Ultrafast spin manipulation of sub-lattice magnetic system with light

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The speed limits for magnetization reversal are of vital importance for spintronic devices, not only for storage media. For ultrafast manipulation of magnetization, optical laser pulses could serve as an alternative stimulus to trigger magnetization reversal. An ultrashort laser pulse allows excitation of magnetic systems at time scales much shorter than fundamental quantities such as spin precession or spin-lattice relaxation times. In particular, the laser excitation brings the magnetic medium into a strong non-equilibrium state[1)], where a conventional description of magnetic phenomena in terms of equilibrium thermodynamics and adiabatic approximations is no longer valid. Consequently ultrafast laser-induced magnetization dynamics is a new and rather unexplored topic at the frontier of modern magnetism.

Here our recent experimental studies of metallic multi-sublattice magnets are summarized. In particular, we focus on magnetization dynamics triggered by an ultrashort laser pulse in ferrimagnetic amorphous rare earth (RE)-transition metal (TM) alloys. The inequivalency of the magnetic sublattices, on the one hand, and a fine balance of their angular momenta on the other, lead to a very peculiar dynamic behavior. This becomes particularly obvious at short time scales, such as the appearance of a ferromagnetic-like state[2)] at time scales below a few picoseconds. The laser-induced ultrafast demagnetization of ferromagnets, already demonstrated in 1996[3)] to occur at a subpicosecond time scale, is still a subject of hot debate. Whether the angular momentum is dissipated into the lattice via phonons and defects, or whether it is carried away by hot electrons or the photons — are still questioned at the forefront of ultrafast magnetism. The element-specific XMCD measurements were performed[2)] to study transient regime of spin dynamics. In order to trigger ultrafast spin dynamics in GdFeCo alloy, the reversal of the magnetizations of the two sublattices is initiated by ultrafast heating of the sample using a 60 fs laser pulse in opposite orientations of the external magnetic field of 0.5 T. However, whereas the net magnetization of Fe has collapsed within 300 fs, the demagnetization of Gd takes as long as 1.5 ps. Remarkably, in spite of the strong antiferromagnetic (AFM) exchange coupling between the Gd and Fe sublattices, they apparently lose their net magnetizations independently, then surprisingly, within the time scale between the zero crossings of the Fe and Gd moments (that is, between 300 fs and 1.5 ps), the net Fe and Gd moments are aligned parallel along the z axis despite the AFM coupling of their spins in the ground state. This state is followed by an inter-sublattice relaxation of the angular momentum, leading to a deterministic switching of the magnetization driven by ultrafast laser-induced heating. We found deterministic magnetization reversal[4)] in same GdFeCo driven by an ultrafast heating of the medium resulting from the absorption of a sub-picosecond laser pulse without the presence of a magnetic field. From the theoretical discussion[5)], the reversal happens because of the interplay of these different demagnetization rates with the exchange interaction coupling the sublattices. These results demonstrate all-optical switching depends only on the amount of energy absorbed by the magnetic system, independent of the wavelength or helicity of the laser pulse. The role of the light helicity in this process is clarified as well. Because of different absorption coefficients for right- and left-handed circularly polarized light in GdFeCo, the switching threshold is helicity dependent. This explanation is consistent with all the experimental findings on all-optical light helicity-dependent magnetic switching[6)] so far, varying from single- to multiple-shot experiments.

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