SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12 - Parallel Session 1

SP12.1.01

The early stages of ultrafast demagnetization

R. Gort, K. Bühlmann, S. Däster, A. Fognini, A. Vaterlaus, Y. Acremann

Text Prior to the development of pulsed lasers, one assigned a single local temperature to the lattice, the electron gas and the spins. With the availability of ultrafast laser sources, these reservoirs can be driven out of equilibrium. The internal degrees of freedom of the spin system are largely unexplored. To study the basic processes relevant for ultrafast spin dynamics we developed a spin and time resolved photoelectron spectrometer. Using this instrument we demonstrate an analogous behavior in the spin polarization of a ferromagnet in an ultrafast demagnetization experiment: at the Fermi energy, the polarization is reduced faster than at deeper in the valence band. Therefore, on the femtosecond time scale, the magnetization separates into different parts similar to how the single temperature paradigm changed with the development of ultrafast lasers. Our measurements show the full evolution of the spin polarization as a function of time. We can observe the initial generation of a non-thermal electron distribution followed by the thermalization and de-polarization at the Fermi energy. Only later, the band structure changes, leading to a reduction of the polarization in the valence band.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12.1.02

Simulation of Ultrafast Electron Spin Dynamics in Ferromagnetic Heterostructures

D. Nenno, B. Rethfeld, R. Binder, H. C. Schneider

Text Ultrashort optical pulses applied to ferromagnets excite far-from-equilibrium electron spin dynamics that can trigger demagnetization [1] and also lead to a loss of electronic spin polarization due to the transport of the hot optically excited electrons in and out of ferromagnetic layers [2]. In materials with spin Hall effect, induced spin-currents can be efficiently converted into charge currents that are the source for Terahertz emission [3]. We present an efficient numerical approach to optically excited hot-carrier transport that we combine with a description of the optical fields, for both laser absorption and broadband THz emission. Carrier dynamics are simulated using the Boltzmann transport equation with ab-initio material data. The hot-electron distribution function is sampled using numerical superparticles in the framework a particle-in-cell approach. We analyze optically excited electron spin transport in Fe-Au bilayers, Fe-Au-Fe spin-valve structures and THz emission from a Fe/Pt-layer. We find good agreement with recent experiments and can provide microscopic understanding of the induced dynamics. We propose a computationally optimized multilayer structure to further improve input/output conversion.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12.1.04

Comparison of induced and permanent magnetic moment in the ultrafast demagnetization and remagnetization dynamics of ferromagnetic alloys

S. Häuser, M. Hofherr, S. Moretti, N. Safonova, J. Shim, D. Steil, S. Sakshath, H. C. Kapteyn, M. M. Murnane, M. Cinchetti, S. Mathias, B. Stadtmüller, M. Albrecht, D. E. Kim, U. Nowak, M. Aeschlimann

Text The element specific magnetic response in ferromagnetic alloys after optical excitation with intense ultrashort laser pulses has been a long-standing debate in condensed matter physics. Here, we use femtosecond pulses in the extreme ultraviolet regime obtained by high-harmonic generation (HHG) as an element-sensitive probe to investigate the demagnetization as well as the subsequent remagnetization of a CoFeB thin film in a transverse magneto-optical Kerr effect experiment. We observe that the demagnetization behavior of the Co and Fe sublattice is similar. In contrast, the remagnetization dynamics of both sublattices show clear differences in their asymptotic value on long timescales. The latter even depends on the substrate suggesting that this observation is driven by heat transport. The latter is supported by calculations using dynamic spin model simulations. More importantly, by comparing these findings to the case of FePt we can distinguish the dynamics between permanent and induced magnetic moments. In the latter case the temperature dependence of the magnetization is governed by the interatomic exchange only. With this work we are able to provide a vital step towards the understanding of ultrafast light-induced magnetization dynamics in ferromagnetically coupled alloys with induced and permanent magnetic moments.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12.1.05

