Supplemental Material

Magnetic phase transition in two-dimensional $CrBr_3$ probed by quantum sensor

Haodong Wang, [1,2,*] Peihan Lei, [1,2,*] Xiaoyu Mao, [1,3*] Xi Kong,[4,†] Xiangyu Ye, [1,2] Pengfei Wang, [1,2,5] Ya Wang, [1,2,5] Xi Qin, [1,2,5] Jan Meijer,[6] Hualing Zeng, [1,3,‡] Fazhan Shi, [1,2,5] Jiangfeng Du, [1,2,5,§]

[1] *Hefei National Laboratory for Physical Sciences at the Microscale and School of Physical Sciences, University of Science and Technology of China, Hefei 230026, China*

[2] *CAS Key Laboratory of Microscale Magnetic Resonance, University of Science and Technology of China, Hefei 230026, China*

[3] *CAS Center for Excellence in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei 230026, China*

[4] *National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China*

[5] *Felix-Bloch institute for solid state physics University Leipzig, Linnéstr. 5, D-04103 Leipzig, Germany*

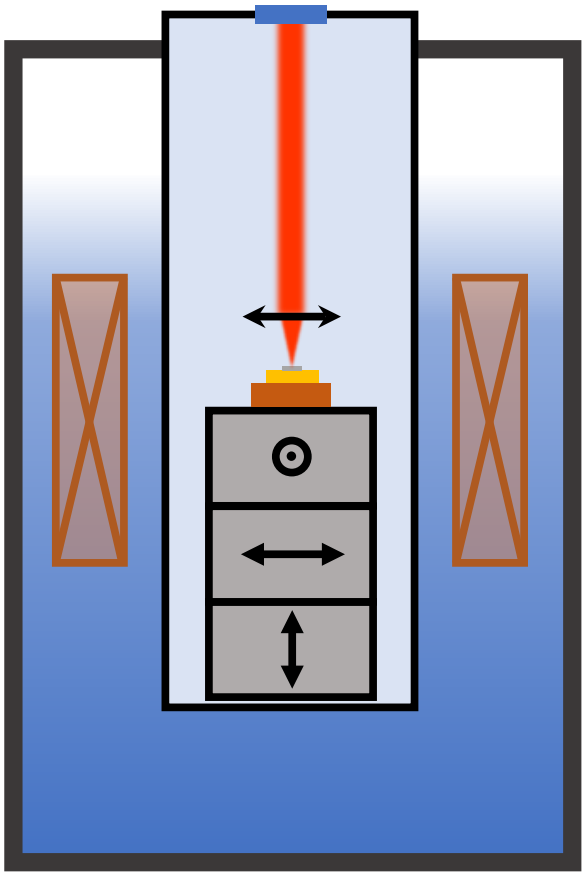

FIG. S1. The experimental apparatus. The vacuum cryostat is immersed in the liquid Helium with superconductor magnet. The diamond and the sample is put on a nanopositioner with a confocal system.

A. Sample preparations

Bulk single crystal CrBr3 and hBN in this study was purchased from HQ Graphene, Inc. The ultrathin CrBr3 and 200nm-thick-hBN were obtained by mechanical exfoliation on polydimethylsiloxane (PDMS) (Gel-Pak, WF-60-X4). Few-layer CrBr3 and monolayer hBN were prepared on PDMS by mechanical exfoliation method. Using the all-dry transfer method[1], hBN flake was transferred onto the surface of diamond right above the NV center layer. Monolayer CrBr3 was stacked on hBN in the same way. The sample e sample is transferred as quickly as possible into the vacuum light shield system to prevent sample decomposition.

B. Apparatus

The ODMR apparatus consist of a objective to focus 532 nm excitation laser on NV center, a microwave coplanar waveguide to deliver driving microwave electromagnetic field on NV centers and a 3-axis nano-stage to scan the sample. The whole sample-sensor system immerses in a liquid Helium-4 cryostat (Fig. S1). Three axis vector superconducting magnet are used to enable vectorial magnetic field control up to 1 T. The measurement temperatures were controlled from 4 K to 70 K by a feed-back thermometer placed close to the sample.

C. Magnetization density distribution reconstruction

We assume the magnetization has only perpendicular component under 200 mT. The method is performed in Fourier space with Fourier-space coordinates $k = (k_x, k_y)$ in the (x, y)-plane.

$$\nabla \times H = 0. \tag{1}$$

Considering the boundary condition of the half-space above the sample,

$$H(k, z) = -\nabla \left[\frac{\sigma(k, 0)}{2} e^{-kz} \right], \tag{2}$$

where $\nabla = (ik_x, ik_y, \partial/\partial z)$ is the gradient operator in Fourier space, $k = \sqrt{k_x^2 + k_y^2}$.

By using the method[2] on single spin probe situation, we can get magnetization distribution with ensemble of NV center. The resolution of our method, performed with ensemble NV sensor, is still limited by the Abbe diffraction limit $l = \lambda/\mathrm{NA}$=800 nm. Thus the high-frequency components of the map need to be filtered out.

REFERENCES

[1] A. Castellanos-Gomez, M. Buscema, R. Molenaar, V. Singh, L. Janssen, H. S. Van Der Zant, and G. A. Steele, "Deterministic transfer of two-dimensional materials by all-dry viscoelastic stamping," 2D Materials **1**, 011002 (2014).

[2] L. Thiel, Z. Wang, M. A. Tschudin, D. Rohner, I. Gutiérrez-Lezama, N. Ubrig, M. Gibertini, E. Giannini, A. F. Morpurgo, and P. Maletinsky, "Probing magnetism in 2D materials at the nanoscale with single-spin microscopy," Science **364**, 973–976 (2019).