Excitation of short wavelength SWs in a ferromagnetic conduit with a microwave pumped perpendicularly magnetized nanodot

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Summary

- We demonstrated the generation of spin waves in a Permalloy stripe
- Using a magnetic skyrmion as an antenna to convert electromagnetic radiations into spin w aves
- The generated spin waves are short wavelength (140 nm) and antisymmetric

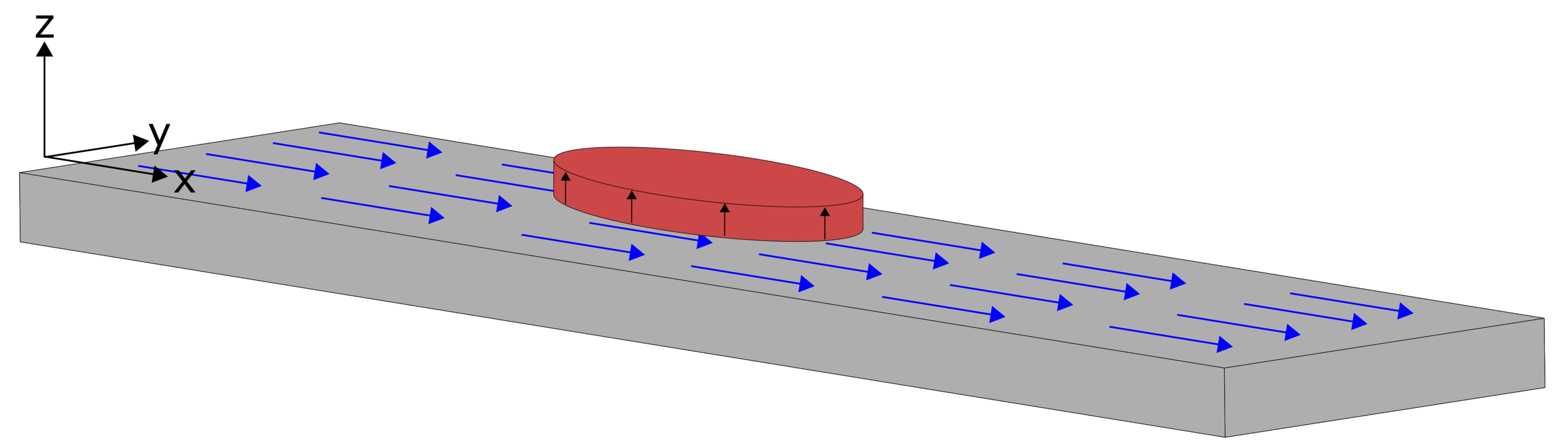

Figure 1: The waveguide (WG) and the nanodot (ND), separated by a vacuum layer, the system used in micromagnetic simulations.

