Non-Local Spin Transport in Complex Oxide Thin Films

CNF Project Number: 598-96

Principal Investigator(s): Daniel Ralph

User(s): Ruofan Li, Tianxiang Nan

Affiliation(s): Physics, Cornell University

Primary Source(s) of Research Funding: Army Research Office (W911NF-15-1-0447)

Contact: dcr14@cornell.edu, rl643@cornell.edu, tn272@cornell.edu

Primary CNF Tools Used: JEOL JBX-6300FS 100 kV electron-beam lithography system, scanning electron microscope, Veeco Icon atomic force microscope for high resolution profilometry

Abstract:

Magnon-mediated spin transport in magnetically-ordered insulators is of interest in the field of spintronics as it enables the transportation of spin information with ultra-low-dissipation compared with that by conduction electrons [1-4]. Recently, long-distance spin transport has been demonstrated in low-damping iron garnets, however the thicknesses of the iron garnet films that are required to possess low damping are typically over 100 nm. Efficient spin transport in low damping magnetic thin films with reduced thickness is essential for the integration of spintronic devices. In this work, we report long-distance spin transport in ultra-thin epitaxial films of magnesium aluminum ferrite ($MgAl_{0.5}Fe_{1.5}O_4$, MAFO). By exciting and detecting magnons by the spin Hall effect in Pt nanowires patterned on MAFO, we measured a magnon spin diffusion length of ~ 1 µm. This finding advances the study of magnon spin transport in the ultra-thin film regime.

Summary of Research:

MAFO is a newly-developed spinel ferrite material that can be grown in thin films [5]. High quality MAFO thin films possess a small Gilbert damping parameter (~0.0015) that is comparable to that of the well-known low-damping material yttrium iron garnet (YIG) but with a much thinner film thickness. This ultra-thin, low-loss and low-damping MAFO thin film could provide a good platform for the study of magnon transport and devices.

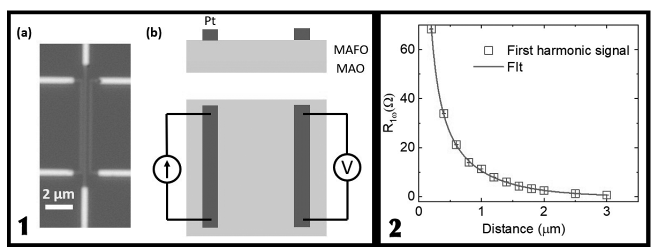

Figure 1, left: (a) Optical microscope image of a non-local Pt device on the MAFO thin film. (b) The device geometry and the measurement schematic.

Figure 2, right: The first-harmonic response of the non-local device as a function of the distance between the injector and the detector. The curve represents the fitting to a magnon diffusion model.

In this study, magnon transport is characterized in a non-local geometry (Figure 1b) in which two Pt nanowires are separated by a certain distance, with one nanowire acting as a spin injector and another one as a spin detector. Owing to the strong spin-Hall effect in Pt, current passing through the spin injector gives rise to the spin accumulation at the interface that can excite the magnons in MAFO depending on the relative orientation between the spin polarization and magnetization directions. Reciprocally, the magnons are detected non-locally as a voltage via the inverse spin-Hall effect in the neighboring nanowire.

Our thin films of MAFO were grown by pulsed laser deposition on $MgAl_2O_4$ <001> single crystal substrates in collaboration with the Yuri Suzuki group at Stanford. The nanowires were then defined using electron-beam lithography (JEOL 6300) and the subsequent deposition and lift-off of a 10 nm Pt thin film. The Pt films were deposited by DC magnetron sputtering in an argon atmosphere with a base pressure < 3×10^{-8} Torr. Finally, the metal contacts to the nanowires using Ti (5 nm)/Pt (100 nm) were patterned (JEOL 6300) and deposited (AJA sputtering system). The nanowire dimension is 200 nm wide and 10 um long with the wire separation ranging from 200 nm to 10 µm. In Figure 1a, we show a finished device.

The non-local measurements were performed at room temperature in a magnetic probe station with an in-plane vector magnetic field. The non-local signal (both first and second-harmonic responses) was then measured as a function of angle φ between the nanowires and the in-plane magnetic field. A series of such nanowire pairs with different spacings between them were measured and their non-local resistances as a function of the separations are plotted as shown in Figure 2. Such decay of the non-local response can be well fitted to a magnon diffusion model [2]:

$$R = \frac{C}{\lambda} \frac{\exp(d/\lambda)}{1 - \mathrm{ex}\ \ (d/\lambda)}$$

where C is a distance-independent constant, d is the injector-detector separation distance, and λ is the spin diffusion length of MAFO. The fitting gives a magnon spin diffusion length of 1 μm for a 10-nm-thick MAFO thin film.

In conclusion, we studied the magnon diffusion length in the ultra-thin magnetic insulator, MAFO films, using non-local measurements with Pt nanowire pairs.

Our observed decay of magnons over distance fits well with the spin diffusion model, from which the spin diffusion length in MAFO was extracted to be around 1 μm. This discovery demonstrates the potential of MAFO thin films as a new platform for energy-efficient spin transport.

References:

[1] Kajiwara, Y. et al. Transmission of electrical signals by spin-wave interconversion in a magnetic insulator. Nature 464, 262-266 (2010).

[2] Cornelissen, L. J., Liu, J., Duine, R. A., Youssef, J. Ben, and Van Wees, B. J. Long-distance transport of magnon spin information in a magnetic insulator at room temperature. Nat. Phys. 11, 1022-1026 (2015).

[3] Lebrun, R. et al. Tunable long-distance spin transport in a crystalline antiferromagnetic iron oxide. Nature 561, 222-225 (2018).

[4] Xing, W., Qiu, L., Wang, X., Yao, Y., and Ma, Y. Magnon Transport in Quasi-Two-Dimensional van der Waals Antiferromagnets. Phys. Rev. X 9, 11026 (2019).

[5] Emori, S. et al. Ultralow Damping in Nanometer-Thick Epitaxial Spinel Ferrite Thin Films. Nano Lett. 18, 4273-4278 (2018).