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The Spin on Electronics! - Science and Technology of spin currents in nano-materials and nano-devices

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Abstract:
Recent advances in manipulating spin-polarized electron currents in atomically engineered magnetic heterostructures make possible entirely new classes of sensor, memory and logic devices - a research field generally referred to as spintronics[1]. A magnetic recording read head, initially formed from a spin-valve, and more recently by a magnetic tunnel junction, has enabled a 1,000-fold increase in the storage capacity of hard disk drives since 1997. The very low cost of disk drives and the high performance and reliability of solid state memories, may be combined in the Racetrack Memory[2]. The Racetrack Memory is a novel three dimensional technology which stores information as a series of magnetic domain walls in nanowires, manipulated by spin polarized currents. Spintronic devices may even allow for "plastic" devices that mimic synaptic switches in the brain, thereby allowing for the possibility of very low power computing architectures.

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Abstract:

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Notes:

RE-TM amorphous films for MO recording media and their future aspects

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Abstract:
Magnetic materials deeply examined for MO-recording were RE-TM ferrimagnetic amorphous thin films and among them TbFe and TbFeCo were practically used as because their characteristics as follows:(1) high Ku perpendicular to the film surface, (2) easy to fabricate by sputtering or evaporation, (3) easy to adjust Curie temperature T_C and the compensation temperature T_{comp}, and (4) high mgneto-optical effect. Among them the most distinguished nature of large MO effect leads to an anticipation of realization of ultra high speed recording as high as 100,000 times of conventional magnetic recording by utilizing direct optical magnetization reversal with the circular polarized light [1].
For proper design of MO recording materials, the control of T_C and T_{comp} are important and for this purpose, the mean field theory usually used [2]. For the amorphous magnetic material, the estimation of coordination numbers of each atom is one of the important parameters. Mansuripur [3] introduced a method to estimate the coordination numbers. For MO recording application, magnetic anisotropy of the films should be normal to the film surface. Among the several sources of magnetic anisotropy such as stress induced, columnar growth, chemical short range order, and anisotropic void networks, it has been believed that growth induced anisotropy is the most significant one [4]. Magneto-optical effects vary with the rare earth element. Gambino and McGuire [5] reported that the light rare-earth elements provide a greater contribution to the MO effects than heavy RE elements such as Gd and Tb.
We developed a method of multi wavelengths read-out for MO recording which can read at high signal to noise ratio for multilayered RE-TM MO media [6]. We are now developing a nano-scale plasmon antenna which can yield circular polarized near field nano-sized light spot for the pupose of high density and high speed recording.
A new scheme which combine the nano-sized circular polarized light spot and the multilayered structure would be an interesting candidate for future high speed and high density storage.

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Notes:

Laser-induced magnetization dynamics in a $Gd_{1-x}Co_x$ ferrimagnetic thin film

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Abstract:
We report here a study of laser-induced magnetization dynamics in a sputtered ferrimagnetic $Gd_{1-x}Co_x$ thin film with a composition gradient along one direction of the film. Using an all-optical pump-probe experimental technique with 100 fs laser pulses, we have studied the composition dependence of the magnetic response at a fixed temperature. We have observed three different modes at frequencies around 10, 20, and 100 GHz, respectively. The 10 GHz mode corresponds to ferromagnetic precession, the frequency of which diverges in that region of the sample where angular momentum compensation composition (AMCC) is reached [1, 2]. The 100 GHz mode is tentatively related to the ferrimagnetic exchange coupling between the Gd and Co sub-lattices [1]. It softens in the region of AMCC. Finally, the 20 GHz mode, visible only in the vicinity of AMCC, still needs to be fully understood. All these three modes are pump-fluence-dependent: particularly, the 10 GHz mode is shown to drastically shrink in amplitude at the threshold fluence where the two other modes appear.
Furthermore, the temperature dependence of laser-induced magnetization dynamics has been studied in this system at a fixed composition. The 20 GHz mode is shown to be most pronounced at the angular momentum compensation temperature, T_A. In the vicinity of T_A, a spin-flop transition occurs under a weak magnetic field [3, 4].