Single-pulse all-optical switching in synthetic ferrimagnetic racetracks

M. Lalieu, M. Peeters, R. Lavrijsen, B. Koopmans

Text All-optical switching (AOS) of magnetic materials has become a widely known phenomenon receiving extensive attention due to its high potential for fast and energy-efficient writing in future data storage devices. Since its discovery, two switching mechanisms have been demonstrated; a fast thermal single-pulse mechanism and a cumulative helicity-dependent multiple-pulse mechanism. To fully benefit from the speed and energy efficiency of AOS, single-pulse switching is necessary. Although this mechanism is well established in RE-TM alloys, future spintronic devices rely on interface-induced phenomena inherent to multilayered structures. In this work, we experimentally demonstrate single-pulse AOS in Pt/Co/Gd synthetic ferrimagnetic multilayers, and report on first steps towards spintronic integration by means of domain wall motion measurements that make use of the SHE and DMI inherent in the material system. Using optical and electrical detection methods, robust single-pulse toggle switching is demonstrated, and the dependence of the threshold fluence on the Co thickness is investigated. Using Hall bar structures, SHE domain wall motion measurements are performed, in which AOS is used to nucleate the domain walls. Lastly, a ‘proof-of-principle’ of the merge between AOS and the racetrack memory is demonstrated, showing magnetic data being written ‘on the fly’ into a Pt/Co/Gd micron-sized wire using AOS, transported using the SHE, and read-out at the end of the wire using the AHE.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12.1.06

Laser-induced spin transfer torques in magnetic domain walls

P. Baláž, K. Carva, P. Maldonado, P. M. Oppeneer

Text When an ultrashort laser pulse is applied to a magnetic metal the magnetization rapidly decreases on a femtosecond scale. One of the possible explanations of this effect rests in mutual relaxation processes of electron, spin and lattice subsystems. On the other hand, in transition metals and their alloys featuring spin polarized 3d valence band and conduction 4s band, a laser pulse can excite electrons from the d band into the s one. Due to a higher mobility of s electrons, the nonequilibrium hot charge carriers migrate away from the laser spot and reduce the local magnetic moment. This process is described by the superdiffusive spin transport model [1], which takes into account scattering of hot electrons on atomic sites leading to nonequilibrium avalanches of excited hot electrons.

Importantly, the ultrafast demagnetization due to spin superdiffusion is accompanied by diffusive spin currents carrying spin momentum. In noncollinear spin textures the spin current can exert spin transfer torque on magnetization located far from the laser spot [2]. Therefore, one can expect that in the presence of a domain wall, laser-induced superdiffusive spin currents can initiate its motion [3]. Here, we develop a model to describe this dynamics and calculate the spin transfer torque an domain wall dynamics in metals.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 1

SP12.1.07

Speed and efficiency of femtosecond spin current injection into a nonmagnetic material

D. Schummer, M. Hofherr, P. Maldonado, O. Schmitt, M. Beritta, U. Bierbrauer, S. Sakshath, A. J. Schellekens, B. Koopmans, D. Steil, M. Cinchetti, B. Stadtmüller, P. M. Oppeneer, S. Mathias, M. Aeschlimann

Text We investigate femtosecond spin injection from an optically excited Ni top layer into an Au bottom layer using time-resolved complex magneto-optical Kerr effect (C-MOKE) measurements [1].

Employing the C-MOKE formalism, we are able to follow layer-resolved demagnetization in Ni and the simultaneous spin injection into the adjacent Au film, both occurring within ~40 fs [2]. W
to diffusive propagation of the spin transfer process with ab initio theory and superdiffusive transport calculations. In particular, our combined experimental-theoretical effort does allow us to quantify the so far elusive amount of spin injection, and therefore the spin injection efficiency at the interface.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12 - Parallel Session 2

SP12.2.02

Ultrafast Dynamics of Spin and Orbital Moments upon Demagnetization in GdFeCo alloys

M. Hennecke, I. Radu, R. Abrudan, T. Kachel, K. Holldack, R. Mitzner, C. Schüßler-Langeheine, A. Tsukamoto, S. Eisebitt

Text The use of light pulses to manipulate and control the magnetic order parameter on the fundamentally limiting time and length scales is an important quest in modern magnetism. Recent studies of ferrimagnetic GdFeCo alloys have revealed an ultrafast laser-induced magnetization reversal mediated by a transient ferromagnetic-like state [1]; such switching was purely thermally-driven without the need of any other external stimulus [2]. However, the ultrafast angular momentum transfer from and into the spin system during demagnetization and switching events as well as the role and dynamic contributions of spin and orbital moments still remain unclear [3].

