“The Hidden Player in Spin-Orbit Torque: Rethinking the Ferromagnet”

Xin Fan

University of Denver

Monday, November 17th, 2025 at 4:00pm

Engineering 100

Abstract

Spin-orbit torque (SOT) enables the electrical manipulation of magnetization using the spin-orbit coupling in materials. It lies at the intersection of condensed matter physics and spintronics device applications, revealing new ways to design low-power magnetic memory and logic devices. A prototypical device structure to realize SOT is a bilayer film consisting of a ferromagnetic layer and a non-magnetic heavy metal layer. Traditionally, it is thought that spin current arises from the spin-orbit coupling in the heavy metal, while the role of the ferromagnet is only to absorb the spin current, which then induces the SOT. However, we found that the ferromagnet can in fact generate significant and unconventional spin currents via its own spin-orbit coupling. In this talk, we will rethink the role of the ferromagnet in the SOT. We will first show that a ferromagnet can generate spin current with spin polarization transverse to magnetization, despite spin dephasing. The transversely-polarized spin current generated from a single-layer ferromagnetic film will induce equal and opposite spin torques on the surface of the ferromagnet itself. Due to the analogy to the famous anomalous Hall effect, we term the spin torques as the anomalous spin-orbit torques. We further show that when symmetry at the ferromagnet surfaces is broken, the anomalous spin-orbit torque is unbalanced, which can lead to a sizable self-generated SOT that was previously overlooked. Understanding the role of the ferromagnet in the generation of SOT will inform the development of SOT-based devices.

Biography

Xin Fan received his Ph.D. in Condensed Matter Physics from University of Delaware in 2010 under the supervision of Prof. John Xiao. After graduation, Xin stayed in the same group as a postdoc fellow. He joined the faculty of University of Denver in 2014, and is currently an associate professor in Physics. He is a recipient of the NSF CAREER award, the JSPS invitational fellowship, and the Humboldt Research Fellowship for Experienced Researchers. His current research interests include magnetic dynamics and spintronics.