Magnetic Anisotropy in Magnetic van der Waals $FePS_3$

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Introduction

Layered transition metal tri-chalcogenides ($TMPS_3$, TM = Fe, Co, Mn, and Ni) represents one of the known layered systems in which both magnetic and crystallographic lattices are 2D. The layers are separated by a vdW gap and represent an antiferromagnetic (AFM) order with a transition temperature in the range of 80–150 K [1, 2]. $FePS_3$ has a monoclinic honeycomb crystal structure with *C2/m* structural space group and performs an Ising-type AFM alignment along the *c*-axis below T_N = 118 K. Magnetic anisotropy plays an important role in the understanding of magnetic vdW materials, which exhibit magnetocrystalline anisotropy owing to the layered structure, and a reduced symmetry. We investigated magnetic properties and magnetic anisotropy for both in-plane and out-of-plane directions using torque magnetic measurements on $FePS_3$ single crystals.

Experimental

$FePS_3$ single crystal was mounted on a piezoelectric resistance cantilever. We measured the angle-dependent torque $\tau(\theta)$ and magnetic field dependent torque $\tau(H)$. We used 18/20 T superconducting magnet (SCM-2). The angular position of the sample was controlled via a rotator, with respect to the applied magnetic field.

Results and Discussion

The in-plane angle dependence of torque, $\tau(\Phi)$, at different applied magnetic fields at T = 50 K as shown in Fig. 1(a), indicates a perfect sin2Φ pattern (red lines) that represents the isotropic behavior of $FePS_3$ along the *a-b* plane. Fig. 1(b) shows the out-of-plane angle dependent torque measurement $\tau(\theta)$. This curve shows a perfect sin2θ pattern at low magnetic field, but at 4T or higher it deviates from sin2θ, the positive torque becomes sharper, and the negative torque becomes flatter. The amplitudes, as a function of the applied magnetic field, obtained from simple sinusoidal fitting of the $\tau(\Phi)$ and $\tau(\theta)$ curves are shown in Fig. 1(d). Larger amplitudes in out-of-plane demonstrate the larger anisotropy of $FePS_3$. The amplitudes are evaluated using the power-law method $A \propto H^{\alpha}$ where α= 1.99 for the in-plane and α= 1.89 for the out-of-plane configurations. As shown in Fig. 1(c), out-of-plane $\tau(\theta)$ curves at different temperatures at 5 T show consistent behavior from 5 K to 100 K. The amplitude slightly decreases with increasing temperature. However, the amplitude sharply decreases at 110 K, and the phase is reversed at 120 K above TN and the amplitude again increases. It is noted that a sign change in the $\tau(\theta)$ curves with increasing temperature is caused by the magnetic transition from the antiferromagnetic to paramagnetic state.

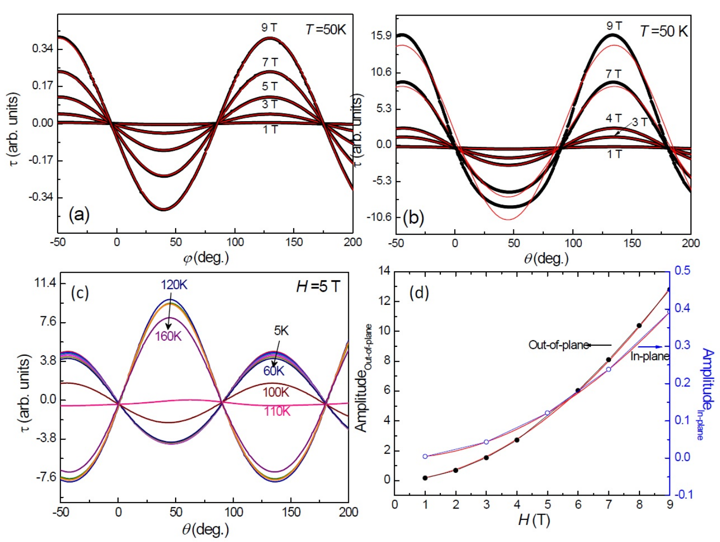

Fig. 1 (a) In-plane and (b) out-of-plane angle dependent torque measurements of $FePS_3$, (c) angle dependent torque at different temperatures, (d) Amplitudes of torque vs. magnetic fields for in-plane and out-of-plane rotations.

Conclusions

A pronounced and explicit difference between out-of-plane and in-plane torque signal was observed that pertains to large anisotropy along these two directions. All the results suggest an imperfect AFM ordering along the *c*-axis with difference in net magnetization along +*c* and –*c* direction. A mixture of Zeeman energy, spin-orbit coupling and single ion anisotropy due to trigonal distortion of FeS_6 octahedra contribute to the overall anisotropy of $FePS_3$.

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References

[1] Lee, S., *et al.*, APL Materials, 4, 086108 (2016).
[2] Kim, S. Y. *et al.*, Physical review letters, 120, 136402 (2018).