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Spin pumping contribution to the magnetization damping in $Tm_3Fe_5O_{12}$/W bilayers

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Abstract

In this work, thulium iron garnet ($Tm_3Fe_5O_{12}$ – TmIG (20 nm)/Tungsten(W)(t) bilayers, sputtered on top of gadolinium gallium garnet (1 1 1) substrate, were used to investigate spin pumping (SP) line broadening mechanism in Ferromagnetic Resonance (FMR). The TmIG, films prior and after tungsten cap layer deposition, were investigated employing FMR and X-ray diffraction techniques. The TmIG films showed (1 1 1) orientation and perpendicular magnetic anisotropy (PMA). Due to the interface TmIG/W, when the TmIG magnetization is in resonance a spin current is pumped out the TmIG into the W layer, increasing the damping of the magnetization. Measuring the out-of-plane angular dependence of the FMR resonance field and linewidth, we were able to obtain solely the SP contribution to the line broadening, filtering Gilbert, mosaicity, and two magnon scattering mechanisms.

Introduction

Magnetic materials with perpendicular magnetic anisotropy (PMA) are of great interest in information storage technologies for achieving high-density nonvolatile memory owing principally to its scalability and thermal stability. As magnetic film thickness approaches to few nanometers, PMA, having its origin in the inversion breaking symmetry that occurs at surfaces and interfaces can be strong enough to dominate most of the magnetic properties of the magnetic systems. The study of PMA has been focused on metallic ferromagnets and multilayers [1], [2], [3], [4], while insulators-based systems have been scarcely explored, despite its advantageous properties such as low magnetic damping, large spin decay length [5], [6], [7] and the lack of resistive Joule heating in the magnetic insulator (MI) layer. When MIs are combined with heavy metals (HM) like Pt, Pd, Ta, or W, various interesting spin-current related phenomena emerge, such as the spin pumping effect (SPE) [8], [9], [10], [11], [12], spin Seebeck effect (SSE) [5], [13], [14], [15], [16], spin Hall effect (SHE) [17], [18], [19] and spin–orbit torque (SOT) [20], [21], [22], [23]. All these effects turn the HM/MI bilayers into an ideal platform to investigate interfacial interactions and related phenomena. PMA also has been consistently reported in epitaxial ferromagnetic insulators like $Tm_3Fe_5O_{12}$ (TmIG) grown on (1 1 1)-oriented gadolinium gallium garnet (GGG) substrates [24], [25], [26]. Additionally, recent reports indicate that TmIG thin films capped with different HM layers could suffer significant changes in their magnetic anisotropies [27], [28] suggesting the need for a detailed study concerning the magnetic properties of TmIG/HM bilayers.

Ferromagnetic resonance (FMR) spectroscopy is a powerful technique for studying basic magnetic properties such as saturation magnetization, g-factor, and magnetic damping. In addition, the absorption linewidth measured by FMR also gives accurate information about the magnetic anisotropies and interfacial interactions in ferromagnetic thin films and magnetic multilayers. In this work, we investigated the influence that a thin W layer deposited on top of a TmIG thin film can have on its magnetic anisotropy and magnetization relaxation. Through the simultaneous fitting of the out-of-plane angular dependence of the FMR resonance field and linewidth, we were able to show how the capping process could change the effective magnetization, g-factor, and even the magnetization relaxation mechanisms. The latter is described by a superposition of different mechanisms, such as the intrinsic Gilbert damping, magnetic inhomogeneities, two-magnon scattering (TMS), and spin pumping. The analysis carried out in this work highlight the importance of correctly characterize the magnetic properties in HM/TmIG bilayers. Neglecting the TMS and magnetic inhomogeneities when analyzing the Gilbert damping factor in HM/MI systems could lead to overestimates of key quantitates like the effective spin-mixing conductance that determines the spin transmission through the interface.

Section snippets

Experiment

The TmIG ($Tm_3Fe_5O_{12}$) films were deposited over (1 1 1)-oriented GGG ($Gd_3Ga_5O_{12}$) using RF sputtering technique. Before the deposition, the substrates were annealed in a quartz tube at 1000 °C for 6 h with an oxygen flow. Next, the substrates were placed in an ultrahigh vacuum custom-built sputtering system with a base pressure of 5×10^{-8} Torr, containing a commercial TmIG target with a purity of 99.9%. The TmIG films were deposited at a rate of 1.4 nm/min at room temperature in a pure argon…

Theoretical approach

To determine the magnetic parameters from the dependence of the FMR resonance field (H_R) and linewidth (ΔH) with the out-of-plane angle θ_H it is necessary to consider a realistic model which includes the following contributions to the free magnetic energy: Zeeman, demagnetizing field, and surface anisotropy energy:$\varepsilon = -\boldsymbol{M} \cdot \boldsymbol{H}_0 + 2\pi M_S^2 \left(\frac{\boldsymbol{M}\cdot\hat{\boldsymbol{n}}}{M_S^2}\right)^2 - K_\perp \left(\frac{\boldsymbol{M}\cdot\hat{\boldsymbol{n}}}{M_S^2}\right)^2.$

Here $\boldsymbol{M}$ and M_S are the TmIG magnetization vector and saturation magnetization, respectively, $\boldsymbol{H}_0$ is the applied magnetic field, the surface…

Results

Fig. 2 shows the fitting results of the out-of-plane angular dependence of H_R and ΔH for sample A before (Fig. 2a) and after (Fig. 2b) the deposition of the W layer. The results of the other five remaining samples are shown in the supplemental material. As we can observe, after depositing the W layer on top of the TmIG film, the linewidths for each θ_H in general increase.

For example, for the case in which $\theta_H = 90°$, that is, for the in-plane configuration ΔH varies from 86 Oe (before the W…

Conclusions

In summary, we used the FMR technique to investigate the magnetic anisotropies and magnetic relaxation mechanisms in TmIG/W bilayers as a function of the W thickness. By the simultaneous fitting of the out-of-plane angular dependence of the FMR magnetic field and linewidth, it was possible to extract the surface anisotropy field, the g-factor, and the different magnetization relaxation mechanisms present in the samples before and after the W deposition. The magnetic relaxation mechanisms…

CRediT authorship contribution statement

A.B. Oliveira: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **R.L. Rodríguez-Suárez:** Conceptualization, Methodology, Validation, Formal analysis, Funding acquisition, Writing - review & editing. **L.H. Vilela-Leão:** Conceptualization, Resources, Writing - review & editing. **G.L.S. Vilela:** Resources. **M. Gamino:** Writing - review & editing. **E.F. Silva:** Writing - review & editing. **F. Bohn:** Writing - review & …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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