Here, we report on time-resolved soft X-ray Magnetic Circular Dichroism (XMCD) measurements performed at the FemtoSpeX slicing facility of BESSY II synchrotron that aim at revealing the angular momentum flow during femtosecond laser-induced demagnetization of ferrimagnetic GdFeCo alloy. A magneto-optical sum rules analysis of the fs-XMCD data allows us to monitor and disentangle the dynamics of elemental spin and orbital moments at Fe and Gd sites. Within the experimental accuracy, we observe a non-equal magnitude change of spin and orbital moments on Fe sites during the first hundreds of femtoseconds, suggesting a direct transfer of angular momentum to the lattice.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12.2.03

Terahertz induced demagnetization in CoPt film:towards ultrafast ballistic switching

D. Polley, M. Pancaldi, M. Hudl Waltin, P. Vavassori, S. Urazhdin, S. Bonetti

Text With the development of strong terahertz (THz) sources scientists are now trying to achieve magnetization reversal with strong THz magnetic fields which has the added benefit of having lower energy deposited and the spin degree of freedom of the material is not as strongly coupled to the electrons and lattice as for the case of infrared excitation. Here, we have studied the demagnetization dynamics of thin CoPt films with perpendicular magnetic anisotropy (PMA) using strong THz pump/NIR probe MOKE geometry with a varying THz electric field (highest electric field ~330 kV/cm and magnetic field ~110 mT). We observed around 1% demagnetization (scales quadratically with the THz magnetic field), which is more than one order of magnitude larger than for an in-plane magnetized sample irradiated with the same field strength. Using numerical simulations, we have designed spiral THz metamaterials for local THz magnetic field enhancement (> 25 times) over micron range. These structures allow accessing regimes where the contribution from the coherent torque terms is strongly enhanced and contribute significantly to the magnetization dynamics. We envision that the combination of optimized PMA magnetic layers and THz metamaterials may lead towards the first, real-time observation of the theoretically fastest mechanism of magnetization reversal, so-called “ballistic” magnetization switching in a table-top experiment.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12.2.04

Optical control of competing exchange interactions and coherent spin-charge coupling in two-orbital Mott insulators

M. M. S. Barbeau, M. Eckstein, M. I. Katsnelson, J. H. Mentink

Text The availability of femtosecond laser pulses opened up new ways to control magnetism in solids, leading to spectacular observations including ultrafast demagnetization and all optical switching of magnetic domains using femtosecond laser-pulses [1,2]. Nonetheless, rather little is known about the direct effect of laser pulses on the spin dynamics at ultra-short timescale. Interestingly, recent experimental and theoretical results demonstrate that even the exchange interactions, can be modified by laser pulses [3-5]. However, so far theoretical models that have mostly been restricted to the study of single orbital systems in order to explain the control of exchange. Here we report studies of a two-orbital Mott-Hubbard model under the action of a time-periodic electric field. Using projection operators and a generalized time-dependent canonical transformation, we derive an effective Hamiltonian which describes two different regimes. First, a regime for which the Heisenberg exchange as well as the additional biquadratic exchange interaction can be controlled by the electric field. Second, for special driving frequencies, we demonstrate a novel spin-charge coupling phenomenon enabling coherent transfer between spin and charge correlations.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12.2.05

