possess excellent optical and magnetic properties, which make them very attractive and promising for a large range of optoelectronic, photonics-related and MO imaging applications.

The specific Faraday rotations measured in our materials were up to about $\Theta_F = 10$ deg/ μm at 532 nm and 2.6 deg/ μm at 635 nm. At the same time, the optical absorption coefficients of between $\alpha = 6000$ -7000 cm^{-1} at 532 nm and 1100-1300 cm^{-1} at 635 nm have been achieved. These parameters are comparable to those achievable so far only in monocrystalline garnet layers fabricated using liquid-phase epitaxy [2]. The resulting record-high MO figure of merit ($2\Theta_F/\alpha$) of our composite garnet-oxide films is about $43^\circ(+/-2^\circ)$ at 635 nm, which makes them very attractive for nano-structured magneto-photonic components and devices. We typically observe high-contrast magnetic domain patterns suitable for MO imaging and very small (submicron-scale) magnetic domain sizes in thin garnet films

after annealing the sputtered layers at temperatures near 600 °C. Very small grains (garnet crystallites of size 40-50 nm) have been imaged within the film microstructures using TEM (Fig. 1(a)). The strong uniaxial magnetic anisotropy in films of type $(\text{BiDy})_3(\text{FeGa})_5\text{O}_{12} : \text{Bi}_2\text{O}_3$ is provided by dysprosium substitution and results in nearly-ideal square-shaped magnetic hysteresis loops suitable for ultrafast switching-type operations (Fig. 1(b)). Some degree of control over the coercive force and switching field properties of iron-garnet- Bi_2O_3 films has been achieved by adjusting the stoichiometry of films. The nanocomposite films have been found to possess switching fields of only 500-600 Oe, compared to about 1kOe in $\text{Bi}_2\text{Dy}_1\text{Fe}_4\text{Ga}_1\text{O}_{12}$ layers.

X-ray diffractometry (XRD) datasets of several material types deposited onto glass substrates are shown in Fig. 1(c). The data confirmed the presence of garnet phase with body-centered cubic lattice type in our garnet films and garnet-oxide composites crystallized by oven-annealing processes. The lattice constants of several MO layer types were derived from the XRD data and these varied with layer stoichiometry (from 12.520 Å for $\text{Bi}_2\text{Dy}_1\text{Fe}_4\text{Ga}_1\text{O}_{12}$ to 12.579 Å for a composite with an added 22% of Bi_2O_3). This suggests that extra Bi_2O_3 content added during the deposition leads to increased Bi substitution in dodecahedral sublattice of garnet. This increases the specific Faraday rotation, as is observed in co-sputtered compositions with up to about 25-30 vol.% of extra Bi oxide. The average garnet grain size calculated from XRD peak linewidths matched closely that observed in high-resolution TEM images.

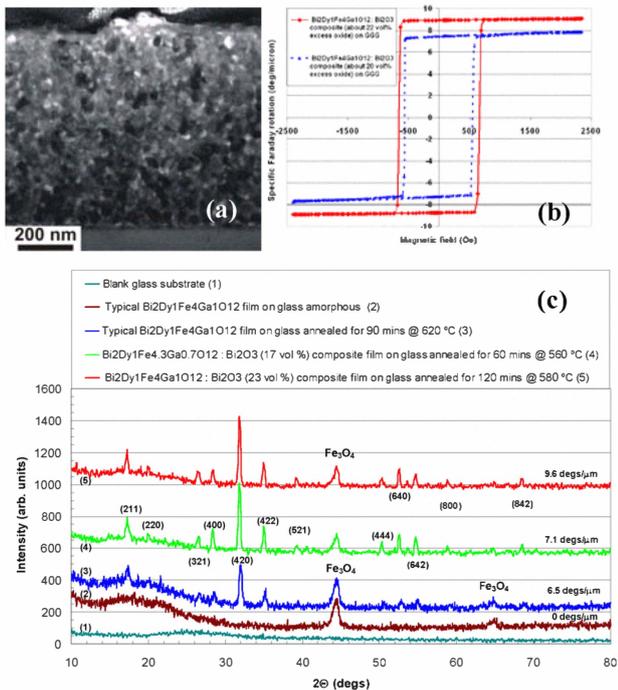


Fig. 1. A cross-section microstructure image (TEM) of a garnet layer on a GGG substrate (a, the image is courtesy of Electron Microscope Unit, UNSW, Sydney, Australia); measured hysteresis loops of Faraday rotation of two different garnet-oxide composite layers (b); and XRD datasets of several garnet-oxide layer types deposited onto Corning 1737 glass substrates (c). Specific Faraday rotations measured at 532 nm in all crystallized garnet materials are shown.

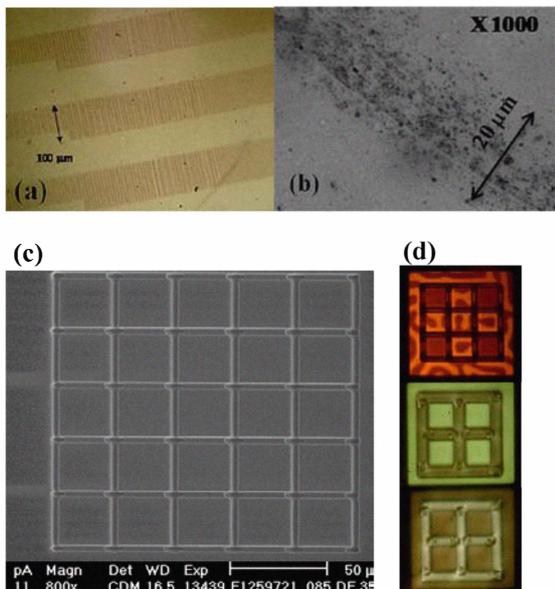


Fig. 2. Applications of MO garnet films in magnetic field imaging and ultrafast image generation. (a) polarisation microscope image of data tracks recorded on a 1.44 MB diskette obtained using visible light; (b) a UV polarisation microscopy image of a credit

card's data-stripe section memorised by a garnet film with submicron-size domains that enable high-resolution imaging; (c) a 5x5 matrix of isolated MO pixels formed within a sputtered garnet layer using FIB milling, and (d) polarisation microscopy images of 3x3 and 2x2 MO pixel arrays with magnetically-isolated pixels proposed for ultrafast image generation devices.

High-contrast images of data recorded onto magnetic media have been memorised by our garnet films after a brief surface contact with these media and later revealed using polarisation microscopy (Fig. 2 (a,b)). Using UV wavelengths and films with very small domain size, ultra-high-resolution MO images can in principle be generated. MO devices for ultrafast image generation (transparencies and spatial light modulators) composed of magnetically-isolated pixel arrays are currently under development. The pixel states will be controlled by a network of conductors deposited by ion-assisted Pt deposition within the FIB-milled grooves formed in garnet films. The switching of individual magnetically-isolated pixels within the arrays has so far been demonstrated using external magnetic fields. Work is ongoing towards the development of arbitrarily-addressable pixel arrays which will find applications in ultrafast spatial light modulators and image recognition systems.

Summary

The properties and applications of RF-sputtered nanocomposite films of composition $(\text{BiDy})_3(\text{FeGa})_5\text{O}_{12} : \text{Bi}_2\text{O}_3$ with very high MO performance have been discussed.

References

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