Introduction

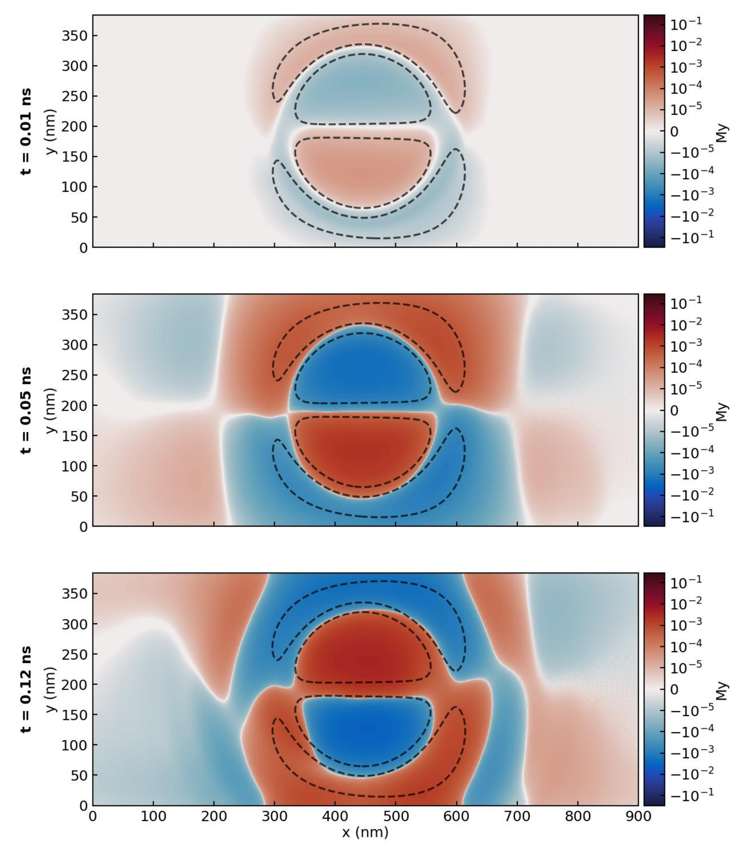

Figure 2: Magnetization in the waveguide along the y-axis just below the nanodot for 3 different time after the start of the excitation. The outline represents the starting magnetization before the excitation

- One of the main research directions in magnonics focuses on the excitation of short wavelength spin waves (SWs) to carry information without losing energy to Joule heating
- A few approaches have been proposed, but with some limitations like the lack of an efficient source of SWs, which further limits the development of magnonic applications
- We propose a system that generates a local excitation of SWs in a thin ferromagnetic waveguide with the help of a nanodot that possesses perpendicular magnetic anisotropy
- Our idea is to use the confined SW modes in the nanodot pumped by a global microwave magnetic field directed along the magnetization of the waveguide, which will emit propagating SWs due to direct static and dynamic coupling with the waveguide

Method

- Simulated using Mumax3 [1]
- The system can function with several combinations of magnetic materials
- The waveguide has to be ferromagnetic and present a low enough damping so that the SWs can propagate over a significant distance, which is why Permalloy is an ideal candidate having one of the lowest Gilbert damping [2]
- The waveguide is magnetically saturated along its length and is separated from the nanodot by a spacer of 1.5 nm
- It is 384 nm wide and 4.5 nm thick, and a few micrometres long with absorbing boundary conditions at its edge both extremities to avoid any kind of back-propagating SWs.
- The nanodot must have a specific geometry and size, as it requires a strong enough interfacial Dzyaloshinskii-Moriya Interaction to allow for the formation of a skyrmion
- For this reason, the nanodot is made of Pt/Co/Ir circular layers with a diameter of 300 nm to create a strong shape anisotropy which allows the presence of a metastable state such as a skyrmion in its core.