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Notes:

An Element-specific View on Ultrafast Magnetization Reversal of ferrimagnetic GdFeCo

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Abstract:
Recent experiments have shown that femtosecond (fs) laser excitation is able to manipulate and even control spins in magnetic systems at unprecedented speeds [1,2]. In particular, a radical new approach in switching the magnetization using circularly polarized fs laser pulses has been recently demonstrated [2]. All these experiments have raised intriguing questions about the ultrafast channels of angular momentum transfer from and to the spin system and the microscopic processes governing the all-optical magnetization switching.
Here, we report on element- and time-resolved X-ray magnetic circular dichroism (TRXMCD) investigations of the fs laser-induced magnetization reversal of the ferrimagnetic GdFeCo alloy. We trigger the magnetization switching by driving the sample over its magnetization compensation temperature upon *excitation with linearly polarized* fs laser pulses. The subsequent dynamics of the Fe and Gd magnetic moments of the composite alloy is probed with 100 fs X-ray pulses. The TRXMCD data reveal a clearly distinct switching dynamics at the Fe and Gd sites: while Fe magnetic moment switches within ~400 fs it takes around 2 ps for the Gd moment to reach the magnetization reversed state. This observation is highly intriguing since the expectation is to have identical dynamics for both sub-lattices accounting for the strong exchange interaction which governs their magnetic ordering. These results suggest a novel non-equilibrium state to be responsible for the genuine magnetization switching process where the elemental magnetic moments show a highly divergent transient behavior. The nature of the novel non-equilibrium state, its possible origins and the implications with respect to the all-optical magnetization switching mechanism will be discussed.

Funding from European Union through UltraMagnetron program and NWO is gratefully acknowledged.

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Notes:

First glimpses with XUV/X-FELs on femtosecond magnetization dynamics

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Abstract:

References:

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First-principles analysis of Elliott-Yafet processes during laser-induced ultrafast demagnetization

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Abstract:
The laser-induced ultrafast demagnetization phenomenon has attracted a lot of attention since the first successful experiment on the fs timescale in 1996 [1]. However even now it is still far from being understood on the microscopic level. A number of possible microscopic mechanisms has been proposed: the Elliott-Yafet scattering on phonons [2], electron-electron interaction [3], direct fast spin transfer across an interface [4], and others.
Here we concentrate on the electron-phonon scattering [2] in Ni. The spin-flip probability associated with electron-phonon scattering in Ni has been estimated - employing the ab initio band structure - to be larger than expected [5]. We calculate the spin-flip Eliashberg function [6] based on ab initio electron-phonon coupling matrix elements, which allows us to obtain the spin-flip probability with much higher accuracy. We extend this method also to the regime of non-equilibrium electron distributions relevant for ultrafast processes. Employing this approach we examine the evolution of the total spin momentum taking into account the real bandstructure of the material, foremost the number of available states at excited energies appears to be important here. We find significant differences between the efficiency of this spin relaxation mechanism for highly non-equilibrium electron distributions pumped by the laser and thermalized ones (still at a very high temperature).

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Numerical investigation of thermally driven domain wall dynamics

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Abstract:
The understanding of the influence of the thermal properties of magnetic materials on its magnetic behavior opens new perspectives for the control of magnetic domains as well as domain walls. Heat pulses can be used for ultrafast switching dynamics, as has been studied extensively as a possibility to improve the writing speed of magnetic data storage [1,2], and even spatial temperature gradients can lead to magnetisation dynamics, as has been demonstrated recently in form of the so-called spin-Seebeck effect [3].
In this talk two different approaches for the computer simulation of coupled thermo-magnetic properties are introduced, namely the stochastic Landau-Lifshitz-Gilbert equation, applied to atomistic spin models, and the Landau-Lifshitz-Bloch equation of motion, which describes the dynamics of the thermally averaged spin polarisation on micromagnetic length scales [4]. Both approaches are applied to the investigation of the domain wall dynamics driven by spin currents that follow from a temperature gradient.
The occurrence of spin currents due to a temperature gradient in a ferromagnet is called spin-Seebeck effect. The existence of this effect was recently experimentally demonstrated [3]. However, two kinds of spin currents can exist in a ferromagnet, namely a spin polarized charge current due to electron motion or a pure angular momentum current driven by spin waves (magnons). The latter case leads to pure thermo-magnetic effects without any electron currents involved. We show that both theoretical approaches mentioned above describe this new type of domain wall motion, where pure spin currents following from a temperature gradient drag a domain wall into the hotter region.