Relativistic spin dynamics applied to ultrafast magnetic phenomena

R. Mondal, U. Ritzmann, P. M. Oppeneer, U. Nowak

Text Ultrafast spin dynamics simulations often use the traditional Landau-Lifshitz-Gilbert (LLG) equation of motion. The LLG equation consists of precession of spins around an effective field and a transverse Gilbert damping [1]. The damping parameter is traditionally a scalar quantity. However, recent first principles derivation from Dirac theory showed that the Gilbert damping parameter is not a scalar quantity, rather it is a tensor [1,2]. It is not only the scalar nature of the damping, but also the proper form of the LLG equation of motion that has to be questioned at the ultrafast timescales. If the magnetic system is driven by nonharmonic fields, an additional field-derivative torque (FDT) also contributes to the LLG equations, which has to be included [2]. This FDT exerts a torque due to the time-derivative of the applied field. If the applied laser pulse is ultrashort, the time-derivative will be large and therefore, FDT will exert a huge torque on short timescales [2]. In this work, we are investigating the contributions of these FDT torques using atomistic spin dynamics simulations for ferromagnets. We compare the influence of FDT by a suitably shaped laser pulse, e.g., Gaussian shaped pulse vs. square shaped pulse. At the same time, we also compute the effects of chiral damping and anisotropic Gilbert damping.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12.2.06

Ultrafast relaxation dynamics in a Kitaev spin-liquid candidate α-$RuCl_3$

S. Y. Agustsson, V. Grigorev, T. Dong, N. Wang, L. Wang, Y. G. Shi, J. Demsar

Text α-$RuCl_3$, which forms an almost ideal 2D honeycomb lattice with weak interlayer coupling, has been proposed to be a prime candidate for the realization of Kitaev physics. While it develops a long-range zigzag antiferromagnetic order at temperatures below T_N = 7 K, numerous experiments suggest spin liquid-like behaviour at temperatures above the Néel transition. Recent optical and electron-energy-loss spectroscopy studies demonstrated the sensitivity of the inter-site Ru d-d optical transition (~ 1.3 eV) to nearest-neighbour spin-spin correlations. To investigate their dynamics in the Kitaev paramagnetic state ($T_N<T$ ≲100 K) we performed systematic temperature and excitation density dependent study of near-infrared reflectivity dynamics, following photoexcitation of the inter-site d-d transition. The dynamics is found to span timescales from 0.1 to 100 ps, and is strongly temperature and photoexcitation density dependent. In particular, in the low excitation density limit, the spin relaxation rate displays a power-law temperature dependence, indicative of spin liquid state.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 2

SP12.2.07

All optical switching and ultrafast magnetization dynamics in doped FePt thin films

M. Stiehl, N. Safonova, B. Stadtmüller, M. Albrecht, M. Aeschlimann

Text The speed of magnetic data storage and information processing is particularly important for device performance but presently limited to a few nanoseconds. In this regard all-optical switching (AOS) is a highly promising effect which allows to switch the magnetization within a few tens of ps.[1]

Here, we focus on the AOS phenomena in technologically important materials [2] and the corresponding fs magnetization dynamics in FePt thin films doped with Tb [3] using all optical detection schemes based on the time-resolved magneto-optical Kerr effect. For a Tb concentration of 11% and linear polarization of the optical excitation, we observe a single-shot magnetization reversal within the first ps which lasts over 20ps without indications of remagnetization. We will compare results for different Tb concentrations to gain insight into the role of the dopant for the observed magnetization reversal.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 3

SP12 - Parallel Session 3

SP12.3.02

The ultrafast AFM to FM phase transition of FeRh probed by magnetic X-ray resonant scattering

R. Carley, A. Yaroslavtsev, R. Kurta, L. Le Guyader, M. Izquierdo, S. Carron, T. Chase, G. Dakovski, P. Granitzka, S. Günther, D. Higley, E. Jal, M. Minitti, A. Mitra, A. Reid, W. Schlotter, B. Clemens, V. Uhlíř, C. Back, H. Dürr, E. Fullerton, J. Stöhr, A. Scherz

