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Femtosecond Optical Excitation of Spin Resonances in the Easy-Plane Antiferromagnetic semiconductor EuTe

R. R. SUBKHANGULOV[1], R. V. MIKHAYLOVSKIY[1], B. A. IVANOV[2], A. B. HENRIQUES[3], P. H. O. RAPPL[4], E. ABRAMOF[4], TH. RASING[1] & A. V. KIMEL[1]

[1]*Radboud University, Institute for Molecules and Materials, 6525 AJ, Nijmegen, The Netherland*
r.subkhangulov@science.ru.nl
[2]*Institute of Magnetism, 03142 Kiev, Ukraine,*
[3]*Instituto de Fisica, Universidade de Sao Paulo, Caixa Postal 66318, CEP 05315-970 Sao Paulo, Brazil,*
[4]*LAS-INPE, 12227-010 Sao Jose dos Campos, Brazil*

Understanding laser-induced spin dynamics in magnetic materials is a cornerstone for high-speed spintronics and magnetic recording. In particular antiferromagnets begin to play an increasingly important role, since their intrinsic spin dynamics can be much faster as it is directly driven by the exchange interaction. In this regard antiferromagnetic semiconductors [1] are particularly interesting because of the potential to combine them with conventional semiconductor technologies [2] as well as the possibility to steer the spin system via exchange coupled conduction electrons. The latter permit one to trigger ultrafast spin dynamics via short laser pulses.

We investigated the ultrafast spin dynamics in the model Heisenberg antiferromagnetic semiconductor EuTe. EuTe has a type-II, MnO, antiferromagnetic structure below the Neel temperature of 9.6 K. This antiferromagnet has a rather small exchange interaction energy. Hence, the application of an external magnetic field of about 0.1 T already causes a spin-flop phase transition [3]. Increasing the magnetic field further causes a canting of the antiferromagnetically coupled spins, followed by the complete parallel spin alignment at the magnetic field of 7.2 T [4,5] called spin-flip transition.
We employed a time-resolved all-optical pump-probe technique at a temperature of 1.7 K and magnetic fields up to 7 T applied in the plane of the sample (See Fig. 1). We demonstrate that the optically excited EuTe band electrons, from 4f to 5d, trigger the antiferromagnetic resonance (AFMR) precession consisting of two modes [7]. Analyzing the efficiency of the excitation of the AFMR modes as a function of the applied magnetic field we found that the excitation is induced by the ferromagnetic 5d–4f exchange interaction, which is an order of magnitude higher (J_{df}=36 meV) than the antiferromagnetic f-f exchange (J_{ff} =1 meV). The d-f exchange in EuTe gives rise to the isotropic magneto refractive effect. It is manifested as a modulation of the bandgap of EuTe at the AFMR frequency and can be monitored by measuring the pump induced reflectivity changes in the probe beam. By fitting the dependence of the AFMR frequencies on magnetic field with the eigen frequencies of the Landau-Lifshitz equation for easy plane antiferromagnets [5], we found that the static anisotropy and exchange fields deviate from those known from literature. We argue that these deviations stem also from the d-f exchange. In particular, the d-f exchange interaction, being ferromagnetic, was found to decrease the antiferromagnetic f-f exchange and increase the anisotropy field, which is consistent with the observation of the Stokes shift between emission and absorption spectra of the order of 1000 cm^{-1} [8].

We found that the AFMR precession is triggered at magnetic fields higher than that of the spin flop transition ~0.1 T, and lower than that of spin flip transition of ~7 T. We discovered that at magnetic fields, corresponding to the crossing of the two AFMR modes frequencies, the amplitudes and Q-factors of both modes are strongly enhanced. This frequency behavior is unique for easy plane antiferromagnets. To explain the enhancement behavior we used a model of two weakly coupled oscillators and demonstrate that the coupling is due to a small noncollinearity of the applied magnetic field to the sample plane. This coupling is enhanced by the presence of the photoexcited d-electrons.

Thus we show that the role of the d-electrons is versatile. In particular d- electrons trigger ultrafast spin dynamics, renormalize static parameters and give rise to an enhancement of the coupling of the AFMR modes, when their frequencies are close, as well as a pronounced magneto-refractive effect.

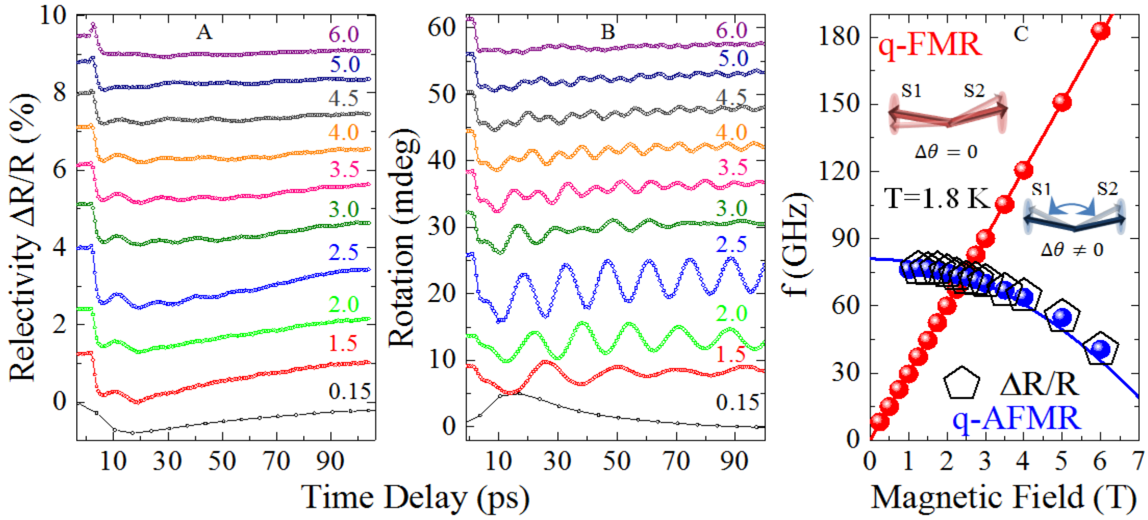

Figure 1 (A) Temporal profiles of the reflectivity changes in EuTe triggered by a 300~fs pump pulse with a fluence of 40 μJ/cm^2 at T=1.8 K for the range of magnetic fields 0.1-7~T. (B) Temporal profiles of probe polarisation rotation measured at the same conditions as the reflectivity data. (C) Frequencies of the two AFMR modes, namely the quasi-antiferromagnetic (q-AFMR) and the quasi-ferromagnetic (q-FMR) mode.

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