Topological Hall Effect in MnFeGe/FeGe Bilayer Thin Films

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Abstract:

We investigate the topological Hall effect (THE) in MnFeGe/FeGe and MnFeGe/FeGe/Pt thin films using Hall measurements. These materials host nanometer-sized quasiparticles called skyrmions in a range of temperature and magnetic field. Skyrmions are promising candidates for future applications in high density magnetic storage devices, for example, as bits to store information, and in racetrack type computing devices owing the low current densities required to move them. The presence of skyrmions results in an effective magnetic field acting on transport electrons that appears as an extra term to the Hall resistance. We compare the THE resistance of MnFeGe/FeGe and MnFeGe/FeGe/Pt and find that it is extended in the Pt-capped film.

Summary of Research:

MnFeGe and FeGe have a chiral B20 structure that induces antisymmetric exchange called the Dzyaloshinski-Moriya Interaction (DMI) that favors canting of magnetic spins. In conjunction with the Zeeman, exchange, magnetostatic, magnetocrystalline anisotropy and dipole-dipole interaction terms it stabilizes exotic spin structures called skyrmions [1] in a region of the temperature and external magnetic field. These quasiparticles are topologically stabilized once formed, and a finite energy is required to collapse a skyrmion into a trivial ferromagnetic (antiferromagnetic) state. A major direction of current research is stabilizing skyrmions at room temperature and zero magnetic fields in thin films for potential applications. Skyrmions can also be stabilized at ferromagnet (FM)/heavy metal (HM) interfaces [2] at room temperature due to interfacial DMI from large spin-orbit coupling (SOC) originating in the HM layer.

Skyrmions can be imaged directly by Lorentz transmission electron microscopy (LTEM), electron holography (EH), and magnetic force microscopy (MFM), and the skyrmion lattice can be detected in reciprocal space by small angle neutron scattering (SANS) and resonant elastic X-ray scattering (REXS) [3]. Indirect methods of detecting the skyrmion phase boundary include AC magnetic susceptibility (ACMS), microwave absorption spectroscopy (MAS), magnetoresistance vs. field and topological Hall effect measurements.

The presence of topologically non-trivial spin textures such as magnetic skyrmions can be modelled by an emergent magnetic field, which contributes an additional term to the Hall effect signal (the topological Hall resistance). The Hall resistance has three contributions; 1) an ordinary Hall resistance (OHR) due to the Lorentz force on electrons proportional to the external magnetic field, 2) an anomalous Hall resistance (AHR) in ferromagnets arising from SOC and/or spin dependent scattering that is approximately proportional to the magnetization, and 3) topological Hall resistance (THR). By subtracting the calculated OHR and AHR contributions from the measured Hall resistance the THR can be estimated in a sample.

Figure 1 shows the fabricated Hall device of two samples, MnFeGe(20nm)/FeGe(7nm) and MnFeGe(20nm)/FeGe(4nm)/Pt(1.5nm). The Heidelberg mask writer DWL2000 was used to make photomasks and photolithography was performed on a GCA 5x Stepper. An AJA ion mill was used to etch the material into a Hall geometry. An SC4500 even-hour evaporator was used to make gold contact pads for electrical measurements. Hall resistance as a function of the magnetic field at temperatures between 40 Kelvin (K) - 240 K was measured in a Quantum Design physical property measurement system (PPMS).

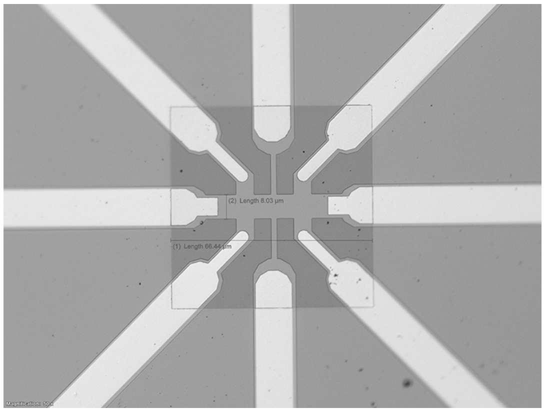

Figure 1: Patterned Hall bar device.

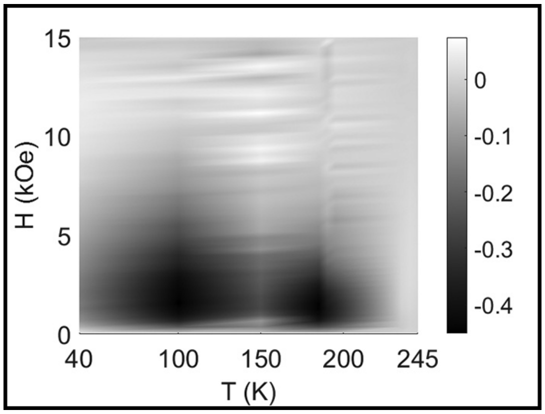

Figure 2: THR of MnFeGe(20nm)/FeGe(7nm).

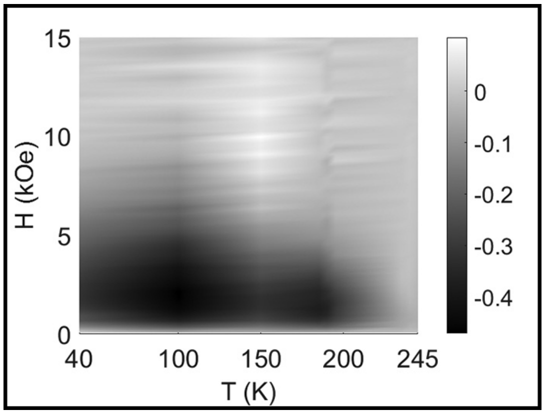

Figure 3: THR of MnFeGe(20nm)/FeGe (4nm)/Pt(1.5nm).

Figure 2 shows the THR (resistance given in ohms) as a function of temperature and external field for MnFeGe/FeGe and Figure 3 shows the THR for MnFeGe/FeGe/Pt. MnFeGe is known to host skyrmions below a critical temperature (T_c) ~ 180K and FeGe hosts skyrmions below T_c ~ 270K.

We observe a broadened phase space of the THR in the Pt-capped sample compared the MnFeGe/FeGe bilayer, which could be due to an increase in skyrmion stability from the interplay between interfacial DMI from Pt and bulk DMI from MnFeGe and FeGe. The THR could also arise due to other non-trivial magnetic textures and further experiments are needed to identify its origin.

Conclusions and Future Steps:

We have measured the THR of skyrmion-hosting B20 thin films and report a broadened phase space in the heavy metal capped sample. To further study the magnetic phases in our thin films we have fabricated spin-transfer ferromagnetic resonance (ST-FMR) [4] devices, which could shed light on resonant dynamics of the skyrmion phase.

References:

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