Acknowledgement

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Static Configuration

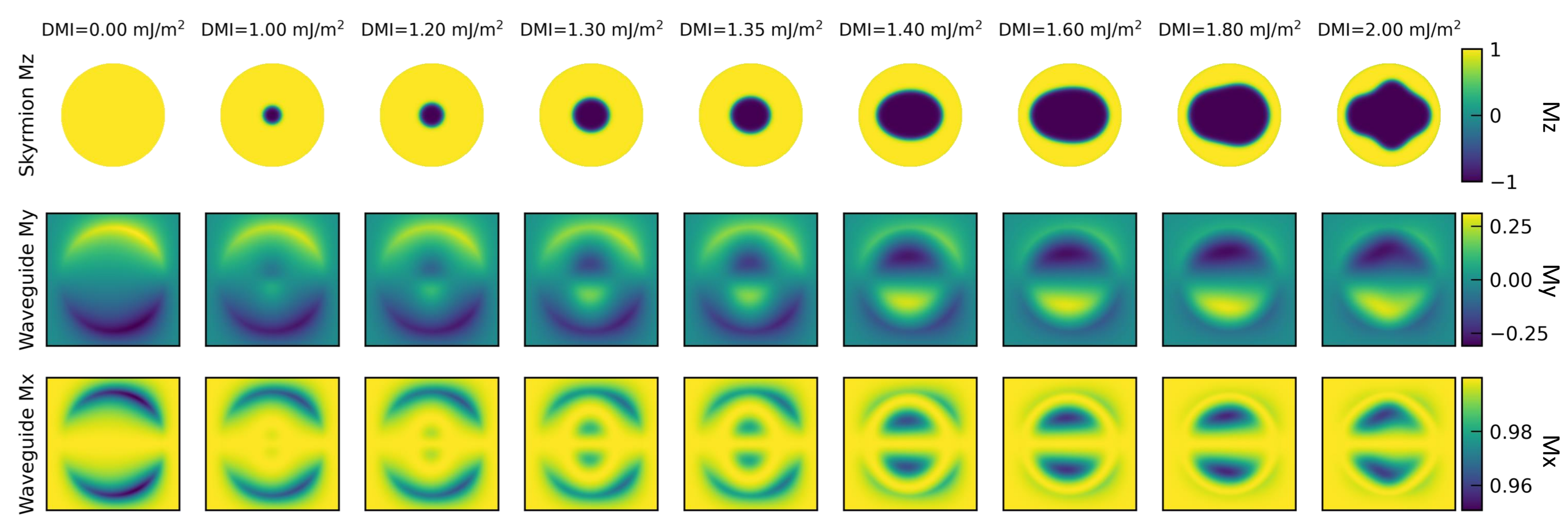

Figure 3: Skyrmion dependance on the value of the Interfacial Dzyaloshinskii-Moriya interaction in the Nanodot.

- When relaxing this system, an imprint of the skyrmion is created in the waveguide, meaning the magnetization below the nanodot will deviate from their saturated magnetization along the x axis because of the dipolar coupling with the skyrmion
- In the same way, the waveguide will influence the magnetization inside the nanodot and affect the shape of the skyrmion
- In our example, the skyrmion's core expends and becomes egg shaped under the influence of the waveguide.
- In the case of a fully saturated nanodot with the same magnetic parameters as the one with the skyrmion, the created imprint is less visible because of the simpler magnetic texture
- It leads to a very inefficient coupling for a narrow range of frequencies compared to the broadband SW excitations that a skyrmion can generate.

Spin wave dynamics

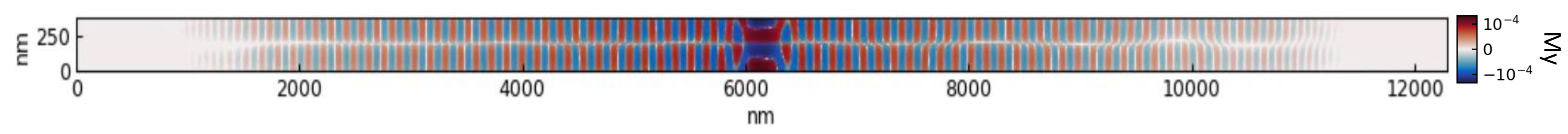

Figure 4: The asymmetric spin waves are propagating along the length of the waveguide until they vanish because of the Gilbert damping. This simulations show a spin wave propagation speed of 960 m/s and a wavelength of 140 nm.

- Confined skyrmions present a wide range of different resonant modes [3] when excited by an external magnetic field
- Such modes are also present here and influence the shape of the resulting imprint which will start oscillating along with the skyrmionic modes acting like an antenna
- This complex movement of both halves of the imprint, alternating phases and amplitude is what generates the coherent and efficient propagating SWs
- Interestingly, only asymmetrical SWs can be created this way, but modifying the material parameters or the geometry will cause the imprint to change shape which allows us to tune the efficiency of the antenna for specific microwave frequencies
- We found that the propagating SWs can be excited in a broad frequency band from a few to a dozen GHz with wavelengths that can be shorter than 100 nm
- Furthermore, our studies look for the magnetic parameters and geometry that would be most suitable for an efficient conversion of global electromagnetic radiation to short wavelegnth SWs

