Towards a Chip-Scale Millimeter-Wave Spectrum/Signal Analyzer Using Spin-Wave Diffraction and Interference

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Abstract — **A new class of device has been proposed that converts millimeter electrical signals into spin waves with micrometer wavelengths, with which computing can be done in a small footprint. The spin waves are then converted back into electrical signals. Essential for this is the design of proper transducers between the two domains. We have simulated an electrical-to-spin-wave transducer that shows improved bandwidth. We are developing a numerical simulation design tool that crosses between these domains.**

Keywords: Magnonics, Microwave magnetics

I. INTRODUCTION

In the presence of an RF small-signal magnetic field perpendicular to a DC magnetic field, the magnetic moments of a magnetic film will precess. This precession propagates with a periodic spatial phase shift and is called a spin wave. This has been demonstrated in magnetic materials deposited on silicon substrates [1], allowing for the possibility of integrating spin-wave devices with CMOS.

One direction for using spin waves is to convert millimeter or microwave electrical signals to spin waves having micrometer wavelengths. All signal processing is then done by the interference of spin waves traveling through a magnetic thin film. These waves are then converted back into electrical signals [2]. Our goal is to demonstrate the feasibility of this new device type by building a chip-scale, real-time spectrum analyzer [2].

II. CPW SPIN-WAVE TRANSDUCER AND SIMULATION TOOL

Coplanar waveguides (CPW) placed on top of a magnetic film can be used to convert electrical signals into spin waves [3] through the coupling of the current-induced magnetic fields. However, because of the interference between the waves, the spin-wave excitation strength from the CPW exhibits a comb-like frequency response, making it unsuitable for the device described above.

We performed simulations using Ansys HFSS [4] and Mumax3 [5] that show that launching high-amplitude spin waves in an out-of-plane bias field launches waves with long wavelengths, which reduces the destructive interference between simultaneously launched spin waves but introduces additional unwanted structure in the wave. When this is followed by a gap in the magnetic material (Fig. 1), both the amplitude and wavelength of the spin wave are decreased, and the unwanted structure is removed. This produces a more uniform frequency response, as shown in Fig. 2. Simulation results of a null are shown in Fig. 3.

Essential to the design of this new class of device is a tool that links the micromagnetic and electromagnetic domains. The flow chart of our tool is shown in Fig. 4 [6]. The tool makes use of Ansys HFSS [4] to simulate the electromagnetics of the transducer. The results of this first simulation are then fed to OOMMF [7] where micromagnetic simulations are performed. Steps 1 and 2 have been validated with measurement (Fig. 5). Steps 3-5 will solve for the effect of the spin waves on the waveguide, and is currently being pursued.

III. SUMMARY

We have taken steps towards building a chip-scale, real-time spectrum analyzer using the diffraction and interference of spin waves. We found that launching large amplitude spin waves followed by a gap in the magnetic material produces a spin-wave launcher with a more uniform response and reaches higher frequencies than using the CPW under normal conditions.

A numerical simulation design tool that connects between electromagnetic and micromagnetic domains is currently being worked on. The first half of the tool has been verified with experimental data.

ACKNOWLEDGMENTS

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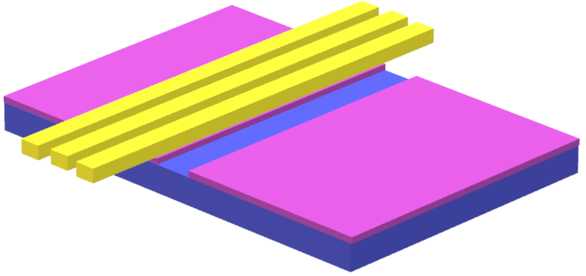

Fig. 1. Schematic of a CPW placed on top of a magnetic film with a gap in the film.

