# Magnetisation dynamics of magnetically coupled multilayer thin films

(in-depth report)

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Ferromagnetic resonance (FMR) is an important technique to characterise the static and dynamic properties of magnetic thin films. Here we present results from three different magnetically coupled systems, (i) synthetic antiferromagnets (SAF) [1] (ii) synthetic ferrimagnetics (SFM) [2] and (iii) hybrid anisotropy multilayers where one constituent layer with in-plane anisotropy is placed in intimate contact with a layer with perpendicular anisotropy [3]. We explore through measurement and simulation both the mutual influence of the individual layers and their effect on resonant modes. Fig.1 shows a schematic of magnetisation dynamics in a SAF or SFM. The coupling in SAFs generates a zero field optic mode with frequencies > 20 GHz, fig. 1b. SFMs possess the same layer structure found in SAFs (fig.1a) but SFMs describe the case where the interlayer exchange coupling promotes the parallel alignment of the layers. The frequency and phase of the dynamic response of these structures depends sensitively on the interlayer exchange coupling as well as on the individual layer magnetizations. Our results show that the dynamic response of the two ferromagnetic layers has an orthogonal dependence on the difference in layer magnetization and interlayer coupling allowing both parameters to be determined accurately. In addition, we obtain the phases of the resonant modes, a hitherto challenging measurement, and thus show that the conventional acoustic and optical description does not fully capture the intricacies of SFM dynamics. The third case of hybrid anisotropy coupled films allows the resonant frequency to be tuned by varying the angle of applied magnetic field with a clear single frequency maximum > 20 GHz observed for an angle of ≈30 deg. in $[Co(0.6)/Pd(0.9)]_8/NiFe(4.3)$ (dimensions in nm) films. Our simulations demonstrate that the modes observed in these hybrid films are essentially PSSW in nature and provide insights into the exchange length. These systems offer new opportunities for magnon spintronics.

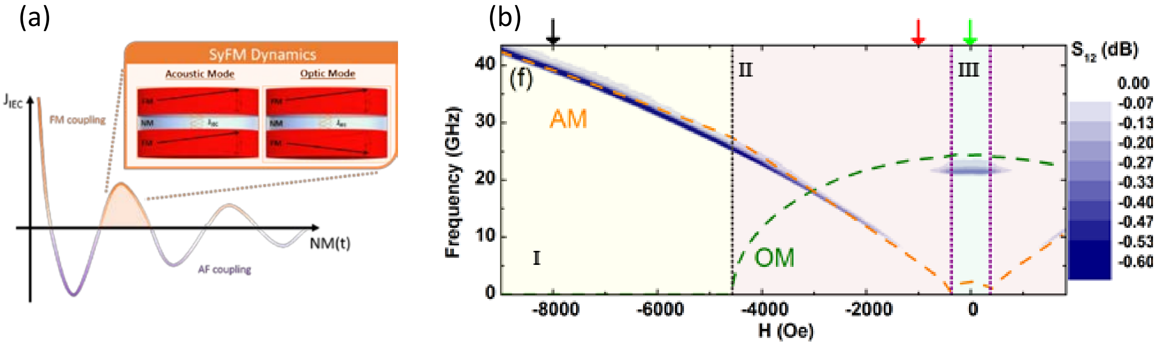


Fig.1: (a) Schematic of SAF/SFM showing acoustic (AM) and optic modes (OM) with 2nd SAF peak highlighted, (b) three magnetisation regimes for 2nd SAF peak: region I where the magnetizations of the layers are ferromagnetically aligned, region II where the magnetisation of each layer are undergoing a spin flop reorientation and region III where the magnetizations are in an antiferromagnetic configuration [1].

[1] H. Waring, N. Johansson, I. Vera-Marun and T. Thomson, "Zero-field Optic Mode beyond 20 GHz in a Synthetic Antiferromagnet," *Phys. Rev. Appl.,* vol. 13, no. 3, 2020.

[2] H. Waring, Y. Li, C. Moutafis, I. Vera-Marun and T. Thomson, "Magnetization Dynamics in Synthetic Ferromagnetic Thin Films," *Phys. Rev. B,* p. 014419, 2021.

[3] C. Morrison, J. J. Miles, T. N. Anh Nguyen, Y. Fang, R. K. Dumas, J. Akerman and T. Thomson, "Exchange coupling in hybrid anisotropy magnetic multilayers quantified by vector magnetometry," *J. Appl. Phys.,* vol. 117, p. 17B526, 2015.