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Femtosecond Magnetization Dynamics – From Demagnetization to Spin Transfer

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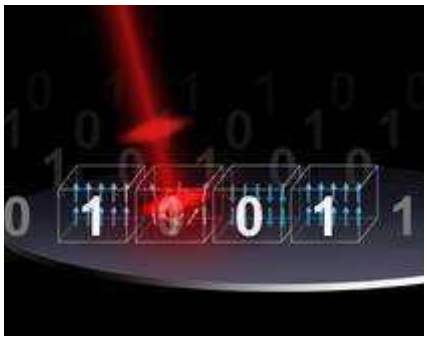
Abstract:



All-optical techniques exploiting femtosecond laser pulses have opened the way towards the exploration of the ultimate limits of magnetization dynamics, providing means to manipulate magnetic systems at down to femtosecond time scales. Apart from addressing fundamental issues in the field of (nano)magnetism the approach is also considered to be of extreme relevance for future progress in (high data rate) magnetic recording and spintronic applications.

In 1996, Beaurepaire and coworkers found that magnetic order in ferromagnetic transition metals can be quenched within a few hundred femtoseconds after laser heating. In contrast, earlier work by Vaterlaus *et al*. on gadolinium reported a much slower response of 100 ± 80 ps, i.e. a factor of thousand slower! The apparent incompatibility of the two results, combined with the large uncertainty in the earlier measurements on gadolinium, has fuelled intense scientific discussion about its origin, and even whether results for gadolinium could be trusted at all. In the presentation, it will be shown that a model based on electron–phonon-mediated spin-flip scattering explains both timescales on equal footing. This interpretation is supported by ab-initio estimates of the spin-flip scattering probability, and experimental fluence dependencies will be shown to agree perfectly with predictions. Moreover, a two-step demagnetization profile, as reported more recently for gadolinium and other materials, is readily reproduced. Thus, after almost 20 years of research, it has become clear why both Vaterlaus and Beaurepaire were right, even though the timescales they found differed by three orders of magnitude.

In the final part the presentation, new activities trying to bridge the worlds of laser-induced magnetisation dynamics and electrically driven spin-transfer phenomena will be addressed. As an example, recent data on femtosecond exchange of spin-polarized carriers between coupled ferromagnetic thin films will be presented. It will be shown that the speed of the ultrafast demagnetization can be tuned merely by controlling the relative orientation of their magnetization from parallel to anti-parallel! Future opportunities of this novel approach will be discussed.

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Mechanisms of ultrafast laser-induced demagnetization in metals – A theoretical investigation

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Abstract:
Laser-induced magnetization dynamics represents a new, viable route to achieve magnetic recording with hitherto unprecedented speeds and is as such highly important for magnetic recording industry [1]. Already more than a decade ago it was shown that excitation with femtosecond laser pulses causes an ultrafast demagnetization within 300 fs in metallic ferromagnets [2]. However, in spite of the technological importance the mechanism underlying the femtosecond magnetization change remains highly controversial. Several theories have been proposed– all based on the assumption that there must exist an ultrafast channel for the dissipation of spin angular momentum. The main proposed mechanisms through which a laser-excited electron may undergo a femtosecond spin-flip are Elliott-Yafet phonon scattering [3], spin-flip Coulomb scattering [4] and laser-induced spin-flips [5].
We have developed a new theory for fs laser-induced magnetization dynamics [6], in which we show that spin-polarized excited electron dynamics in the super-diffusive regime can effectively cause a fast demagnetization. Solving the derived transport equation numerically we find that super-diffusive flow of hot electrons can account for the experimentally observed demagnetization within 200 fs in Ni, without the need to invoke any spin angular momentum dissipation channel.
To establish which of the proposed mechanisms is the dominant one for laser-induced demagnetization, further first-principles based calculations are required. To this end we have investigated the influence of relativistic electron-phonon spin-flip scattering in Ni to estimate its possible contribution. Putting the obtained results in perspective, allows drawing conclusions regarding the relative effectiveness of the various proposed demagnetization mechanisms.