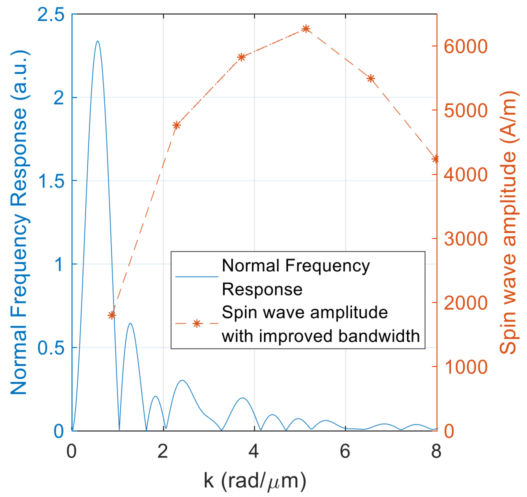

Fig. 2. The relative spin wave intensity as a function of wavenumber when launched from a CPW under the condition of no gap in the magnetic film. The plot also shows the spin wave amplitude from simulations of a CPW launching high-amplitude spin-waves with a gap in the film.

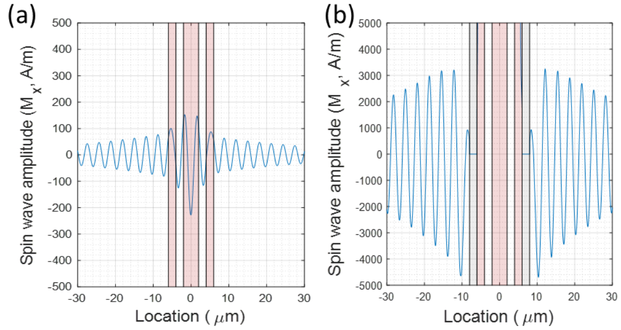

Fig. 3. (a) Simulation results showing a spin wave launched from a CPW with no in the film. The wavenumber used ($k = 2\ \mu m^{-1}$) is a null in the response of the CPW. (b) Simulation results for the same wavenumber when launching high-amplitude, long-wavelength spin-waves which are then decreased in amplitude and wavelength by a gap in the magnetic film.

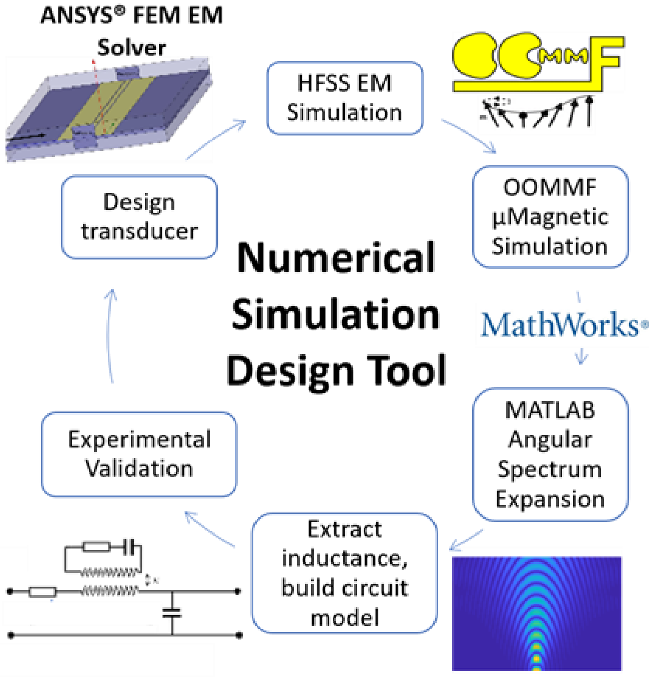

Fig. 4. Flow chart of the numerical simulation design tool that links the electromagnetic and micromagnetic domains. [6]

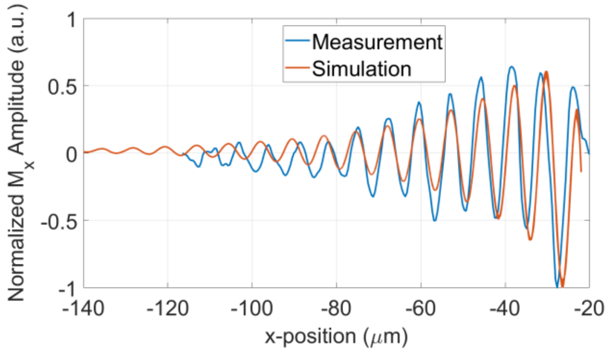

Fig. 5. Comparison of experimental data showing a spin wave launched from a CPW and comparison with simulation with ND's simulation tool.