Characterizing Spin Wave Propagation in Lithium Aluminum Ferrite Thin Films

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Summer Program Website(s): https://www.cnf.cornell.edu/education/reu

Research Group Website: https://fuchs.research.engineering.cornell.edu/

Primary CNF Tools Used: MLA150 Maskless Aligner, Oxford 81 Reactive Ion Etcher, AJA1 Sputter Tool, Sonicator, DSCO dicing saw

Abstract:

Lithium Aluminum Ferrite (LAFO) is a material that has emerged as interesting for applications in magnonics. Its low magnetic damping rate makes it ideal for magnon transport. The goal of this project is to investigate the nature of magnons propagating through LAFO. Scanning nitrogen-vacancy (NV) microscopy will be paired with coplanar waveguide readouts to image and quantify these spin waves. The first task is to fabricate a microchip stack that includes the LAFO thin film sample, coplanar waveguides to excite/readout spin waves, and a global microwave antenna to enable magnon detection. The LAFO is patterned using photolithography and ion milling, while the coplanar waveguides and the global antenna are fabricated using photolithography, metal deposition, and lift-off. The motivation for these experiments is the development of next generation, magnon-based interconnects for low-energy, intermediate scale data transfer.

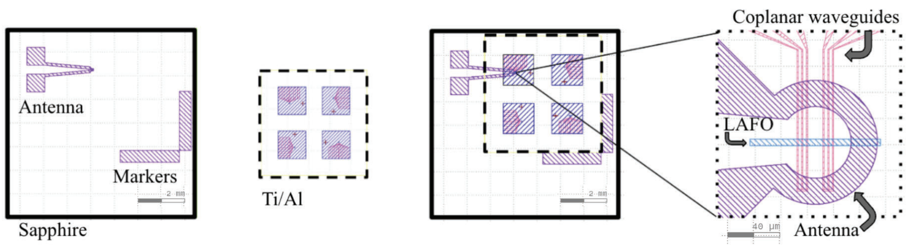

Figure 1: Chip Stack Design.

Summary of Research:

As electronics scale down, copper interconnects have increasingly higher resistance, decreasing the efficiency of data transfer between devices. One mission of the "Center for Energy Efficient Magnonics" (CEEMag) is to investigate energy efficient interconnects in microelectronics that use spin waves, or magnons. Lithium Aluminum Ferrite, or $Li_{0.5}Al_{1.0}Fe_{1.5}O_4$ (LAFO), is the primary material we are investigating. It is a spinel ferrimagnet, and has an extraordinarily small Gilbert damping constant of about 0.004 (O'Mahoney et al.). This allows magnon propagation on an intermediate scale. We aim to characterize spin wave propagation in LAFO to explore its possible application in interconnects.

Our chip stack was fabricated in the Cornell Nanoscale Facility. The bottom layer of the chip, outlined in a solid line in Figure 1, hosts markers to place the top layer and a global antenna that will carry an RF signal. The top layer, outlined in a dashed line in Figure 1, has four identical sample sections, each with two coplanar waveguides, and a 100 by 1 micron sample of LAFO. The LAFO film, with a thickness of 35nm, sits above the antenna, with a 500 micron offset. An RF current is sent through the first waveguide, exciting a magnon that propagates 20 micrometers along the LAFO sample to the second waveguide which gives a time-domain of the magnon's amplitude. The underlying antenna emits an RF signal that interferes with the stray field produced by the magnon to aid in the scanning NV readout.

Scanning NV microscopy uses a point defect in diamond to detect micromagnetic properties of materials. This defect, the nitrogen-vacancy center, consists of a nitrogen substitutional atom with an adjacent carbon vacancy. Electrons in this center are sensitive to the surrounding magnetic field through their spin. In the scanning NV microscopy setup there is a diamond probe with an NV center at its tip, shown in Figure 2. The magnon produces an oscillating magnetic field with a constant

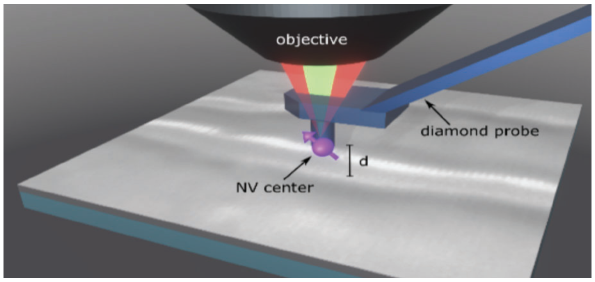

Figure 2: Scanning NV Probe.

spatial amplitude, but spatially varying phase. The NV center cannot detect this phase directly. Therefore, we need the global antenna to emit an RF signal which interferes with the stray field. This interference results in a static signal with a space-dependent amplitude. This signal is detected with the NV center to give a spatial image of the sample's micromagnetism. Pairing this with the electrical readout from the coplanar waveguide we can investigate how the magnon is propagating through the LAFO.