Text We report on the femtosecond laser-driven antiferromagnetic (AFM) to ferromagnetic (FM) phase transition in FeRh studied with the time, element, and spatially resolved technique of magnetic X-ray resonant diffraction at the Fe L3 edge. Equiatomic FeRh undergoes a first order transition from the antiferromagnetic (AFM) to ferromagnetic (FM) phase, where the magnetization is the order parameter. The phase transition has been extensively studied theoretically and experimentally, in thermal equilibrium and in the time domain, but a precise understanding of the roles of the electronic, phononic and spin sub-systems remains elusive. Time resolved magneto-optical Kerr effect measurements suggest FM generation on sub-picosecond (ps) time scales, indicating an electronically driven phase transition. In contrast, time-resolved hard X-ray diffraction reveals nucleation and growth of FM regions on 10ps timescales, suggesting a phononic driver. Our experiments were performed at the Linac Coherent Light Source and provide microscopic insight into the very beginning of the non-equilibrium phase transition. We observe a sub-picosecond transient hinting at an ultrafast electronic seeding of the FM nucleation that spreads through the sample over the next 10ps. At later times slower domain coarsening dynamics can be seen as the system reaches thermal equilibrium.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 3

SP12.3.04

Spin currents generated during ultrafast demagnetization

K. Carva, P. Baláž, P. Maldonado, P. M. Oppeneer

Text Application of femtosecond lasers has opened new possibilities in the field of magnetization dynamics, one of these is the generation of spin currents accompanying ultrafast magnetization quenching. These spin currents arise and decay on timescales unprecedent in spintronics. Such spin currents can exert spin transfer torque on an adjacent magnetic layer as as seen experimentally [1].
Spin currents originate from migration of nonequilibrium hot charge carriers excited to bands with higher mobilities by a laser. This effect also reduces the local magnetic moment, as described by the superdiffusive spin transport model. This model has been extended to study spin transfer torques induced by a fs laser pulse in spin valves consisting of two perpendicularly oriented magnetic layers, FM1 and FM2, separated by a nonmagnetic one, NM. Calculated spin transfer torques are used to model magnetization dynamics described by the Landau-Lifshitz-Gilbert equation. We have shown that a femtosecond laser pulse focused on FM1 can lead to magnetization precessions in FM2, which can persist for few nanoseconds. We have also found an optimal thickness of the polarizing (FM1) layer that optimizes torque in the spin valve [2]. We discuss the role of non-thermal phonon populations generated by lasers [3].

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 3

SP12.3.05

Magnetic and Structural Dynamics in Antiferromagnetically Coupled Fe/Cr Superlattices

D. Schick, D. Bürgler, N. Pontius, S. Eisebitt, C. Schüssler-Langeheine

Text Employing the femtosecond soft X-ray pulses with variable polarization and photon energy delivered by the FemtoSpeX facility at the electron storage ring BESSY II we are able to probe the AFM (resonant magnetic diffraction), FM (XMCD), and structural (non-resonant diffraction) dynamics of Fe/Cr superlattices in one and the same pump-probe experiment. Hence, we can directly compare AFM vs. FM spin dynamics in the same material system by only applying a moderate magnetic field (< 100 mT). Moreover, we can probe the sub-ps structural dynamics due to coherent phonon excitation and its interaction with the spin system. The element selectivity of the resonant X-ray techniques further allows for differentiating the spin dynamics of Fe and the non-magnetic Cr layers after photoexcitation and thus for probing possible transient magnetization in Cr due to ultrafast spin injection from the Fe layers.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 3

SP12.3.06

Spin – charge interconversion at nonmagnetic metal/oxide interface mediated by light and spin orbit interaction

