Micromagnetic study of spin wave transmission in bent ferrimagnetic strips

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Abstract

Magnon propagation in antiferromagnetic (AFM) and/or ferrimagnetic (FiM) insulators is drawing attention due to the benefits as opposed to their ferromagnetic (FM) counterparts, such as higher fundamental frequency and insensitivity to external magnetic field perturbations. Spin wave (SW) propagation in these materials connects magnonics with spintronics, since spin current is mainly transported by magnons[1].

A comprehensive study of the transmission of SWs in bent waveguides made of FiM material is made here. SWs are promoted by spin currents at one end of the guide and their transmission is measured at the other end. Current frequency is chosen to excite a single wavelength λ according to forward volume spin wave (FVSW) propagation dispersion curves. The guide has two bends at its center forming a certain angle and are distant a length apart. Both the angle and the distance are determinants on the transmission coefficient τ of the SW, defined from the quotient between the amplitude of the SW at the measurement point and the amplitude at a point at the same distance as the measurement point with respect to the excitation point in a strip without bends, i.e., without reflections associated with the geometry.

Transmission minima and maxima are found for the different lengths between bends considered which coincide respectively with lengths equal to multiples of $\frac{\lambda}{2}$ and odd multiples of $\frac{\lambda}{4}$, which is reminiscent of interferometry results for other types of guided waves, although in this case they are only explainable through an imaginary reflection coefficient at both bends.

Micromagnetic modeling of FiMs

- **A pair of coupled Landau-Lifshitz-Gilbert equations are used**: [2]

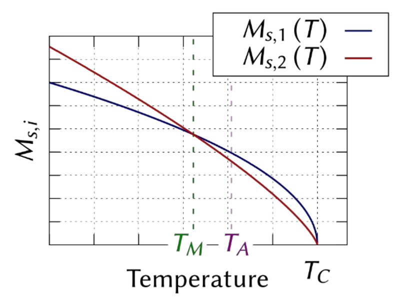
$$\dot{\mathbf{m}}_i = -\gamma_i \mathbf{m}_i \times \mathbf{H}_{\text{eff},i} + \alpha_i \mathbf{m}_i \times \dot{\mathbf{m}}_i + \tau_{\text{SOT},i} \qquad i = 1, 2.$$

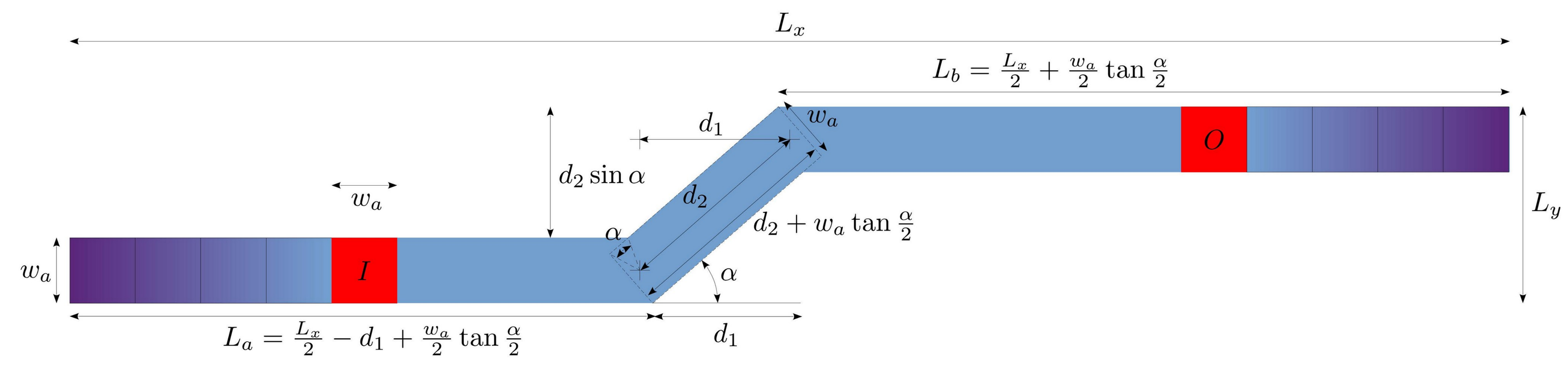
  $\mathbf{m}_i$, γ_i and α_i are the local orientation of the magnetization, the gyromagnetic factor and the damping parameter for each sublattice, respectively, $\mathbf{H}_{\text{eff},i}$ is the effective field associated with all relevant interactions within the system, and $\tau_{\text{SOT},i}$ corresponds to the **spin-orbit torque** due to spin currents.
- Our model uses computational elementary cells in a finite difference scheme, every cell containing two magnetic moments, one for each sublattice forming the FiM.
- **Typical values of the micromagnetic parameters** of a FiM **have been chosen.**
- Temperature is here used to obtain the saturation magnetizations of each sublattice, in particular, the condition of angular momentum compensation (at T_A). Other temperatures shown in the graph are Curie temperature (T_C) and temperature of magnetization compensation (T_M).

