Ultrafast photoinduced softening in a ferromagnetic semiconductor

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Abstract: Two-color time-resolved magneto-optical Kerr spectroscopy is used to manipulate and detect the dynamics of carrier-induced ferromagnetism in III-V ferromagnetic semiconductors. Our data demonstrates that magnetic properties, e.g., the coercivity, can be tuned reversibly and nonthermally on subpicosecond time scale.

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III-Mn-V ferromagnetic semiconductors such as InMnAs and GaMnAs have unique properties that are expected to add spin degrees of freedom to conventional electronic and optoelectronic devices. Recent demonstrations of photoinduced [1, 2] and voltage-tuned [3] alteration of ferromagnetism in these systems have provided a prototype for building novel "multifunctional" devices that can function as magnetic, photonic, and electronic devices simultaneously. Carrier density tuning is the key to externally manipulate ferromagnetism of carrier-induced nature.

Creation of transient carriers using femtosecond MIR pulses and monitoring the time domain evolution of ferromagnetic order by ultrafast magneto-optical spectroscopy provide interesting possibilities of ultrafast manipulation of ferromagnetic properties in semiconductors (Fig. 1). In addition, this experiment may provide new insight into two highly controversial issues in the recent literature, e.g., the origin of carrier-induced ferromagnetism in III-Mn-V semiconductors and ultrafast demagnetization in itinerant ferromagnets.

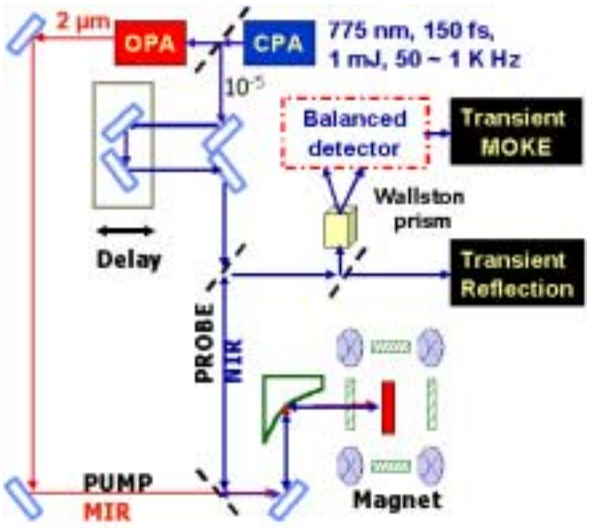

Fig. 1 Schematic diagram of the two-color time-resolved MOKE spectroscopy setup.

In this presentation, we report a demonstration of ultrafast photoinduced softening (i.e., transient coercivity decrease) in an InMnAs/(Al,Ga)Sb heterostructure (Fig. 2). A large density of spin-polarized transient carriers was created only within the InMnAs magnetic layer using intense 140 fs mid-infrared pulses, and then time-resolved magneto-optical Kerr effect (MOKE) spectroscopy was used to directly monitor the transient magnetic properties induced by the photo-generated carriers. The source of MIR pulses was an optical parametrical amplifier pumped by a Ti:Sapphire-based regenerative amplifier (Model CPA-2010, Clark-MXR, Inc., 7300 West Huron River Drive, Dexter, MI 48130).

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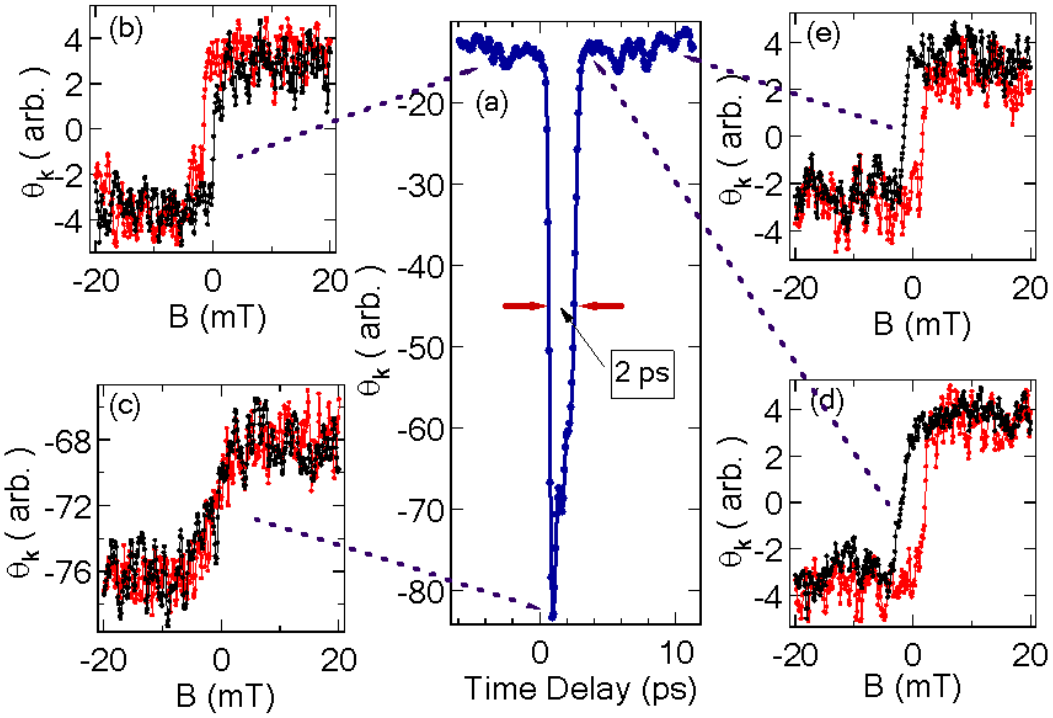