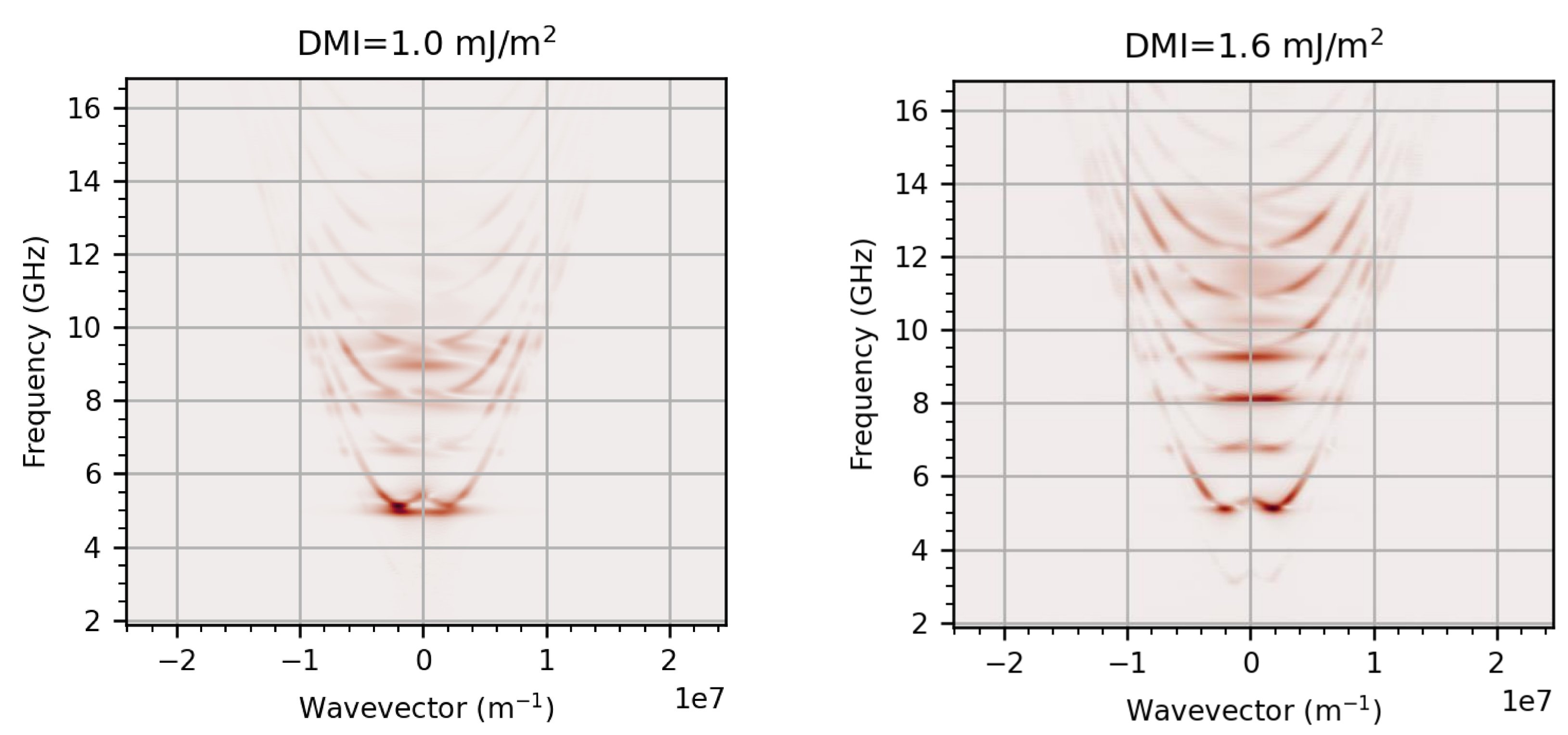

Figure 5: The dispersion relation calculated in the waveguide for 2 values of the DMI. A more complex structure in the nanodot will result in a larger bandwidth of spin wave emissions.

References

- [1] Vansteenkiste, Arne, et al. "The design and verification of MuMax3." *AIP advances* 4.10 (2014): 107133.
- [2]: Zhao, Yuelei, et al. "Experimental investigation of temperature-dependent Gilbert damping in permalloy thin films." Scientific reports 6 (2016): 22890.
- [3]: Kim, Joo-Von, et al. "Breathing modes of confined skyrmions in ultrathin magnetic dots." Physical Review B 90.6 (2014): 064410.