Geometry and simulation parameters

Exchange: $A_i = 70\ \frac{\text{pJ}}{\text{m}}$
Interlattice Exchange: $B_{ij} = -9\ \frac{\text{MJ}}{\text{m}^3}$
Gilbert constant: $\alpha_i = 0.001$
Anisotropy constant: $K_{u,i} = 1.4\ \frac{\text{MJ}}{\text{m}^3}$
DMI: $D_i = 0\ \frac{\text{mJ}}{\text{m}^2}$
Landé factors: $g_1 = 2$, $g_2 = 2.05$

Magnetizations at 0 K:
$M_{s,1}(0\ \text{K}) = 1.71\ \frac{\text{MA}}{\text{m}}$
$M_{s,2}(0\ \text{K}) = 1.4\ \frac{\text{MA}}{\text{m}}$
Curie temperature: $T_C = 450$ K
$b_1 = 0.76$, $b_2 = 0.5$
$M_{s,i}(T) = M_{s,i}(0\ \text{K}) \left[1 - \left(\frac{T}{T_C}\right)^{b_i}\right]$
$T_M = 241$ K, $T_A = 260$ K

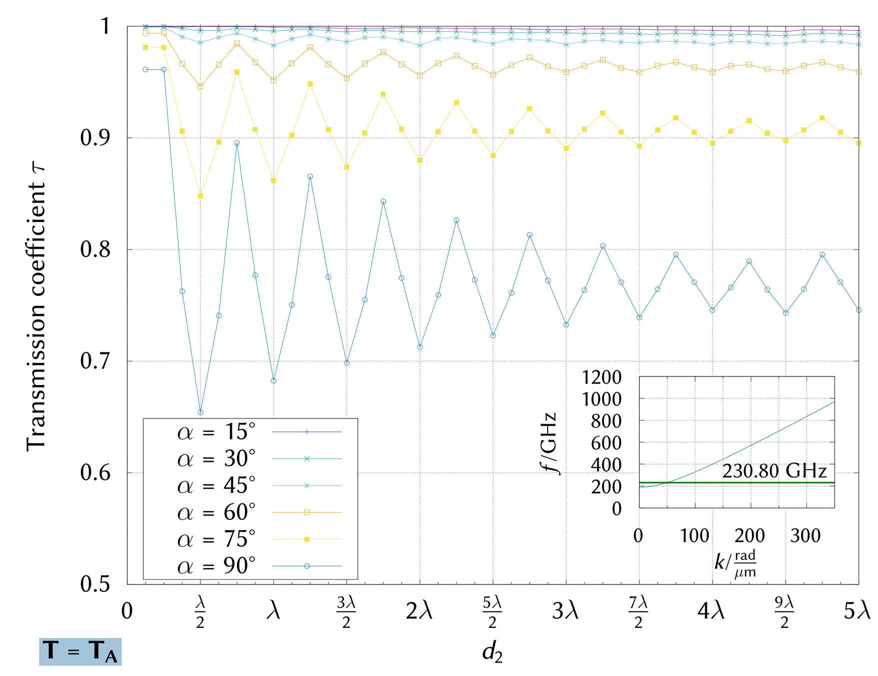




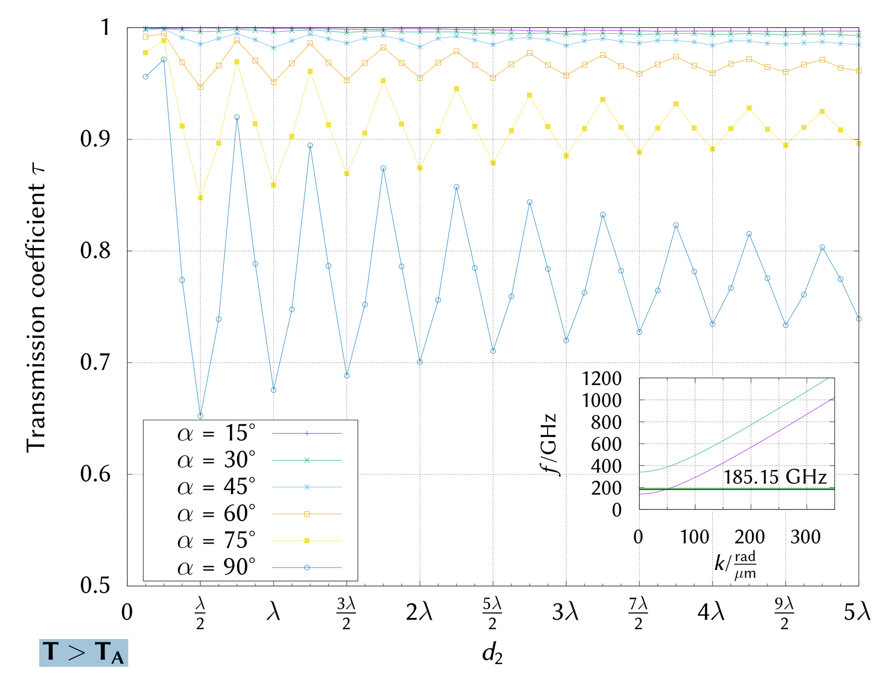
SWs in bent FiM strips

- **FVSWs in the FiM strip are promoted by spin currents** excited by the **spin-Hall effect** in a **heavy metal** (HM) strip (not shown) under the area marked *I*.
- A thin guide of width w_a fixed to $\frac{\lambda}{4}$ = 32 nm is considered to ensure **one-dimensional propagating modes**.
- **The amplitude of the propagating SWs is measured at the red area marked with an** *O*.
- Equidistant probes are placed from *I* to *O* to evaluate the magnetization along the strip (not shown).
- **Two bends of angle** α **and separated a distance** d_2 are located **in the middle of the strip**.
- **Wave absorption zones** have been established, represented by the gradient of color, **to eliminate reflections at the ends of the guide**.
