Large area fabrication of electrically switchable magnetic garnet using a plasma process

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Electrically switchable ferrimagnetic garnets (FMGs) have garnered renewed interest due to their insulating nature and compensated magnetic moments. These materials, particularly thulium iron garnet (TmIG), have shown promise in spin-orbitronics applications, such as low-power magnetic switching and high-speed domain wall motion. Historically, FMG research was driven by magnetic and magneto-optical properties of YIG ($Y_3Fe_5O_{12}$) grown by flux and liquid phase epitaxy (LPE). The need for thinner films led to advancements in chemical deposition and later, high-precision techniques like pulsed laser deposition (PLD) and magnetron sputtering. TmIG films grown on GGG substrates exhibit strong perpendicular magnetic anisotropy and Dzyaloshinskii-Moriya interaction (DMI), essential for spin-orbit torque (SOT) applications.

We developed uniform, high-quality TmIG films over 80 mm in the diameter using on-axis magnetron sputtering, a scalable and industry-friendly method based on a low-temperature plasma technology. While ion irradiation from negative oxygen ions was initially a concern, we found minimal impact on magnetic properties and spin transport.

Composition uniformity was optimized via TRIM simulations, accounting for differences in sputter rates and atomic mass (Tm:Fe ≈ 3:1).

Radio-frequency (RF) magnetron sputtering was performed using a TmIG target and a gadolinium gallium garnet (GGG) (111) substrate at room temperature. The post annealing was carried out after the sputtering at 800°C in an O_2 atmosphere. The structural and magnetic properties were characterized using X-ray diffraction (XRD) and magnetometry. These results are disclosed elsewhere[1,2] and will be discussed in the presentation.

The spin-oribit torque (SOT) was measured by fabricating micro Hall cross devices by TmIG/Pt heterostructure. From the harmonic measurements, the effective spin Hall angle was evaluated as 0.015. Current-induced magnetization switching was demonstrated at a low threshold of 1.5×10^{11} A/m². From these results, we concluded that the effects of the irradiated energetic cations are negligibly small if the growth conditions are optimized.

FMGs offer a platform for exploring ultrafast domain wall motion at room temperature due to their high domain wall mobility. They also offer a playground for transport measurement using topological materials by breaking the spacious inversion symmetry and the time reversal symmetry. FMGs are also ideal for studying pure SOT and orbital Rashba effects, thanks to their insulating character and simple current paths. Thus, these results pave a way toward both fundamental and applied physics based on the unique magnetic insulators.

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