Perpendicular standing spin waves in thin films with Dzyaloshinskii-Moriya interaction

E. Lu[1], K.S. Buchanan[2], K.L. Livesey[1,3*]

[1] School of Information and Physical Sciences, University of Newcastle, Australia, [2] Physics Department, Colorado State University, USA, [3] Department of Physics, University of Colorado – Colorado Springs, USA
*klivesey@uccs.edu

The interfacial Dzyaloshinskii-Moriya interaction (DMI) is known to induce nonreciprocity in spin wave propagation within the plane of magnetic thin films.[1] This nonreciprocity can be utilized to design spin wave devices such as signal isolators and also provides an important means to quantitatively measure the magnitude of the DMI. Analytical expressions have been developed to estimate the effects of DMI on spin waves by assuming the magnetization dynamics are uniform throughout a film thickness. Here, we relax this assumption and calculate spin wave dispersion relations for not just the uniform thickness mode, but also for the perpendicular standing spin waves (PSSWs).

We use a so-called atomic layer method to calculate spin waves, which has been used before to study films without DMI (see for example [2]). Coupled magnetic equations of motion are written for each atomic plane within a thin film made of one or more materials. The method is tested against known analytic and numerical theories, and is then used to calculate the PSSW frequencies and mode profiles for single and bilayer magnetic films with interfacial DMI applied to the outer interfaces. These calculations show that the PSSW mode frequencies depend nonlinearly on the interfacial DMI strength. This is surprising as it is not predicted under the usual assumption of uniform precession through the film thickness. We develop a new analytic estimate to explain this nonlinear dependence.

Figure 1 shows an example of the frequency nonreciprocity, $\Delta f = f(+k_x) - f(-k_x)$, as a function of in-plane spin wave number k_x. The data is calculated for 20 atomic layers of iron, with the exchange stiffness assumed to be softer in the top half versus the bottom half of the film. Identical DMI strength (D=3.9 mJ/m^2) on the top (solid line) or bottom (dashed line) of the film produces different nonreciprocity. This is one example of the nontrivial dependence of frequency on the DMI strength.

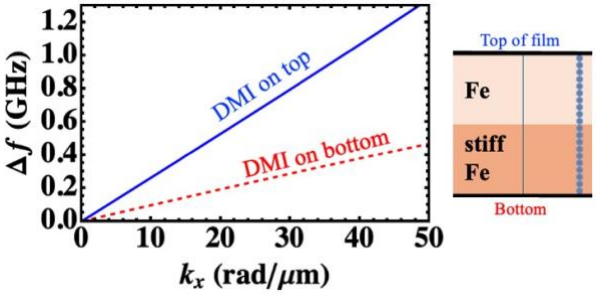

Figure 1. Calculated results for frequency nonreciprocity as a function of in-plane wavevector for an iron thin film (pictured right) with interfacial DMI strength D=3.9 mJ/m^2. The results change dramatically depending on which interface has DMI.

Our method has the advantage that it can be used to calculate spin wave frequencies and depth profiles in any thin-film magnetic stack with atomic-scale variations in magnetic parameters, such as multiple DMI interfaces, or gradient properties.

References

[1] R.E. Camley and K.L. Livesey *Surface Science Reports*, 2023, *78*, 100605.
[2] K.L. Livesey, D.C. Crew and R.L. Stamps *Physical Review B*, 2006, *73*, 184432.
[3] E. Lu, K.S. Buchanan and K.L. Livesey, *Physical Review B*, 2025, *111*, 064432.