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All-optical ultrafast control of the four-state memory of ferromagnetic semiconductors by using coherent trains of femtosecond optical pulses

ILIAS PERAKIS, Department of Physics, University of Crete and IESL/FORTH, Heraklion, Crete, Greece

We present a many-body theoretical framework based on density matrix equations of motion for investigating ultrafast all-optical manipulation of ferromagnetism in magnetic semiconductors. We develop a theory of collective spin dynamics triggered by femtosecond photoexcitation and demonstrate non-thermal control of magnetization switchings between the four metastable magnetic states of (Ga,Mn)As by using sequences of linearly-polarized optical pulses. We study the influence of such pre-designed coherent pulse trains on the four-state magnetic memory and demonstrate its full ultrafast control by tuning of relative phase, intensity, and frequency. We show the development of a light-induced magnetization tilt governed by suitable quantum-mechanical superpositions of conduction and valence band states created during the optical pulse. This femtosecond magnetization dynamics is followed by a distinct picosecond temporal regime governed by the magnetic anisotropy of thermal holes. We address the fundamental question of how spins couple to transient optical coherences during time intervals shorter than the photo-excitation and elucidate the role of the competition between magnetic exchange and spin-orbit interactions. Our results indicate the possibility of reading/writing magnetic states at THz speed and propose protocols for multiple switchings between the four metastable states.

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