Fabricating Micron-Sized Skyrmion-Spintronic Devices

CNF Project Number: 598-96
Principal Investigator(s): Daniel C. Ralph
User(s): Maciej Olszewski

Affiliation(s): Laboratory of Atomic and Solid State Physics (LASSP), Cornell University

Primary Source(s) of Research Funding: Defense Advanced Research Projects Agency (DARPA), National Science Foundation (NSF)

Contact: dcr14@cornell.edu, mwo34@cornell.edu

Website(s): https://ralphgroup.lassp.cornell.edu/

Primary CNF Tools Used: GCA 6300 DSW 5X g-line Wafer Stepper, GCA AutoStep 200 DSW i-line Wafer Stepper, Heidelberg Mask Writer - DWL2000, AJA Ion Mill, AJA Sputter Deposition, YES Asher, DISCO Dicing Saw

Abstract:

Magnetic skyrmions are a candidate for next-generation spintronic devices. Their topological nature makes them robust, allowing for a non-volatile, high-speed, and low-power-consumption method of storing and processing information. In addition, recent advances in skyrmionics have demonstrated both electrical and thermal techniques for controlling skyrmion densities in thin films. Here, we present initial measurements of magnetic resonance in ferromagnetic multilayers with interfacial Dzyaloshinskii-Moriya interaction. We have performed room temperature experiments utilizing both conventional field-driven ferromagnetic resonance and spin-torque ferromagnetic resonance. We find a difference in the resonance readout between the phases with and without skyrmions but are yet to find direct evidence for resonance readout of skyrmions themselves. Our work is further supported by Lorentz transmission electron microscopy with spatial resolution on the order of a few nanometers, where we directly observe skyrmions in our thin films.

Summary of Research:

Conventional spin-torque ferromagnetic resonance (ST-FMR) devices consist of two layers, one heavy metal (HM) spin Hall layer and one ferromagnet (FM) with in-plane anisotropy [1]. As current passes through the HM layer a spin current is generated in the direction perpendicular to the current direction. The generated spin current then proceeds into the FM layer and exerts a torque on the magnetization. If alternating current is passed, the spin current generated will also be alternating, and under certain conditions the spin torque can cause the FM to resonate. The resonance of the magnet can be captured with the changes in the magnetoresistance of the device. Further, the resonances can be fitted to extract various parameters, such as the strength of the torques, magnetic damping, and effective magnetization.

Skyrmions, topologically protected spin textures, present a novel and robust system for resonance-based spintronic devices. They can be found in a variety of systems, including thin ferromagnetic films with the presence of the Dzyaloshinskii-Moriya interaction and broken inversion symmetry [2]. Due to their topological nature, skyrmions are stable under small perturbations from defects and other external fluctuations, making them a great candidate for various memory-based applications. Further, it has been demonstrated that skyrmions can be observed via the topological Hall effect and their density can be controlled with current pulses [3].

The main goal of our work is to incorporate thin films which host skyrmions into ST-FMR devices to directly measure skyrmion resonances and control their density to increase or decrease the resonance readout. We grow our skyrmion multilayers, consisting of platinum, cobalt, and ruthenium on a sapphire substrate, using our own AJA magnetron sputtering tool. After depositing the films, we perform one round of photolithography on either the g-line or i-line stepper to outline the shape of the devices and use the AJA ion mill to mill our film to the proper device size. Next, we do either one or two rounds of photolithography for writing the contacts for the devices. Finally, we use the AJA sputter to deposit titanium and platinum to make proper electrical connection to the devices. This process usually yields very consistent results with device fabrication, and we can fabricate

