Ultrafast enhancement of magnetization in ferromagnetic semiconductor (In,Fe)As quantum wells

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Ultrafast control of the magnetic properties of ferromagnets, such as demagnetization, phase transition, spin precession, and magnetic switching, generates much interest from the viewpoint of high-speed spintronic applications such as non-volatile memory and logic devices. Thus far, however, enhancement of ferromagnetism has been only observed in ferromagnetic semiconductors (FMSs) owing largely to their low carrier density and strong spin-carrier interactions [1]. Unfortunately, the change of magnetization occurs due to the slow process of relaxation of photo-carriers to low-energy bands, which is typically in the order of ~100 ps. Therefore, ultrafast sub-ps enhancement of ferromagnetism has not been achieved.

Here we demonstrate for the first time sub-ps enhancement of ferromagnetism in *two-dimensional (2D)* FMS (In,Fe)As/InAs bilayer quantum wells (QWs, Curie temperature T_C ~ 20 K). The samples consist of (In,Fe)As (10 nm, 8-10% Fe)/InAs (5 nm)/AlSb (300 nm)/AlAs (5 nm) grown on SI GaAs (001) substrates by molecular beam epitaxy (Fig. 1a). We conducted pump-and-probe X-ray magneto-optical Kerr effect (XMOKE) measurements at SACLA, using a fs-pulse laser (wavelength 793 nm, pulse width 30 fs) as the pump source and an X-ray free electron laser (XFEL) beam with energy of 52 eV, which is resonant with the *M* absorption edge of Fe, as the probe. We monitored the Kerr rotation angle of the XFEL beam reflected from the (In,Fe)As/InAs QW surface at various temperatures and magnetic fields. As shown in Fig. 1b, the Kerr rotation angle of the reflected XFEL beam rapidly enhances upon irradiating the QW by the pumping laser pulse (see the black arrow in Fig. 1(b)). This indicates an extremely fast sub-ps enhancement, corresponding to 667 fs, of the magnetization of the (In,Fe)As/InAs QW. Unlike previous works, this result cannot be explained by the accumulation of photo-carriers in the conduction band bottom, but it is caused by instant deformation of the QW potential that moves the 2D wavefunction and changes the 2D carrier distribution as shown in Fig. 1(c). This is a unique feature —*wavefunction engineering of ferromagnetism*— of 2D ferromagnetic systems, which was previously confirmed in (In,Fe)As QWs [2].

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Refs: [1] J. Wang et al., PRL **98**, 217401 (2007). [2] L. D. Anh et al., PRB **92**, 161201(R) (2015).

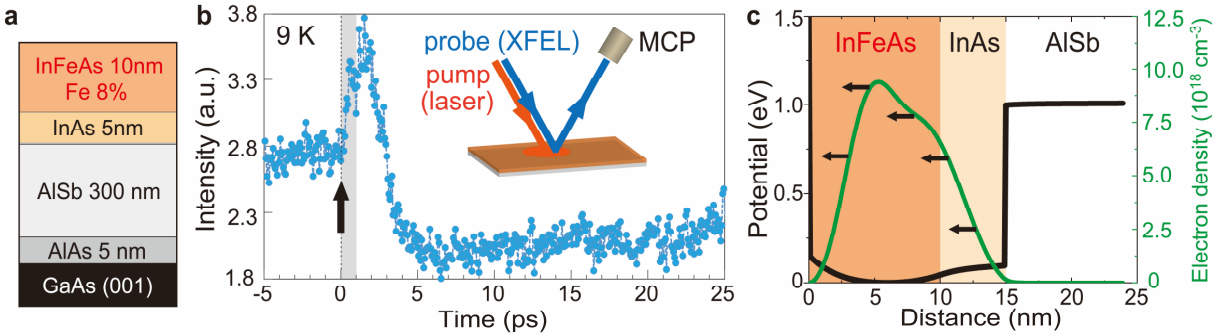

Fig. 1. (a) Sample structure with 15 nm-thick (In,Fe)As/InAs. (b) Time-dependent enhancement of the Kerr rotation angle of a probing XFEL reflected from the sample upon irradiating by the pumping laser (wavelength 793 nm, pulse width 30 fs). (c) Potential profile (black curve) and electron density distribution (green curve) of the (In,Fe)As/InAs QW. The electron distribution is expected to shift to the (In,Fe)As area following the 2D wavefunctions movement upon irradiating (In,Fe)As/InAs by the pump laser, leading to the enhancement of magnetization.