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Spin and Orbital Angular Momentum Dynamics in Ultrafast Magnetization Studied with fs X-Ray Spectroscopy

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Abstract:
X-ray spectroscopy allows us to separately determine the spin ***S*** and the orbital angular momentum ***L*** through x-ray magnetic circular dichroism (XMCD) sum rules. When x-ray probing is combined with fs laser pumping, a powerful new technique to investigate magnetization dynamics emerges. Until recently its time resolution was limited by the x-ray pulse duration at Synchrotron radiation sources, typically 50-100 ps. However, we overcome this limitation using the femtoslicing facility at the BESSY-II storage ring, where circularly polarized soft x-ray pulses of 100 fs duration are generated [1].
During the ultrafast demagnetization of a thin Ni film, we found that contrary to previous ideas, the orbital system does not act as a reservoir to accommodate the angular momentum originally stored in the ferromagnetically ordered spin system [2]. Both ***S*** and ***L*** decrease with a time constant of 130 fs, demonstrating the need for a very fast transfer of angular momentum to the lattice. X-ray absorption measurements additionally reveal a transient increase of the spin-orbit interaction during the demagnetization process [3]. This temporal correspondence demonstrates the importance of the spin-orbit interaction during ultrafast demagnetization.
When measuring the evolution of perpendicularly magnetized thin films of CoPd, a difference in the dynamics of ***S*** and ***L*** is found. The spin, carrying the biggest contribution to the magnetic moment of the film, decays with a time constant of 280 fs. A faster decrease with 220 fs is found for the orbital angular momentum, as well as for the response of the electronic system, measured as a shift of the L_3 absorption edge [4]. In short, one can argue that “first a change of the orbital motion of the electrons is necessary, before the spin ordering can be destroyed”.

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Notes:

Enhancing Magnetic Hardness in Self-Assembled Island Superlattices

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Abstract:
We show that the blocking temperature of Co double layer islands arranged in a self-assembled superlattice on Au(11,12,12) with a density of 15 Tera/in^2 can significantly be enhanced by interfacing them with small amounts of Fe.
The magnetic ground state of each island is a single domain ferromagnet. Magnetic torque measurements on pure Co double layer islands containing 600 atoms reveal that also the transition state during thermal magnetization reversal is monodomain, namely, the reversal takes place by coherent rotation of all magnetic moments [1]. As a consequence, the blocking temperatures are proportional to the magnetic anisotropy energies. Former measurements of such islands on Au(788), where the density is 24 Tera/in^2, have revealed uniaxial out of plane magnetization and the absence of dipolar interactions [2].
A good benchmark for hard magnetic nanostructures is the ratio of the number of constituent atoms to the blocking temperatures that has to be minimized. For this number we achieve 7.1 for pure Co islands and it goes down to 4.7 for Co core – Fe shell islands [3, 4]. Since Fe grows in single layer not much Fe can be added before coalescence sets in. However, decoration of the islands with Pd from the top gives rise to a further enhancement of the magnetic hardness [4].

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Notes:

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Investigation of artificial kagome spin ice with photoemisssion electron microscopy

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Abstract:
The possibility to directly observe the fascinating behaviour of frustrated systems is given by arrays of dipolar coupled ferromagnetic islands arranged in specific geometries where the local dipolar interactions can not all be satisfied simultaneously [1, 2]. We begin by focusing on finite systems, in particular studying the three basic building blocks of an artificial kagome spin ice, consisting of 1, 2 and 3 rings of elongated single domain islands. Here frustration is present at each vertex where three islands interact. The most favorable configuration occurs when two of the three dipolar interactions are favorable, obeying the so-called spin ice rule which dictates that either two moments point towards and one away from the vertex or vice-versa (2-in/1-out or 1-in/2-out). Employing dipolar energy calculations, we are able to make a full characterization of the magnetic states of these finite kagome structures and are therefore able to identify the lowest energy states.
An overview of the different possibilities for fabrication of magnetic nanostructures will be presented. For this particular project, arrays of the kagome ice building blocks consisting of cobalt or permalloy islands were created on silicon substrates by electron beam lithography and investigated with photo emission electron microscopy. Following demagnetization, we found that the ice rule is always obeyed. As the number of rings is increased, the number of frustrated vertices increases, and there is a clear decrease in the ability to achieve the low-energy states, a behavior also identified in the magnetization reversal [3]. This implies that the ground state will never be achieved in the infinite system via such demagnetization method.
We then focus on infinite kagome spin ice arrays, which allow real space observations of the behaviour of emergent magnetic monopoles on application of a magnetic field. Our observations, including hysteresis, monopole densities and 1D Dirac string avalanches, are fully duplicated by Monte-Carlo simulations [4].

