High Frequency Ferromagnetic/Antiferromagnetic Resonance of Thin Films

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Introduction

Ferromagnetic resonance (FMR) has been a major characterization technique for understanding the magnetic excitations and spin dynamics in magnetic materials. In recent years, FMR spin pumping (**Fig.1**) has generated intense interest for its potential application in spintronics, particularly in heterostructures of ferromagnets (FM), antiferromagnets (AF), and nonmagnetic materials (NM). Most spin pumping studies use frequencies of 1 – 20 GHz while spin pumping above 40 GHz is essentially unexplored. Higher frequency will lead to larger spin currents desired for spin-based electronics and eventually drive the dynamic spin transport into a nonlinear regime where new functionalities are expected to emerge [1]. We have investigated a variety of ferromagnetic thin films as well as single crystals of CrI_3, a two-dimensional (2D) van der Waals crystal with ferromagnetic properties, which could be of interest for spintronic applications.

Experimental

We have studied the temperature, field, and orientation dependence of the magnetic properties of CrI_3 with ferromagnetic resonance (FMR) at 120 and 240 GHz using the multi-frequency heterodyne quasi-optical spectrometer equipped with a 12.T SC magnet in the EMR facility at the NHMFL in Tallahassee. The thin single crystal was mounted on a single axis rotator in a variable temperature flow cryostat, which allows temperatures in the 2.6–400 K range under active helium flow conditions.

Results and Discussion

FMR and spectra were collected at a several temperatures above and below the Curie temperature (61K) and with 9 degree increments of the external magnetic field with respect to the crystal plane normal. **Fig.1** shows some typical spectra recorded at 40 K and 120 GHz for a few angles of the crystal with respect to the magnetic field. There is a very strong orientation dependence due to a combination of crystal shape, crystal structure and anisotropic interactions.

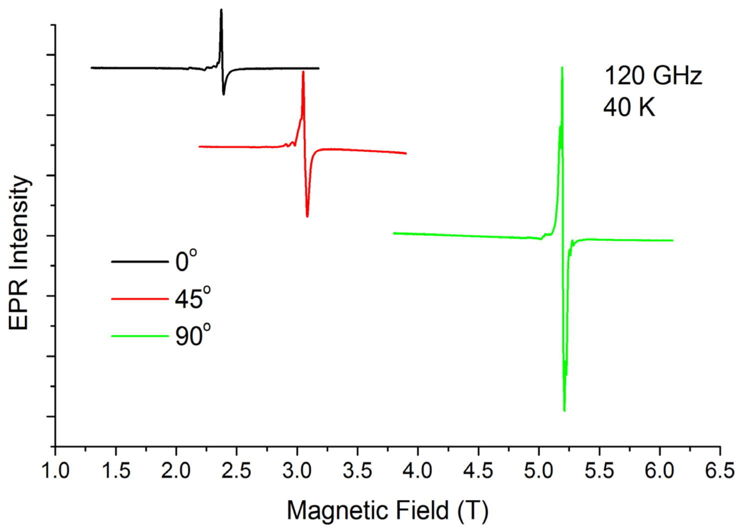

Fig.1 Typical FMR spectra at a few selected angles of the external magnetic field with respect to the crystal c-axis at 120 GHz and 40K.

Conclusions

The FMR data have allowed us to construct a detailed microscopic spin model that describes the anisotropic interactions in a monolayer in terms of the measured Heisenberg, Kitaev, symmetric anisotropic, and quadrupole interactions. The largest anisotropies appear to arise from Kitaev interactions rather than Heisenberg exchange.

Acknowledgements

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References

[1] Ando, K., *et al.*, Appl.Phys. Lett., **99**, 092510 (2011).