Ph.D. DISSERTATION DEFENSE

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Title: Field-Free Spin-Orbit Torque Switching of 2D Dilute Magnetic Semiconductors via Spin-to-Spin Conversion
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ABSTRACT

The Spin-Orbit Torque Magnetic Random-Access Memory (SOT-MRAM) is a type of non-volatile memory that uses SOT to write data instead of traditional magnetic fields or electrical currents. This technology is promising for future memory applications due to its potential for lower power consumption, faster operation, and scalability compared to other types of MRAM. Heavy metals exhibiting strong spin-orbit coupling and topological insulators with unique surface states that support spin-momentum locking can generate substantial spin currents when subjected to an electrical current. When these materials are paired with van der Waals (vdW) or non-vdW magnets, high-efficiency spin-torque transfer to the magnetic layers can be achieved. The strong perpendicular magnetic anisotropy (PMA) in vdW magnets is particularly beneficial for spintronics applications.

Room temperature, field-free SOT switching was achieved using WTe_2, combined with vdW materials, including Fe_3GeTe_2 and Fe_3GaTe_2, synthesized via flux-growth or molecular beam epitaxy. However, as the number of layers is reduced to achieve thinner structures, their Curie temperature significantly drops, well below room temperature. This limitation presents a significant challenge for achieving high-efficiency SOT switching reliably.

This work presents an ultra-low power, field-free, deterministic, and non-volatile perpendicular magnetization switching by SOT up to 380 K using a DMS, monolayer Fe:MoS_2, through interfacial coupling with a Pt Hall bar. The geometry-induced strain in the crystal breaks the rotational switching symmetry in Fe:MoS_2, promoting field-free SOT switching by generating out-of-plane spins via spin-to-spin conversion. The anisotropy of field-free SOT on the crystallographic axis of Fe:MoS_2 was proven by injecting current in the armchair or zigzag direction. Perpendicular magnetization switching of Fe:MoS_2 was confirmed by measuring the AHE in the adjacent Pt layer. An apparent AHE loop shift was observed at a zero in-plane magnetic field, verifying the existence of an out-of-plan antidamping torque-- τ_{AD}^{OOP} in Fe:MoS_2/Pt heterostructure with a reduced crystal symmetry, facilitating field-free SOT switching with the current density of 7 x 10^4 A cm^{-2} at 380 K. This SOT application using a 2D monolayer DMS provides a new pathway for developing highly power-efficient spintronic devices.