Femtosecond Magneto-Optics: Quantum Spin Switching

The challenge to push the gigahertz switching speed of today’s logic and magnetic memory devices into the terahertz regime underlies the entire field of information processing, communication and integrated photonic-electronic-magnetic multi-functional devices. The physics of present-day devices imposes serious limitations on this technological transformation, so we must invent new paradigms based on quantum dynamics in the femtosecond regime. This challenge could be met by all-optical quantum switching based on femtosecond coherent laser excitation in strongly correlated magnetic oxides.

There is growing evidence that femtosecond laser-induced transient polarization can be used to manipulate magnetic order during a laser pulse. The idea draws on an analogy to femtosecond chemistry and photosynthetic dynamics in which photoproducts of chemical and biochemical reactions can be influenced by creating suitable coherent superpositions of molecular states. Similarly, femtosecond-laser–excited coherence can create a controllable transient superposition of quantum spin/charge states that switches magnetic order by suddenly breaking the delicate balance between competing phases of colossal magneto-resistive (CMR) manganites.

We recently published a potential way to implement such quantum magnetic switching with femtosecond laser pulses in a CMR oxide Pr$_{0.7}$Ca$_{0.3}$MnO$_3$. Our results demonstrate a photo-induced switching from antiferromagnetic (AFM) to ferromagnetic (FM) ordering that completes during 100-fs laser pulses, while the optical polarization/coherence still interacts with the spins.

Many 2-D layers and 1-D spin chains can experience gigantic magnetic changes from AFM insulating to an FM metallic state during ultrafast laser excitation less than 100 fs, with photo-excitation threshold behavior absent in the picosecond dynamics. This new paradigm, quantum femtosecond magnetism, means photo-induced femtosecond magnetic phase transitions driven by laser-excited inter-atomic coherences and quantum spin flip fluctuations. The laser electric field and quantum dynamics make electrons oscillate between neighboring atoms to initiate local FM correlations that compete with the AFM matrix. A quantum-spin-canted state thus emerges, with local ferromagnetic polarons made of an electron surrounded by a ferromagnetically aligned neighboring spin cluster. These local magnetic regions grow with increases in laser intensity, causing a magnetic order switch during the 100-fs-long laser pulse.

The femtosecond magneto-optics thus reveals an initial quantum coherent regime of magnetism that merges quantum non-equilibrium kinetics and exotic phase competition in complex materials.

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References

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