Anisotropic Gigahertz Antiferromagnetic Resonances of the Easy-Axis van der Waals Antiferromagnet CrSBr

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Abstract:

We report measurements of antiferromagnetic resonances in the van der Waals easy-axis antiferromagnet CrSBr. The spectra show good agreement with a Landau-Lifshitz model for two antiferromagnetically-coupled sublattices, accounting for inter-layer exchange and triaxial magnetic anisotropy. Fits allow us to quantify the parameters governing the magnetic dynamics: at 5K, the interlayer exchange field is μ_0H_E = 0.395(2) T, and the hard and intermediate-axis anisotropy parameters are μ_0H_c = 1.30(2) T and μ_0H_a = 0.383(7) T [1].

Summary of Research:

Chromium bromide (CrSBr) is an A-type antiferromagnetic vdW semi-conductor with intralayer ferromagnetic coupling and interlayer antiferromagnetic coupling [2-4]. It has a bulk Néel temperature (T_N) of 132K and an intermediate ferromagnetic phase with Curie temperature (T_C) in the range of 164-185 K as measured using transport and optical methods [2,5,4]. Each vdW layer consists of two buckled rectangular planes of Cr and S atoms sandwiched between Br atoms. The layers are stacked along the *c*-axis through vdW interactions to form an orthorhombic structure (space group *Pmmn*). We investigate the antiferromagnetic resonances of CrSBr by placing the crystal on a coplanar waveguide and measuring the microwave absorption spectrum using a two-port vector network analyzer.

We align the crystal with its long axis perpendicular to the waveguide, such that the Néel axis is perpendicular to the in-plane RF field (H_{RF}). An external DC magnetic field is swept in-plane, either perpendicular, parallel, or at intermediate angles to the Néel axis. Representative transmission spectra as a function of applied field at 5K are shown in Figure 1. Dark green features represent

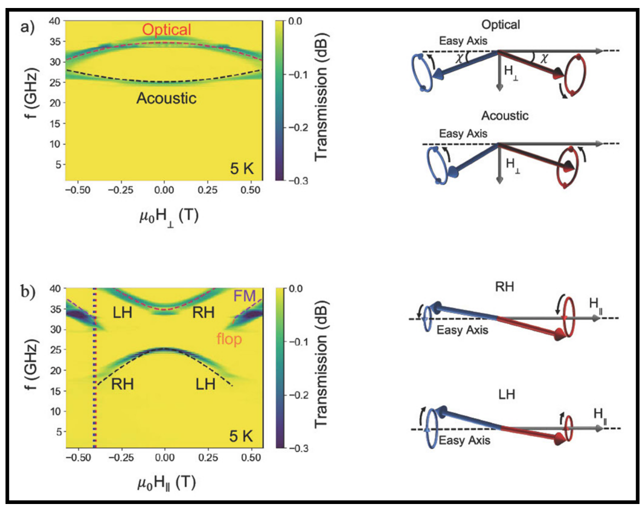

Figure 1: (a) Microwave transmission (S_{21}) signal as a function of $H_\perp$, magnetic field applied along the crystal a *axis. (b) The corresponding spectra as a function of H∥, magnetic field applied along the crystal* b *axis. S_{21} values are shown relative to a field-independent subtracted background. Dashed lines show a fit to the results of the L-L model. Diagrams on the right illustrate the form of some of the resonant modes.*

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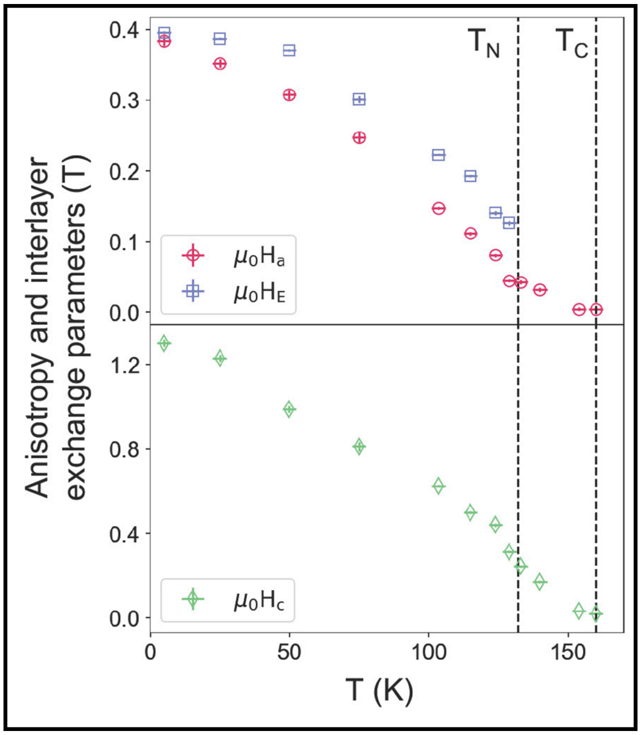

Figure 2: (a) Temperature dependence of the interlayer exchange H_E (blue squares) and the in-plane easy-axis anisotropy parameter H_a (red circles). (b) Temperature dependence of out-of-plane anisotropy parameter H_c. The black dashed lines indicate the estimated Néel temperature $T_N \approx 132$ K and the Curie temperature $T_c \approx 160$ K, previously measured in magnetometry and magnetotransport measurements.

strong microwave absorption due to resonance modes. We observe two resonance modes in the $H_\perp$ configuration and show their dependence on magnetic field in Figure 2a up to the maximum applied field of ± 0.57 T. We identify the two resonances in Figure 1a as acoustic and optical modes originating from an initial spin-flop configuration in which the two spin sublattices are canted away from the easy axis. In the $H_\parallel$ case (Figure 1b), two resonance features are also observed, but with opposite signs of concavity compared to Figure 1a.

Next, we investigate the evolution of the resonant modes with temperature. We observe qualitatively similar resonance features over the temperature range from 5 to 100 K. With increasing temperature, the modes shift to lower frequency and the magnetic field scales decrease for both the value of $H_\perp$ where the two modes become degenerate and for the value of $H_\parallel$ corresponding to the discontinuous transition. These observations can be attributed to decreasing values of all of the exchange and anisotropy parameters H_E, H_a and H_c with increasing temperature. Figure 2 plots the values of the parameters for a series of temperatures from 5 to 128K. We observe a monotonic decrease in all three parameters.

Conclusion and Future Steps:

In summary, we report measurements of gigahertz-frequency antiferromagnetic resonance modes in the van der Waals antiferromagnet CrSBr that are anisotropic with regard to the angle of applied magnetic field relative to the crystal axes. The modes are well described by two coupled Landau-Lifshitz equations for modeling the spin sublattices, when one accounts for interlayer exchange and triaxial magnetic anisotropy present in CrSBr. Our characterization of antiferromagnetic resonances in an easily-accessible frequency range, and the understanding of how the resonances can be tuned between uncoupled and strongly-coupled by adjusting magnetic field, sets the stage for future experiments regarding manipulation of the modes and the development of capabilities like antiferromagnetic spin-torque nano-oscillators.

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