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Notes:

Size-dependent Spin Structures in Fe nanoparticles on ferromagnetic Co supports

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Abstract:
Magnetic nanoparticles exhibit a variety of unusual phenomena when compared to respective bulk materials, particularly when the dimensions involved are comparable to critical magnetic length scales such as the exchange length. An open challenge is to build a consistent picture of the single-domain limit and of the particle size dependence of the spin arrangement close to the single- to multi-domain transition. In addition to this fundamental interest, a clear understanding of spin configurations at the nanoscale is required for improving the performance of materials and devices. A detailed picture of such size-dependent transitions is hindered in magnetic measurements encompassing large particle ensembles since single-particle properties are masked by distributions of particle size, anisotropies and dissimilar local interactions with the underlying substrate.
In this work we combine x-ray magnetic circular dichroism (XMCD) with photoemission electron microscopy (PEEM) to study the magnetization orientation in individual iron particles with sizes of 5 to 25 nm. For particles coupled to a ferromagnetic cobalt support, we find a non-collinear alignment between the particle and substrate magnetization above a critical size of ~6 nm and a parallel alignment for smaller sizes. Numerical calculations reproduce the experimental trend and reveal a sharp transition from an exchange- to an anisotropy-dominated regime on increasing the particle height: the smaller particles are in a single-domain collinear state while larger particles exhibit a spin-spiral magnetic structure determined by the magnetic anisotropy energy, analogous to an exchange spring [1].

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Notes:

Ultrafast all-optical magnetization reversal in RE-TM alloys

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Abstract:
The feasibility of all-optical magnetization reversal has been an intriguing issue since the first demonstration of ultrafast laser-induced spin dynamics [1]. Recently, it was shown that 40 fs circularly polarized laser pulses can indeed reverse the magnetization in a thin film of ferrimagnetic RE-TM alloy GdFeCo [2]. The understanding of the mechanism and the time scale of this process emerged as an issue of fundamental and practical importance for magnetic recording and data processing.
To address these issues we developed a single-shot time-resolved magneto-optical microscopy technique, allowing visualizing the magnetic state of a sample at different delay times after the excitation by a *single* circularly polarized 100 fs laser pulse. With this technique we unveiled a novel path for the magnetization reversal [3]. We have shown that the all-optical magnetization reversal has a linear character and proceeds via a strongly-nonequilibrium demagnetized state formed within 1 ps after the excitation by a femtosecond laser pulse. This is followed by either formation of a domain with a reversed magnetization or by the relaxation to the initial state, depending on the helicity of the pump pulse. We show that in GdFeCo this process can be realized within just 30 ps, which is the fastest write-read event demonstrated for magnetic recording so far.
In the process of all-optical reversal the laser pulse serves, on the one hand, as the stimulus for ultrafast demagnetization. On the other hand, it acts as the helicity-dependent effective magnetic field $\mathbf{H}_{\text{eff}}$ [4], which microscopical origin comprises an intriguing issue. Therefore, we investigated the process of all-optical reversal for the laser pulses with different characteristics. Interestingly, the all-optical reversal could be also realized with elliptically polarized laser pulses, which suggests that the strength of $\mathbf{H}_{\text{eff}}$ can be lower than estimated previously value of 20 T [3]. Also we show that the longer laser pulses (up to 3 ps) are still suitable for the all-optical reversal, which is consistent with the concept of linear reversal.
We also discuss how magnetic properties of the GdFeCo and other RE-TM alloys affect the process of all-optical reversal and suggest which media are the most promising for the fastest and the most efficient all-optical control of magnetization.
This research has received funding from NWO, FOM, NanoNed and EC FP7 [Grants No. NMP3-SL-2008-214469 (UltraMagnetron) and No. 214810 (FANTOMAS)].

