Ph.D. DISSERATION DEFENSE

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Degree: Doctor of Philosophy

School/Department: Charles V. Schaefer, Jr. School of Engineering and Science/Department of Mechanical Engineering

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Title: Magnetotransport Properties in Two-Dimensional Materials and Field-free Orbital-Torque Switching in a Symmetry-Engineered Monolayer van der Waals Ferromagnet

Chairperson: Dr. Eui-Hyeok Yang, Department of Mechanical Engineering, Stevens Institute of Technology

Committee Members: Dr. Annie Zhang, Department of Mechanical Engineering, Stevens Institute of Technology
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ABSTRACT

Electron transport in semiconductors can be significantly influenced by external magnetic fields, giving rise to magnetotransport phenomena such as the quantum Hall effect, spin–orbit coupling, and magnetoresistance. These effects have attracted considerable interest due to their potential applications in next-generation optoelectronic and spintronic devices. Among semiconducting systems, two-dimensional (2D) materials are particularly promising because of their tunable electronic and magnetic properties, strong spin-orbit coupling, and diverse crystal symmetries.

Harnessing orbital torque (OT) generated by the orbital Hall effect (OHE) for magnetization control in 2D van der Waals ferromagnets offers a promising route to next-generation orbitronic devices. Orbitronics leverages the orbital degree of freedom, revealing that electrons can carry a transverse orbital angular momentum flow, owing to OHE. Recent experimental studies have elucidated the mechanism by which a pure OAM current, generated via the OHE in a non-magnetic orbital-Hall material, can be converted into a spin current in materials with strong spin-orbit coupling. While OT switching, both with and without magnetic fields, has been reported to achieve perpendicular magnetization switching, room temperature, field-free OT switching in monolayer vdW magnets has not been demonstrated.

This study demonstrates deterministic room-temperature OT switching in Fe-doped MoS_2 ($Fe:MoS_2$), identifies an unusual angular dependence of the antisymmetric component in OT-FMR measurements, and shows that Fe doping and strain reduce the crystal symmetry from the C_3 to the C_1 point groups. It elucidates the temperature-dependent behavior of both field-free and field-assisted OT switching up to 300K with a minimum current density of ~1.69×10^6 A cm^{-2}. The orbital torque-ferromagnetic resonance measurement shows a nonzero term in the antisymmetric component, indicating an out-of-plane antidamping torque. It also shows that strain and Fe doping reduce the crystal symmetry from C_3 to C_1, as evidenced by magnetic switching responses that are independent of the crystal direction. This comprehensive study of magnetic switching in a 2D ferromagnetic monolayer provides a new route toward the development of future memory devices.