The fabrication of the bottom layer chip is done on a sapphire wafer. Layers of LOR3a and S1813 photoresist are deposited. The pattern is then exposed using the MLA150 maskless aligner and developed in AZ 726 MIF. Residual resist is removed with an oxygen plasma in the Oxford 81 reactive ion etcher. Next, the AJA1 is used to sputter on 10nm of titanium and 150nm of platinum. Finally, the lift-off of excess metal is facilitated by heating in 1165, and sonicating in 1165 and IPA. The devices are diced with the DSCO saw to fit into the printed circuit board, which can be placed in the scanning NV setup for measurements. The finished devices can be seen in Figure 3.

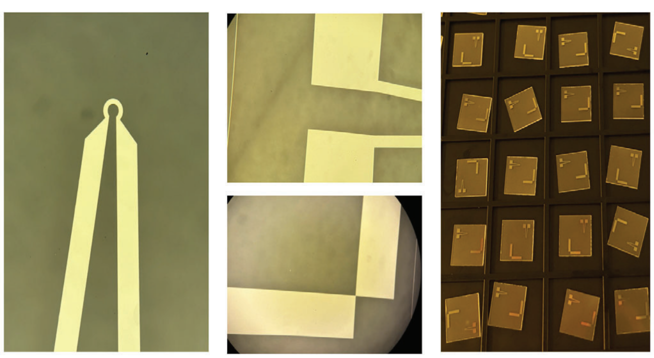

Figure 3: Fabrication Results.

In addition to this work, we have begun Mumax+ micromagnetic simulations to understand the physical meaning of future measurements. This aspect of the project is still developing, but the simulations show interesting effects.

Images in Figure 4 show samples of a different size than in our experiment to emphasize the pattern in the center of the sample, rather than the boundary effects. The bottom image in Figure 4 represents a continuous driving signal from the waveguide. Boundary magnetic conditions, edge reflections, and coplanar waveguide geometry could be causing the variations seen along the edges of the sample. The upper images in this figure use a one nanosecond driving pulse. The top left image represents a pulse from the current coplanar waveguide geometry. The top right image represents a pulse from a waveguide without ground lines. The interference that appears around four nanoseconds in the left plot, but not in the right, suggests that these ground lines may be problematic. While there are more simulations to be done, these results may motivate the fabrication of new devices with altered coplanar waveguides.

Conclusions and Future Steps:

The current focus of this project is determining the parameters for scanning NV measurements. The RF signals and bias field needed for the experiment must be found before data is collected. Additionally, there is continuing work on mumax+ micromagnetic simulations.

After characterization of magnons in LAFO, the next step will be to test transmissions of spin waves at the boundary between LAFO and another material. This will build further understanding of how magnons behave at the interface between the propagation material and the material used for magnon detection.

Acknowledgements:

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References:

[1] O'Mahoney, Daisy, et al. "Aluminum Substitution in Low Damping Epitaxial Lithium Ferrite Films." Applied Physics Letters, vol. 123, no. 17, 2023, article 172405. https://doi.org/10.1063/5.0163362.

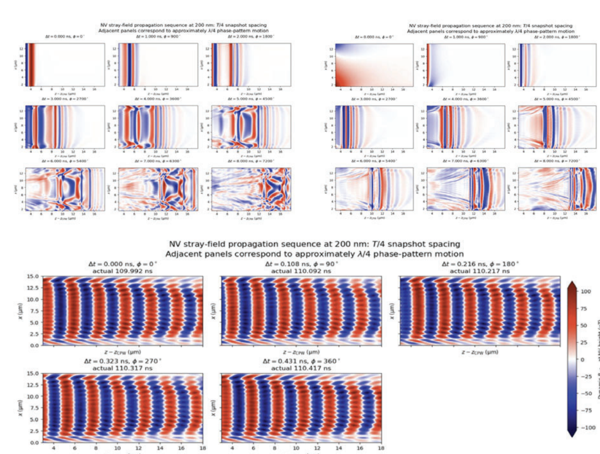

Figure 4: Preliminary Simulation Results.