High-sensitive torque magnetometry for 2D materials

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Background of the project: Progress in fabrication and development of nanomechanical resonators now allows measurement of mass, force, and torque with exquisite sensitivity.

Torque magnetometry is an established and highly sensitive technique for studying nanomagnets, correlated metals, and superconductors. Dynamic torque (frequency shift), which is proportional to the curvature of the magnetic free energy with respect to rotations, is a particularly useful observable for identifying magnetic phase transitions. Torque magnetometry is broadband and capable of measuring both magnetostatic effects and magnetization dynamics, including spin resonance and relaxation processes.

The sensitivity of the mechanical torque sensors can be improved by decreasing size and defect density, phonon engineering, properly designing the supports to optimally clamp the resonator.

Here, we intend to fabricate ultra-sensitive mechanical torque sensors and to design these sensors especially for the investigation of 2D materials – including 2D magnets and van der Waals (vdW) heterostructures. In addition to being sensitive enough to measure ultrathin magnetic materials, our sensors will incorporate the possibility of making electrical contact to the sample, something which has been practically challenging in the most sensitive cantilever-based torque sensors.

The improved sensitivity of our planned torque sensors and the ability to integrate electrical leads and contacts to the sample will enable a whole series of experiments: e.g. detecting superconducting and magnetic phase transitions in 2D materials and vdW heterostructures. Our vision is to create and apply a new experimental platform for the investigation of magnetic and superconducting phase transitions in 2D systems.

Goals:

- To fabricate torsional resonators allowing for electrical contact to the sample and integrated within a phonon band-gap support with optimal clamping;
- To demonstrate state-of-the-art torque sensitivity on samples with electrical contacts;
- To use the transducers to measure the magnetic and superconducting phase transitions in 2D materials as a function of applied gate voltages, magnetic field, and temperature.

Methods: As a first step, we intend to design ultra-sensitive torsional resonators. The geometry will be optimized for ultimate torque sensitivity, to accommodate 2D samples and the possibility of electrical contacts, and for ease of fabrication. Simulations will be crucial for designing the phonon band-gap structure surrounding the torsional resonator. Once the torsional resonators have been fabricated, we will characterize them in our custom-built torque magnetometry setup. We will then use our transducers in torque magnetometry experiments focusing on 2D samples, to which we will have electrical contact to apply gate voltages. Our expectation is to then measure magnetic and superconducting phase transitions in these materials as a function of gate voltage, magnetic field, and temperature via measurement of dynamic torque.

Outcome of the project and relevance for Nanoscience: Our specially designed torque sensors will allow us to measure these phase transitions, yielding the associated phase diagrams and giving new insight into these poorly understood condensed matter phenomena.

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