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Origin of spin-orbit torques in thin film heterostructures

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Spin-orbit torques arising from current flow in heavy-metal thin films have the potential to enable very efficient manipulation of magnetic devices. I will describe recent studies aiming to better understand the mechanisms behind these torques and to enhance their effectiveness through improved control over materials and interfaces. Studies as a function of inserting a spacer layer between the heavy metal and ferromagnet indicate that both the anti-damping and effective-field components of spin-orbit torque originate from the spin Hall effect within the heavy metal, rather than a Rashba-Edelstein effect at an interface of the ferromagnet, but spin scattering at both interfaces of the magnet can still affect the strength of the torque components. We have also studied how the introduction of impurities into heavy metals influences the spin-orbit torque, finding significant improvements in both the strength of the torque per unit current and the energy cost for switching. This is consistent with expectations if the spin Hall effect is dominated by an intrinsic band structure mechanism. In addition to enhancing the strength of spin-orbit torques, we are learning to manipulate their direction, by generating spin currents using materials that break inversion symmetry within the sample plane. I will describe measurements in which a thin layer of WTe_2, a low-symmetry transition metal dichalcogenide, produces an out-of-plane anti-damping spin-orbit torque, an orientation that is forbidden by symmetry in more conventional devices. This work is done in close collaboration with the group of Bob Buhrman at Cornell University.