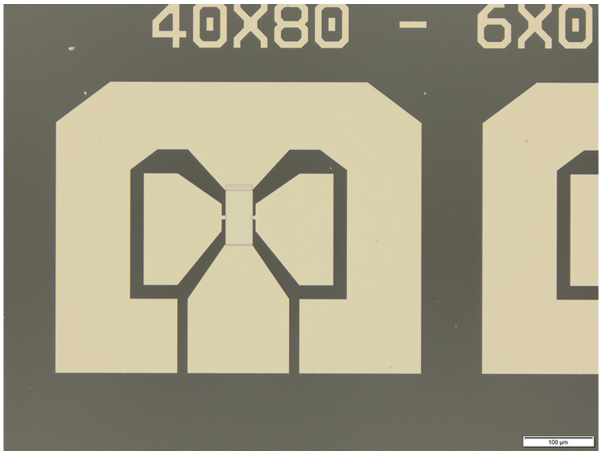

Figure 1: An image of fabricated thin film devices with contacts on a sapphire substrate.

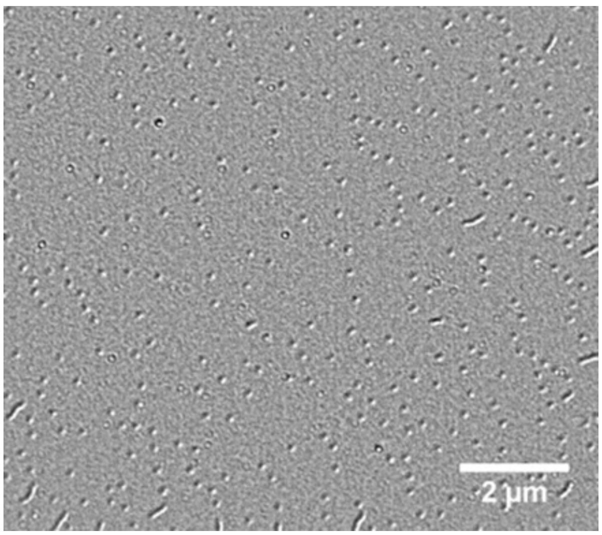

Figure 2: A Lorentz transmission electron microscopy scan of out thin film showing the density and size of the skyrmions.

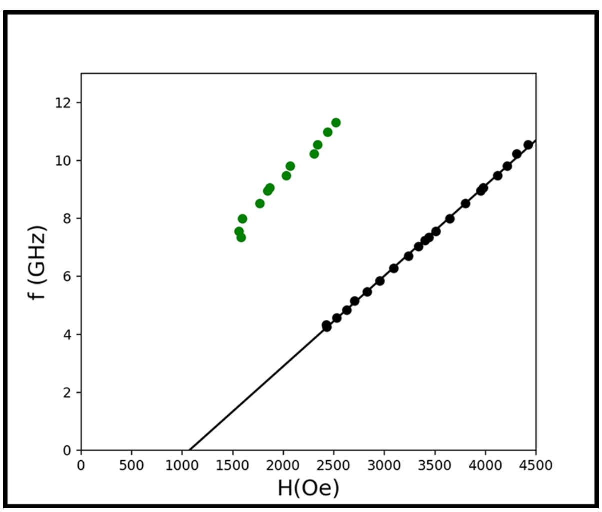

Figure 3: Positions of the magnetic resonances of the skyrmion film as a function of frequency and magnetic field.

around 100 devices of different shapes and sizes during this procedure, an example of which is shown in Figure 1.

We can directly observe if skyrmions are present in our samples by conducting Lorentz transmission electron microscopy (L-TEM) and looking at the changes in the reflections of the transmitted electrons, as shown in Figure 2. After, ensuring that we have skyrmions present, we conduct standard ST-FMR measurements as a function of the frequency of the current applied and the strength of the external magnetic field. In Figure 3, we show the positions of the resonance peaks as a function of frequency and magnetic field. Unfortunately, our preliminary work does not show any resonances in the regions where skyrmions are present, based on the L-TEM scans. We are continuing our efforts to find skyrmion resonance by considering other device geometries and slight changes to the thin films.

References:

[1] Karimeddiny, et al., Phys. Rev. Applied 14, 024024 (2020).
[2] Fert, et al., Nature Review Materials, 2, 17031 (2017).
[3] Park, et al., Journal of Applied Physics 128, 23 (2020).