Phase transitions and mechanical degrees of freedom in 2D magnets

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Nanoelectromechanical systems (NEMS) made of two-dimensional (2D) crystals are promising to address challenges in creating better sensors, smaller electronic and mechanical devices due to their atomic thickness [1][2]. When NEMS utilize suspended membranes made of magnetic 2D materials, the reduced dimensionality of these results in characteristic types of magnetically ordered phases that leave a fingerprint in their mechanical response to stress. This magneto-mechanical coupling allows modification of magnetic properties of these membranes through controlled straining [3], and vice versa - to affect the dynamics of their motion via a magnetic field [4]. Here, we investigate 2D material membranes with magnetic phase transitions using their nanomechanical motion in both linear [3] and nonlinear [4] regimes. We explain the fabrication of ultrathin 2D material membranes and techniques used to probe their motion. We then discuss their notable mechanical properties and show that 2D magnetic phases can be studied by looking at anomalies in the resonant motion of these membranes [5]. Finally, we theoretically substantiate the correlation between the motion of these membranes and the magnetic ordering at the phase transition temperature, and experimentally verify it for materials of different 2D layered antiferromagnets, ferromagnets, and their heterostructures.

References

[1] Steeneken, P.G. et al. Dynamics of 2D material membranes. 2D Mater 8, 042001 (2021).
[2] Lemme, M.C. et al. Nanoelectromechanical Sensors Based on Suspended 2D Materials. Research, 2020, 8748602 (2020).
[3] Šiškins, M., Lee, M., Manas-Valero, S. et al. Magnetic and electronic phase transitions probed by nanomechanical resonators. Nat Commun 11, 2698 (2020).
[4] Šiškins, M., Keskekler, A., Houmes, M.J.A. et al. Nonlinear dynamics and magneto-elasticity of nanodrums near the phase transition. Pre-print at arXiv:2309.09672 (2023).
[5] Houmes, M.J.A., Baglioni, G., Šiškins, M. et al. Magnetic order in 2D antiferromagnets revealed by spontaneous anisotropic magnetostriction. Nat Commun 14, 8503 (2023).

Figures

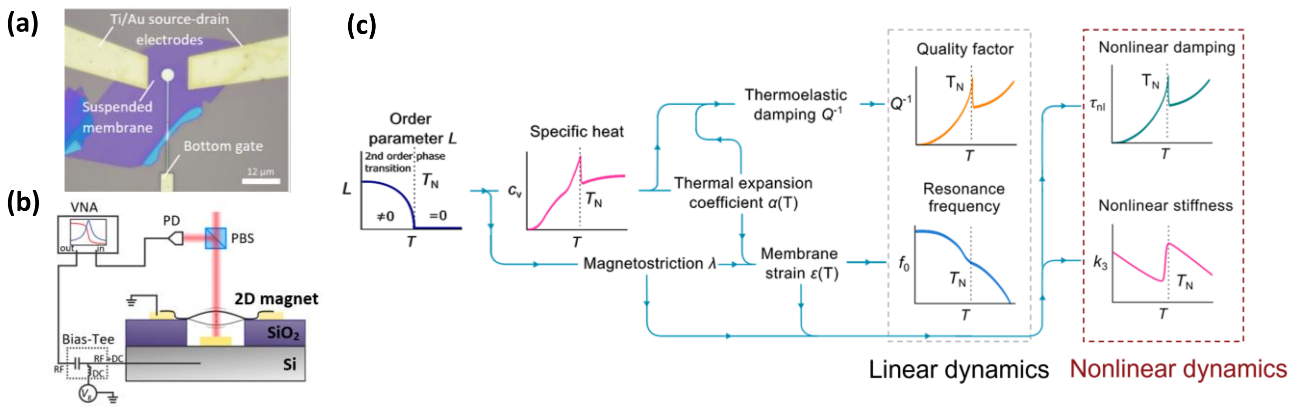

Figure 1: Example of magnetic 2D membrane sample and readout technique of its motion. (a) Optical image of a suspended membrane and contacting electrodes. (b) Schematic cross-section of the sample in (a) with electric excitation and optical probe experiment arrangement. (c)Schematic diagram indicating coupling between mechanical and magnetic parameters in antiferromagnetic 2D membranes in both linear and nonlinear regimes of motion.