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Theoretical investigation of the ultrafast laser-induced magnetization dynamics in many-electron systems

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Abstract:
Ultrafast optical control of a magnetic state of a medium is presently a subject of intense research. It is of importance for the development of novel concepts for high-speed magnetic recording and information processing and at the same time reveals fundamental questions on the dynamics of magnetism. A set of experiments has revealed direct optical control on magnetization via the inverse Faraday effect [1]. In these experiments circularly polarized high-intensity laser pulses at femtosecond time scale are used to excite the magnetic system of the sample. But the mechanism of the orbital momentum transfer from light to the medium, which defines the fundamental time limit on magnetic switching, is still not understood.
In order to provide an insight into the origin of the inverse Faraday effect, we investigate the magnetization dynamics of atoms, which are constituents of materials used in experiments, excited by femtosecond circularly polarized Gaussian-shaped laser pulses. We study the stimulated Raman-like scattering process, which was suggested to be responsible for the magnetization reversal by light [2]. The time-dependent Schrödinger equation is solved up to the second order using the Volterra iteration method to describe the action of the laser light on the system. The time evolution of the probability of excitation from the ground state to an excited level and back to the ground state with a different magnetic state is calculated. We show, that due to this process the magnetization of the system changed after the action of the laser pulse on it.
We are thankful for the financial support by the FANTOMAS project.

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Notes:

Photo Control of Magnetism in a (Ga,Mn)As thin film

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Abstract:
Non-thermal optical control of the coercive field has been recently demonstrated in the ferromagnetic semiconductor (Ga,Mn)As [1]. It was observed that the coercive field of a (Ga,Mn)As thin film could be efficiently reduced by exposure to light, allowing magnetic information to be written, using only a low-power light source. Here we report new data on the effect including its dynamical properties.
Our results indicate that the magnitude of the photo-induced reduction of the coercive field depends on the duration of the light pulse. The reduction is significantly more pronounced when an ultrashort (100 fs) light pulse is used. In this case, a single pulse with an energy of only 0.1 nJ can reduce the coercive field in an area of approximately 100 μm^2 from 50 mT to nearly zero. This is a dramatic increase in efficiency (six or more orders of magnitude) as compared to continuous excitation. It is interpreted as being the result of the intrinsically short lifetime of the effect.
This is further confirmed by the direct measurement of the photo-coercive effect's lifetime using two time-delayed pulses. The total reduction in the coercive field is measured as a function of the time delay between the two co-incident pulses. These measurements reveal that the effect exponentially reduces as the delay between the pulses is increased, with a characteristic time constant of 1.5 ns. This makes the effect a uniquely fast and efficient method of optically switching magnetization.

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POSTERS

in alphabetical order

Exploring magnetization dynamics using time-resolved MOKE

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Abstract:
Starting with the pioneering experiments by Beaurepaire et al. in 1996 [1] that revealed the ultrafast demagnetization in nickel, time-resolved MOKE has become an indispensable experimental tool to study magnetization dynamics on ultrashort (fs) time scales. It has proven particularly useful in unraveling the variety of energy relaxation processes on these timescales, as we have shown earlier [2]. Here, we present our state-of-the-art TRMOKE system with a time resolution < 50 fs dedicated to advancing and exploring further the field of ultrafast magnetization dynamics and spin transfer torque. The detailed discussion of the setup is complemented by preliminary measurement results demonstrating the capabilities of the system. Selected results from studies of the Spin Seebeck effect [3] are presented along with an overview of the planned experiments.