J. Puebla, F. Auvray, M. Xu, Y. Otani

Text In this contribution, we present spin – charge interconversion experiments, mediated by light and spin orbit interaction at the interface formed between nonmagnetic metal (Cu, Ag) and oxide (Bi2O3). Spatial symmetry breaking at these interfaces induces Rashba like spin orbit coupling (SOC). First, we report the direct observation of uniform in-plane spin accumulation at room temperature by magneto optical Kerr effect. The formation of spin accumulation is the result of current induced spin polarization at our interfaces (direct Edelstein effect, DEE), without external magnetic field or proximity to ferromagnetic materials. We observe opposite orientation of spin accumulation at Cu/Bi2O3 and Ag/Bi2O3 interfaces reflecting their opposite sign of Rashba SOC (Rashba parameter). Second, we demonstrate the functionality as novel spin-photovoltaic converter at visible excitation laser energies, with conversion links to spatial asymmetry and plasmon Schockley surface states in Cu(111)/Bi2O3. Here, the helicity dependent photovoltaic generation is the result of spin polarized carriers excited by light across the optical transition of Bi2O3 and its spin to charge conversion via inverse Edelstein effect (IEE). Furthermore, we also obtained photovoltaic generation below the band gap energy of Bi2O3 which is assigned to plasmon induced charge separation via absorption of Schockley surface states in Cu(111) protected by our oxide layer.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 3

SP12.3.07

Exchange and Elliott-Yafet scattering in a ferromagnetic multi-sublattice model

K. Leckron, H. C. Schneider

Text We study the microscopic electronic dynamics underlying magnetization dynamics on ultrashort timescales in an exchange-coupled magnetic model system which contains itinerant ferromagnetic bands with effective spin-orbit coupling and localized electron bands [1]. We calculate the time-dependent momentum-resolved spin-density matrix due to electron-phonon and exchange scattering, which are described at the level of Boltzmann scattering integrals. The electron-phonon scattering effectively changes the total spin and energy of the system via an Elliott-Yafet-type mechanism [2] while the exchange scattering redistributes spin and energy between the itinerant and localized electrons.

We study the characteristics of the dynamics for different strengths of the magnetic coupling parameters (intra-itinerant bands and exchange between itinerant and localized bands) and the Elliott-Yafet spin relaxation. We compare the dynamics for ferrimagnetic and ferromagnetic coupling between the localized subsystems. We study in particular the case of ferromagnetic exchange coupling and show how the system can get stuck in a non-equilibrium state with extremely slow remagnetization dynamics.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12 - Parallel Session 4

SP12.4.01

Spectral and polarization selective ultrafast photo-magnetic switching in iron garnet

K. Szerenos, A. Stupakiewicz, A. V. Kimel, A. Kirilyuk

Text All-optical magnetization switching (AOS) has attracted a lot of attention, first exclusively in metals and later in transparent dielectrics. The latter observation is based on an entirely nonthermal mechanism of light-induced modification of magnetic anisotropy, and thus with exceptionally low energy dissipation.

Here, we investigated the AOS in Co-doped garnet films using time-resolved Faraday effect and imaging of magnetic domain structures. We report the spectral properties of all-optical switching by selective pumping of octahedral or tetrahedral Co-sublattices in a garnet. The switching properties at the observed resonances are vastly different, related to the crystal site hosting the excited Co ions. As these ions are the source of strong magnetic anisotropy in a garnet, their excitation between the crystal filed split states results in a coherent and ultrafast manipulation of magnetic anisotropy.

The nonthermal mechanism makes it possible to repeat the switching in a fast succession, as there is no accumulated heat. We carried out double pump experiments in various configurations, manipulating and even reversing the dynamic magnetization trajectory in-flight during switching. We probe the bit write, erase and rewrite dynamics and find the ultrashort timescales of these processes along with the key parameters affecting them, relevant for the memory applications. We demonstrate repeatable erase and rewrite of magnetic domains with 60 ps delay between single laser pulses.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12.4.02

Reversing the exchange bias using all-optical helicity-dependent magnetic switching

