Experimentelle Physik 2

Seminar Festkörperphysik (CMP Seminar)

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All-THz metrology of ultrafast spin-orbit torques and spin-charge interconversion in magnetic heterostructures

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Ultrafast magnetization control is essential for next-generation memory, logic, and neuromorphic devices operating at terahertz (THz) frequencies. Efficient picosecond spin-orbit-torque (SOT) switching is currently realized in ferromagnet/heavy-metal (FM/HM) heterostructures, but reliance on heavy metals is costly and environmentally burdensome. Self-generated SOT in nanostructures comprising a single conducting ferromagnetic layer offers an attractive alternative, yet ultrafast SOT has not been demonstrated in such systems and the underlying torque mechanisms remain unclear.

I will present an all-THz metrology that directly probes both ultrafast SOT and spin-charge interconversion in magnetic heterostructures. Using THz-driven coupling to nanometre-wavelength magnons, we demonstrate SOT-driven picosecond magnetization dynamics in oxide-capped $Ni_{81}Fe_{19}$, with efficiencies comparable to benchmark $Ni_{81}Fe_{19}$/HM stacks. By resolving spin-charge interconversion on the picosecond timescale, we show that SOT is active only at off-stoichiometric oxide interfaces and negligible at stoichiometric ones, identifying interfacial atomic-scale oxidation as the key ingredient. The magnitude and even the sign of the effective spin Hall angle are tunable via oxidation level and oxide type.

In the second part, I will introduce spintronic THz harmonic generation (STHG) as a toolbox for disentangling charge-to-spin interconversion: THz-driven ultrafast demagnetization combined with the inverse Rashba–Edelstein effect, and unidirectional spin Hall magnetoresistance (USMR), provide two complementary second-harmonic generation channels that can be separated by symmetry and geometry. Together, this all-THz approach yields a unified view of ultrafast SOT and spin-charge interconversion and points to atomic-layer oxidation engineering as a viable route to THz spintronic technologies.

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