- **The excitation frequency of the guide is chosen** according to the corresponding dispersion curves[3] at the desired temperature **to obtain a unique propagation wavelength** of λ = 128 nm ($k \approx 50\ \frac{\text{rad}}{\mu\text{m}}$). One dispersion curve is obtained for each sublattice. Dispersion curves collapse at T_A (see graphs insets).
- **SW transmission coefficient (**τ**) is computed by comparing the signal at** *O* **for the bent strip and for a strip without bends**, i.e., without reflections associated with the geometry.

Transmission coefficient



T = T_A



T > T_A

Results and conclusions

The dependence of τ on d_2 is shown for different α at two temperatures ($T = T_A$ and $T_A < T \ll T_C$):

- τ is computed for d_2 multiple of $\frac{\lambda}{8}$ (lines are drawn only as a guide for the eye).
- τ **has minima for** d_2 **multiple of** $\frac{\lambda}{2}$ **and maxima for** d_2 **odd multiple of** $\frac{\lambda}{4}$.
- This behavior is **reminiscent of interferometry results** for other types of guided waves: **only explainable through an imaginary reflection coefficient at both bends**.

References

[1] A. G. Gurevich and G. A. Melkov, *Magnetization oscillations and waves* (CRC Press, Inc., 1996).

[2] E. Martínez, V. Raposo, and Ó. Alejos, "Novel interpretation of recent experiments on the dynamics of domain walls along ferrimagnetic strips", Journal of Physics: Condensed Matter **32**, 465803 (2020).

[3] L. Sánchez-Tejerina, D. Osuna Ruiz, V. Raposo, E. Martínez, L. López Díaz, and Ó. Alejos, "Analytical dispersion relation for forward volume spin waves in ferrimagnets near the angular momentum compensation condition", Physical Review B **112**, 104418 (2025).

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