P. Vallobra, T. Fache, Y. Xu, L. Zhang, G. Malinowski, M. Hehn, J.-C. Rojas-Sanchez, E. Fullerton, S. Mangin

Text All-optical helicity dependent switching (AO-HDS) has been demonstrated for both ferromagnetic (FM) and in ferrimagnetic materials using femto-second pulses. Our goal was to study the impact of polarized light on an antiferromagnetic (AFM) material namely IrMn. In order to be able to probe the magnetic configuration of the AFM we grew exchange bias structure as IrMn(7nm)/[Co(0.6nm)/Pt(2nm)]xN for N=1 and N=2. Using magneto-optical Faraday effect we image the final state after sweeping a pulsed laser beam over the sample with either linear or circularly polarized light. First we observed that the exchange coupling does not affect the AO-HDS of the ferromagnetic layer. The effect of light on the exchange bias properties were studied by measuring the local hysteresis loops within the illuminated areas [1]. Those results demonstrate that the sign of the exchange bias is determined by the helicity of light used during light sweeping. Static beam experiments were also performed by varying the number of pulses from 1 to 50000. We used the σ- helicity on the as grown sample and measured local hysteresis loops at different positions inside and outside the disk left by the laser spot. We report the spatial evolutions of the corresponding exchange bias fields and the coercive fields.
Our work tends to show the exchange bias is set by the FM configuration at the interface with AFM when the pulse hits the sample.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12.4.03

Unraveling the phonon magnon coupling, theory and first principles simulations Ab initio microscopic theory of phonon-magnon interactions

P. Maldonado, Y. Kvashnin

Text Ultrafast laser induced excitation of magnetic materials has recently made it possible to experimentally monitor the energy and angular momentum transfer between lattice vibrations and spin waves[1,2]. These experimental observations shine light on the coupling between phonon and magnons, which is a cornerstone in understanding optical magnetization dynamics[3]. However, the microscopic description of this coupling and its relevance on those effects remain elusive and is one of the most challenging scientific problems in condensed matter physics.

Here, we present a novel and general theory that governs the laser-induced out-of-equilibrium system dynamics, and provides the energy transfer between magnons and phonons. The theory allows the determination of the laser-induced relaxation time of the involved quasi-particles and provides the frequency and momentum-dependent energy flow between phonons and magnons. We show that the dynamics is driven by the known Kasuya-LeCraw process (Cherenkov process) and by a novel microscopic process (confluent process). The ab initio determination of the magnon-phonon and phonon-phonon coupling parameters provide our fitting-free theory with predictive power. We use NiO as a benchmark material to test our out-of equilibrium model obtaining the phonon-magnon lifetimes and the system relaxation time.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12.4.04

Influence of interface alloying on ultrafast spin dynamics in Co/Pt heterostructures

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Text Interface magnetism has recently been identified to play an important role in spin dynamics, governing microscopic processes such as altered spin-orbit coupling at the boundary of two different elements and spin-injection across interfaces. A fundamental understanding of these processes will bring us one step closer to precise spin control via light; also crucial for future applications in spintronics and data storage technologies.
In this contribution we tackle the complexity of the problem by a joint experimental and theoretical approach and investigate the influence of ultrafast spin dynamics on different characteristics of the interface. As a model system we systematically compare the element resolved spin dynamics of thin films of pure Co, CoPt alloys with varying stoichiometry and Co/Pt heterostructures. Experimentally, we use laser based high harmonic radiation for element specific access to the optically triggered spin dynamics via magnetic circular dichroism. The generated harmonics in the extreme ultraviolet spectral range allow to accurately map the response of Co (M2,3 edge at 60 eV) and Pt (N7 edge at 71.2 eV). Additionally, we perform simulations in a fully ab initio manner by employing time dependent density functional theory to yield the magnetization dynamics under the influence of a femtosecond laser pulse. Our findings yield qualitatively different spin dynamics depending on the interface and could help to reconcile conflicting results in literature.

SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12.4.05

Ultrafast magnetization dynamics and switching in ferrimagnets with and without compensation temperature

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Text Ultrafast spin dynamics and switching in magnetic materials have attracted a lot of interest in the last years due to the potential of their utilization for ultrafast energy-efficient magnetic memory. For example, all-optical non-thermal switching by femtosecond linearly polarized laser pulse was recently observed in a transparent dielectric YIG: Co film [1]. On the other hand, materials with a compensation point are also prospective, in particular because the exchange mode activation may lead to a significant enhancement in the speed of switching.
We study two possible mechanisms of interaction of femtosecond laser pulse with magnetic material with cubic anisotropy: non-thermal (laser electric field-dependent optical spin-torque) and thermal (demagnetization). The theoretical model is based on nonlinear Landau-Lifshitz-Gilbert equations. In the transparent dielectric case the non-thermal mechanism takes place, and we investigate different types of switching and dynamics features under the action of linearly polarized laser pulse and obtain phase diagrams in the space of material parameters and laser pulse intensity and polarization. In the case of metallic ferrimagnet demagnetization occurs, which causes the system to be strongly driven out of equilibrium. We study the influence of the temperature and the external magnetic field on the magnetization dynamics and switching.
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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

