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Magnetic order in 2D antiferromagnets disclosed by spontaneous anisotropic magnetostriction

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Abstract—The temperature dependent order parameter provides important information on the nature of magnetism. Using traditional methods to study this parameter in two-dimensional (2D) magnets remains difficult, however, particularly for insulating antiferromagnetic (AF) compounds. We show that its temperature dependence in AF MPS₃ (M(II) = Fe, Co, Ni) can be probed via the anisotropy in the resonance frequency of rectangular membranes, mediated by a combination of anisotropic magnetostriction and spontaneous staggered magnetization. Density functional calculations followed by a derived orbital-resolved magnetic exchange analysis confirm and unravel the microscopic origin of this magnetization inducing anisotropic strain. We further show that the temperature and thickness dependent order parameter allows to deduce the material's critical exponents characterising magnetic order. Nanomechanical sensing of magnetic order thus provides a future platform to investigate 2D magnetism down to the single-layer limit.

Index Terms—two-dimensional materials, antiferromagnetic, Transition-metal phosphorus trisulphides, phase transition, nanomechanics, membrane resonator

I. INTRODUCTION

Layered two-dimensional (2D) magnetic materials offer an emerging platform for fundamental studies of magnetism in the 2D limit. Their stackability into van der Waals heterostructures opens pathways to non-trivial magnetic phases and technological applications, including sensors, memories and spintronic logic devices [3]. However conventional techniques to study the magnetism in these materials, such as neutron scattering, magnetization measurement by a superconducting quantum interference device (SQUID) are challenging, due to the small volumes of exfoliated 2D materials. Other methods, suited to 2D materials, require electrical conductance, the presence of specific optical modes or ferromagnetic order; they are therefore difficult to apply [3].

II. RESULTS

Here [1] we show a general opto-mechanical method that, by using the direct coupling between magnetization, strain, and resonance frequency of suspended 2D magnets, allows us to study the phase transitions in insulating 2D magnetic materials [2], [4], [5]. We transfer a thin flake of

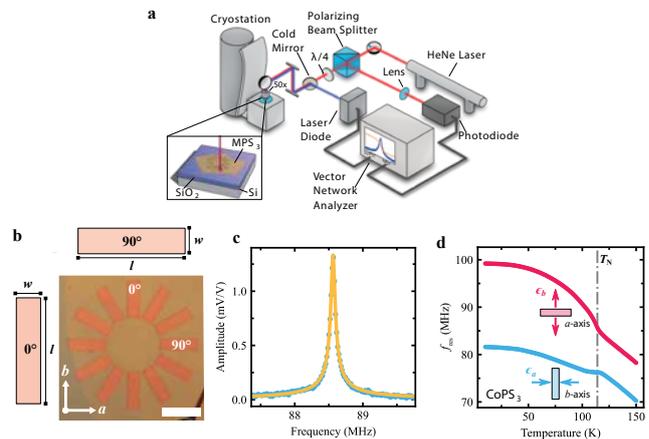


Fig. 1. a, Schematic illustration of the laser interferometry setup and sample with rectangular cavity array. b, Measured amplitude of the fundamental resonance peak in a CoPS₃ drum at $T = 10\text{K}$ and the fitted Lorentzian. c, Temperature dependence of f_0 of a CoPS₃ rectangular membrane with different crystalline orientations. The dashed line indicates the transition temperature T_N extracted from the data. d, Difference of the corrected frequency squared $f_b^2 - f_a^2$ as a proportional to the order parameter. The dashed-dotted line indicates the measured transition temperature T_N . The dashed black line is a powerlaw fit through the data close to T_N from which β is extracted.

MPS₃ (M = Fe, Co, Ni) on to a substrate with rectangular cavities arranged in a star like pattern to create drums of a single crystal with different cavity orientations. We opto-mechanically actuate these drums and extract their resonance frequency as a function of temperature. By studying the difference between different orientation we are able to extract the magnetic order parameter. From the temperature dependence of the order parameter we are able to determine the critical exponents characterizing the magnetism. By comparing these between different flakes their thickness dependence is investigated.

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