Fig. 2 (a) Time scan of MOKE. Pump wavelength was 2 μm with circular polarization. Probe wavelength was 775 nm. The data was taken at 0.02 T and 20 K. A ~2 ps photo-induced MOKE response is observed. (b), (c), (d), (e): MOKE signals are plotted vs. field at different time delays, which correspond to the specific positions shown in (a). (b) –4 ps; (c) 430 fs; (d) 3 ps; (e) 11 ps. At timing zero, the ferromagnetic hysteresis loop is shown to totally collapse in the horizontal direction, i.e., the coercivity becomes almost zero. It is seen that ferromagnetic loops "open up" horizontally as soon as photoinduced signal are gone (shown in (a)).

We attribute the photoinduced softening to the increased exchange interaction due to the increased carrier density, which is expected to decrease the domain wall energy and hence a decreased coercivity. We will discuss our results in light of recent theoretical studies on carrier-mediated ferromagnetism in III-Mn-V semiconductors. The subpicosecond decay and extremely fast recovery of the loop are probably due to the ultrashort carrier lifetime in this system (Fig. 3), which arises from the low temperature molecular-beam epitaxy growth employed. This ultrafast nature leads to a new scheme for recording information on a magneto-optical disk entirely non-thermally, thus with an extremely fast manner.

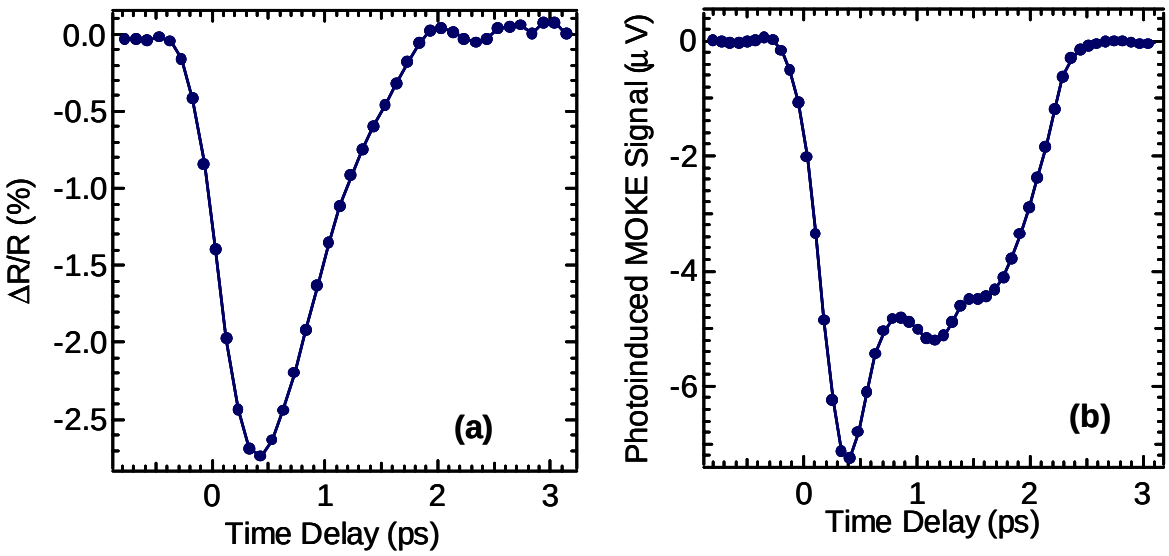

Fig. 3 (a) Two-color time-resolved transient reflectivity of InMnAs. The reflectivity of NIR probe is plotted vs. time delay under MIR pumping, showing extremely fast charge decay. The data was taken at 20 K. (b) Photoinduced MOKE signal at 20 K under pumping with σ^- polarized MIR radiation, showing a spin decay time which is comparable to the charge life time seen in (a).

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