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Electron dynamics driving ultrafast demagnetization in itinerant ferromagnets and alloys

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Text Irradiating ferromagnetic films with an ultrashort laser pulse leads to a quenching of the magnetization on a subpicosecond timescale [1]. With help of a spin-resolved Boltzmann description, which allows to describe the out-of-equilibrium electrons and their microscopic collision processes including spin-flips, we have identified the equilibration of chemical potentials of majority and minority electrons as a driving force for ultrafast magnetization dynamics [2].

Recent experiments have revealed element-specific dynamics in exchange coupled ferromagnetic alloys [3], here Permalloy. One component demagnetizes earlier, which tows the demagnetization of the other alloy component. The speed of and the time delay between the demagnetizations can be tuned by doping the alloy or changing its composition.

We set up a model to trace the spin-resolved electron dynamics in dependence on the material in the alloy. Therefore, we calculate the dynamics of spin-up and -down, as well as phonon temperature for each material component separately. Then, we couple the different components in respect to the exchange interaction. Our results show the influence of the involved coupling mechanisms on the different relaxation processes and pave the way towards a microscopic understanding of the magnetization dynamics in different alloys.

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SP 12 Ultrafast laser-induced magnetization dynamics, magneto-optics and magnetoplasmonics

SP12 - Parallel Session 4

SP12.4.07

On-chip generation of unipolar THz current pulses by the inverse spin Hall effect

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Text We use optical pump pulses to generate current pulses using the spin-dependent Seebeck effect and the inverse spin Hall effect (ISHE) in heavy metal/ferromagnet bilayers. In our on-chip approach the bilayer structures are used to terminate coplanar waveguides. The optical excitation from an ultrafast amplified laser system injects ultrashort spin current pulses from the ferromagnet into the heavy metal layer via the spin-dependent Seebeck effect [1]. Subsequently, this spin current pulse is converted into a charge current pulse inside the heavy metal layer via the ISHE. The electric signal that is generated by the ISHE is recorded by a fast sampling oscilloscope with a bandwidth of approximately 50 GHz. Based on other experiments we expect an actual pulse length of only a few hundred femtoseconds [1,2]. By normalizing the ISHE signals to the pump pulse energy we determine optical pulse to THz pulse conversion efficiency and compare it to other methods such as the tilted pulse front approach [3].

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Ultrafast spin dynamics in transition metal dichalcogenides probed by terahertz spectroscopy

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Text Despite their first preparation at the beginning of the 20th century, the transition metal dichalcogenides (TMDCs) have attracted considerable attention in the recent years following the emergence of graphene. Thanks to their layered hexagonal crystal structure, they possess similar electronic properties to multilayer graphene, however, they also feature strong spin-orbit coupling delivered by transition metal atoms. [1] The unique electronic and spin properties made thin-layered TMDCs excellent candidates for two-dimensional optospintronic applications. [2]

The latest achievements in terahertz (THz) spectroscopy has showed that the investigation of the spintronic processes can be extended further beyond the GHz range, giving a new drive to ultrafast spintronic applications. [3] In this contribution, we make use of both fields and study the carrier spin dynamics in metallic and semiconducting TMDCs, such as NbSe2 or WSe2, in the ultrafast time scale (< 1 ps) by analyzing THz radiation emitted after ultrafast optical excitation or by means of the THz Kerr effect. The THz techniques allowed us to address crucial spintronic processes as spin transport through an interface or spin-to-charge current conversion via the inverse spin Hall effect in TMDCs in the contactless and ultrafast manner.

References

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