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Picosecond Spin Caloritronics

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The coupling of spin and heat, i.e., spin caloritronics, gives rise to new physical phenomena in nanoscale spin devices and new ways to manipulate local magnetization. Our work in this field takes advantage of recent advances in the measurement and understanding of heat transport at the nanoscale using ultrafast lasers. We use a picosecond duration pump laser pulses as a source of heat and picosecond duration probe laser pulses to detect changes in temperature, spin accumulation, and spin transfer torque using a combination of time-domain thermoreflectance and time-resolved magneto-optic Kerr effect Our pump-probe optical methods enable us to change the temperature of ferromagnetic layers on a picosecond time-scale and generate enormous heat fluxes on the order of 100 GW m^{-2} that persist for $\sim$ 30 ps. Thermally-driven ultrafast demagnetization of a perpendicular ferromagnet leads to spin accumulation in a normal metal and spin transfer torque in an in-plane ferromagnet. The data are well described by models of spin generation and transport based on differences and gradients of thermodynamic parameters. The spin-dependent Seebeck effect of a perpendicular ferromagnetic layer converts a heat current into spin current, which in turn can be used to exert a spin transfer torque (STT) on a second ferromagnetic layer with in-plane magnetization. Using a [Co,Ni] multilayer as the source of spin, an energy fluence of $\approx$ 4 J m^{-2} creates thermal STT sufficient to induce $\approx$ 1 % tilting of the magnetization of a 2 nm-thick CoFeB layer.