Spin Wave Interference in Magnetic Nanostructures

Hyunsoo Yang[1*], Jae Hyun Kwon[1], Sankha Subhra Mukherjee[1], Mahdi Jamali[1],
and Masamitsu Hayashi[2]
[1]Department of Electrical and Computer Engineering and NUSNNI-NanoCore,
National University of Singapore, 117576, Singapore
[2] National Institute for Materials Science, Tsukuba 305 - 0047, Japan

1. Abstract

Although yttrium iron garnet (YIG) has provided a great vehicle for the study of spin waves in the past, associated difficulties in film deposition and device fabrication using YIG had limited the applicability of spin waves to practical devices. However, microfabrication techniques have made it possible to characterize both the resonant as well as the travelling characteristics of spin waves in permalloy (Py)[1,2]. A variety of methods have been used for measuring spin waves, including Brillouin light scattering (BLS), magneto-optic Kerr effect (MOKE), vector network analyzer ferromagnetic resonance (VNA-FMR), and pulse inductive microwave magnetometry (PIMM)[3-5]. PIMM is one of the most preferred methodologies of measuring travelling spin waves. In this method, an electrical impulse is applied at one of two coplanar waveguides patterned on top of oxide-insulated Py, producing a local disturbance in the magnetization of the Py. The resulting disturbance travels down the Py in the form of waves, and is inductively picked up by the other coplanar waveguide.

We investigate the effect of the pulse width of excitation pulses on the generated spin wave packets using both experimental results and micromagnetic simulations. We show that spin wave packets generated from electrical pulses are a superposition of two separate spin wave packets, one generated from the rising edge and the other from the falling edge, which interfere either constructively or destructively with one another, depending upon the magnitude and direction of the field bias conditions. A method of spin wave amplitude modulation is also presented by the linear superposition of spin waves. We use interfering spin waves resulting from two closely spaced voltage impulses for the modulation of the magnitude of the resultant spin wave packets.

2. Experimental method

A 150 μm × 40 μm Py strip was patterned on a Si/SiO_2 (100 nm) substrate. A 30 nm SiO_2 layer was sputter-deposited on top of the Py layer, and subsequently, Ta (5 nm)/Au (85 nm) was sputter-deposited, and patterned into asymmetric coplanar strips (ACPS). The distance between the source lines of the excitation and detection ACPS is 10 μm. The width of the signal and ground arms of the ACPS is 10 μm and 30 μm, respectively, and the distance between the two is 5 μm. Voltage pulses applied by a pulse generator at one of the waveguides launch a Gaussian spin-wave packet, and may be inductively detected by the other waveguide using a high-frequency oscilloscope.

For the study of the interference of Gaussian wave packets resulting from the rising and falling edges of the input pulse, the pulse width of the applied pulse is varied form one pulse to another. At certain values of the pulse width, the resultant Gaussian pulses from the rising and falling edges constructively interfere, and enhance the resultant signal, while at some other values of the pulse width, they destructively interfere, decreasing the resulting signal.

For the study of the modulation of spin wave packets, two excitation pulses are applied 100 ps from one another. As the bias magnetic field is changed, the frequency of Gaussian wave packets resulting from each excitation pulse changes. Thus, at certain frequencies, the Gaussian wave packets resulting from the two pulses constructively interfere, while at other frequencies, they destructively interfere. At frequencies between those at which they constructively or destructively interfere, they are modulated to a value somewhere between the magnitudes representing constructive and destructive interference.

Another method of spin wave modulation via constructive and destructive interference comprises of changing the temporal distance between the two pulses. Here too, we see interference between two Gaussian wave pulses, depending upon the time lag between the applied pulses.

3. Results

Spin wave packets interfering due to the rising and falling edge of the input excitation will be discussed. For pulse widths (t_δ) < 1.5 ns there is clear interference between Gaussian waves generated from the rising and the falling edge of the wave. When two pulses are 100 ps apart, the Gaussian wave resulting from one pulse interferes with that resulting from the other pulse. This causes the total amplitude of the Gaussian wave packet generated from the two pulses (m_2) to be modulated from the amplitude of the Gaussian wave packet resulting from one pulse (m_1). Contour plots for the spin waves resulting from one plots will be discussed. The modulation given by m_2/m_1 will be discussed, along with calculated predictions by two different methods.

4. Conclusion

Thus we have demonstrated clear interference patterns from PIMM measurements. We have not only demonstrated that it is possible to show interfering waves from the rising and falling edge of a pulse, but also use interference from two consecutive pulses to modulate spin wave signals.

5. References

[1] M. Covington, T. M. Crawford, and G. J. Parker, Physical Review Letters **89**, 237202 (2002).

[2] M. Bailleul, D. Olligs, and C. Fermon, Applied Physics Letters **83**, 972 (2003).

[3] T. J. Silva, C. S. Lee, T. M. Crawford, and C. T. Rogers, Journal of Applied Physics **85**, 7849 (1999).

[4] S. S. Kalarickal, P. Krivosik, M. Wu, C. E. Patton, M. L. Schneider, P. Kabos, T. J. Silva, and J. P. Nibarger, Journal of Applied Physics **99**, 093909 (2006).

[5] J. H. Kwon, S. S. Mukherjee, M. Jamali, M. Hayashi, and H. Yang, Applied Physics Letters **99**, 132505 (2011).