Spin electronics take advantage of the electron's spin apart from its charge for processing and information storage. Magnetic memory devices controlled by the spin-current have the potential to be non-volatile, fast (ns-scale writes and reads), high-density, CMOS-compatible, and to operate at low voltages. Among competing technologies for future nonvolatile memories, magnetic devices also have the unique virtue that they can have essentially infinite endurance, because during operation only the magnetization direction changes, while the atoms do not move. This makes them attractive for embedded memory applications, memory-in-logic, and circuit architectures optimized for machine learning in post-Moore's era. The critical remaining challenge in developing magnetic memories and nonvolatile logic is a fundamental condensed-matter physics problem – to identify a mechanism capable of achieving efficient and reliable electrical control of the magnetization vector. The mechanism currently in use is spin-transfer torque from a spin-polarized current. Spin transfer-torque magnetic random access memory (STT-MRAM) samples using this mechanism are sufficiently efficient that they have been commercialized successfully by Everspin and in 2019 they began to be manufactured for more widespread application by the major semiconductor foundries. However, the efficiency of STT-MRAM has a fundamental quantum limit – the torque cannot be stronger than 1 angular momentum transferred per unit charge in the current, which means that existing devices still require relatively large costs in current and energy. The large currents require larger-than-minimum-area transistors to source the current, so that the transistor size (rather than the magnetic device itself) limits the achievable storage density and economics of production.

The proposal seeks to develop extremely low-power spintronic based nonvolatile memory and logic technologies with infinite endurance, through experimental studies of new quantum materials and devices that can greatly increase the efficiency of magnetization switching. With these materials, we will realize physical phenomena and device functionalities that are not possible in traditional polycrystalline metal-based spintronic. Range of hybrid materials will be designed, synthesized, dynamically tunned structurally and electronically, and integrated into the state-of-the-art MRAM devices.

The objective of the study is to explore material-based solutions for maximizing the spin-to-charge interconversion, designing the symmetries of spin current polarizations, and dynamic tunning of such spin-orbit phenomena through ferroelectric polarization switching. The project is designed to access the hypothesis that the quantum material symmetry design is the key enabling efficient deterministic magnetization switching, and such design and the fabrication of quantum materials are building blocks for future spintronic devices. The results of the study will lead to new understanding of the fundamental mechanisms by which spin-orbit coupling can produce current-induced torques, and what materials can be used to maximize the strength of these torques, and will enable the exploration of other new scientific opportunities to better control both the properties of the magnetic film (e.g., magnetization saturation and damping, Dzyaloshinskii-Moriya interactions, magnetic anisotropy, interlayer coupling etc.) and the spin and valley dynamics within the spin-orbit material (e.g., magnetic control of optical properties, valley Hall effect, valley ferromagnetism, and superconductivity).