Spin Plasmonics

We demonstrated during this ICC-IMR project that the FMR absorption of a very thin insulating magnetic film can be enhanced by placing it on top of a dielectric. We find that the signal is enhanced by at least an order of magnitude due to a new nonreciprocal interface resonance that is a mixture of the magnetic surface plasmon mode and a wave-guide mode. Our model applies to experiments performed in the YIG/GGG system. Indeed, our picture resolves the disagreement on the magnitude of the spin diffusion lengths obtained with the FMR and the Brillouin scattering techniques. It also provides for a way to make new adaptive thin film miniaturized photonic nonreciprocal devices with low loss.

Spintronics with magnetic insulators exhibits less loss than spintronics with magnetic metals. To study spintronics with magnetic insulators, recent studies involve driving with external electromagnetic (EM) fields thin magnetic yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG) films [1-3] with thicknesses of the order of nanometers. In metals, due to the eddy current, the signal is absorbed within a skin depth that is of the order of a micron. In insulators no currents can be generated, the signal is absorbed in a length scale of the order of a wavelength that is of the order of a cm. The ferromagnetic resonance (FMR) signal is much weakened when the film becomes very thin and it is important to find ways to increase the signal strength. Ever since the discovery of surface enhanced Raman scattering, much work has been done in the area of plasmonics in enhancing the absorption of EM fields on films with surface resonances. For magnetic systems, there is a corresponding analog of the ideas of plasmonics [4], which involves the magnetic surface plasmon (MSP) that is also known as the Damon Eshbach mode. The MSP comes from a coupling of the electromagnetic wave and the surface spin wave that produces a magnetic charge density, similar to the surface plasmon, which comes from a coupling of the electromagnetic wave and the electronic charge density. In this project we demonstrated how to enhance the absorption of EM waves for insulating magnetic films with spin plasmonics [4]. Motivated by ideas in plasmonics, we consider placing the film on top of a dielectric as shown in Fig. 1.

We found that the signal is enhanced by orders of magnitude due to a nonreciprocal interface resonance that is a mixture of the magnetic surface plasmon mode and a wave-guide mode. The line width of absorption is reduced by an order of magnitude less than the Gilbert damping parameter. At some frequency, the group velocity of this resonance is negative.

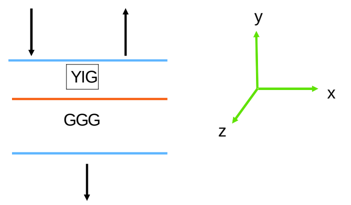

Fig.1: The geometry of the system and the wave vectors we have in mind. The coordinate system is also shown.

Experiments have been carried out in which very thin YIG films are grown on a gadolinium gallium garnet. ($Gd_3Ga_5O_{12}$, GGG) substrate. Theoretically, the substrate can be considered the dielectric.

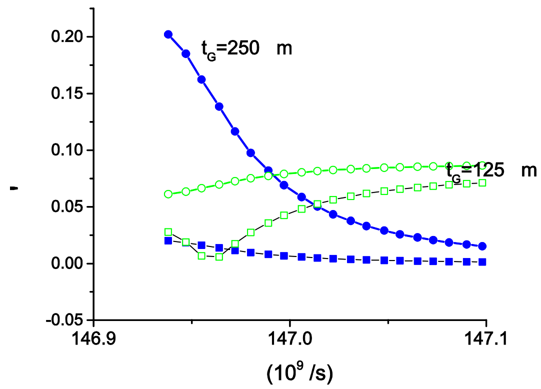

Fig.2: The normalized effective Gilbert damping parameter as a function of the angular frequency in units of 10 GHz. The thickness of the GGG is 250 micron (solid symbols) and 125 micron (open symbols). The larger damping curves are for the smaller wave vector resonances.

Keywords: ferromagnetic, insulator
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Recent experimental results of the damping of FMR [1,2] but not Brillouin scattering [3] can be interpreted in this light. Our theory provides for an explanation of the different results for the spin diffusion length obtained with the two experimental techniques. It also provides for a way to make new adaptive thin film miniaturized photonic nonreciprocal devices with low loss.

References

[1] C.W. Sandweg, Y. Kajiwara, A.V. Chumak, A. A. Serga, V. I. Vasyuchka,1 M. B. Jungfleisch, E. Saitoh, and B. Hillebrands, Phys. Rev. Lett. **106**, 216601 (2011).
[2] B. Heinrich *et al.*, Phys. Rev. Lett. 107, 066604 (2011); Appl. Phys. Lett. 100, 092403 (2012); H. Chang, P. Li, W. Zhang, T. Liu, A. Hoffmann, L. Deng, and M. Wu, IEEE Magn. Lett. **5**, 6700104 (2014).
[3] M. B. Jungfleisch, W.i Zhang, W. Jiang, H. Chang, J. Sklenar, S. M. Wu, J. E. Pearson, A. Bhattacharya, J. B. Ketterson, M. Wu, and A. Hoffmann, arXiv:1412.4032v1 and to appear in J. Appl. Phys. May, (2015).
[4] S. T. Chui, Z.-F. Lin, Chin. Phys. B **23** 117802. (2014); S. T. Chui, J. Appl. Phys. **117**, 183902 (2015).

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