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[2] Walowski, J. et al., Phys. Rev. Lett., 101 (237401), 2008
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Notes:

Ultrafast demagnetization by indirect pumping investigated with time-resolved x-ray spectroscopy

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Abstract:
The microscopic origin of the ultrafast demagnetization of ferromagnetic materials has been hotly debated since the first observation of a sub-picosecond laser-induced quenching of the magnetization in Ni [1]. Competing theories are demagnetization through a coherent interaction of the laser pulse with the electron spins [2] and an Elliott-Yafet type of spin-flip scattering of hot electrons [3]. A recent addition is a model based on superdiffusive spin transport [4].
We aim to illuminate the role of hot electron transport in laser-induced ultrafast demagnetization by employing indirect pumping: a 30 nm thick Au layer is deposited on top of a 15 nm thick Ni film, in order to absorb the laser pump pulse in this cap layer. We then take advantage of the Femtoslicing setup at BESSY II to probe the magnetization dynamics in the buried Ni layer with 130 fs time resolution via XMCD measurements [5].
A comparison of the evolution of the magnetization in a gold-capped Ni sample and an uncapped Ni sample after laser excitation shows that demagnetization is achievable with the indirect pumping method, with identical time constants of demagnetization. Furthermore, the onset of demagnetization in the gold-capped sample is delayed by several hundred femtoseconds, dependent on the pump fluence. These first results, which indicate the importance of transport effects for ultrafast demagnetization, will be discussed in context with theory.

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Notes:

Laser induced magnetization dynamics in structured systems

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Abstract:
Faster writing time and smaller bit size are two of the main research directions for the magnetic recording industry. Recent experiments have shown that a single 40 fs laser pulse is enough to switch the magnetization of GdFeCo thin films via an Inverse Faraday Effect where the polarization of the light creates a magnetic field. How small the reversed domain can be is a crucial question for technological application. But in addition, investigating this question would permit to test the currently suggested reversal scenario where the time of complete reversal is given by the domain wall velocity and the final domain size. I will present our recent progress on nanostructured GdFeCo thin films where using a Photoemission Electron Microscope and thanks to the X-ray Magnetic Circular Dichroism, we are able to resolve the changes of magnetic states of these structures after femtosecond laser illumination. This setup also allows us to investigate the dynamics of the control of the spin orientation in more conventional materials like ferromagnetic Co thin films which are exchange coupled with a canted antiferromagnet.

Notes:

Acoustic phonons in thin magnetic films

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Abstract:
The aim of our study is to create coherent acoustic phonons in magnetic structures in order to study spin-phonon interactions. The first results are shown for an exchanged biased magnetic film, IrMn/Py. High frequency phonons are successfully created and their time and frequency domains correspond well with simulations. The ability however to study spin-phonon interaction in the current structure was limited by heating. Small adjustments of the magnetic structure are made in order to avoid heating.

Notes:

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Light induced magnetization dynamics in ultrathin Pt/Co/Pt layers approaching a spin reorientation phase transition

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Abstract:
A spin reorientation phase transition (SRPT) is a property of ultrathin cobalt layers and it involves a change of magnetization direction from in-plane to out-of-plane with decreasing film thickness [1]. In the present work we study the light-induced ultrafast magnetization dynamics of MBE-deposited Pt/Co/Pt systems in the vicinity of this SRPT. Using all-optical time-resolved Kerr magnetometry we observe laser-induced magnetization precession with a Co-thickness-dependent amplitude, frequency and damping. This behavior can be explained by pump pulse induced thermal changes of both the direction and amplitude of the effective magnetic field affecting the sample. Numerical simulations using the Landau-Lifshitz-Gilbert equation and data obtained with static MOKE measurements support that explanation.

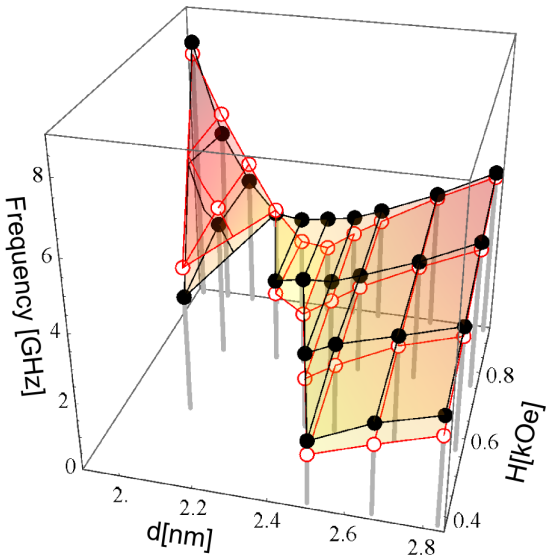

Figure: measured (solid) and calculated (open) frequency of magnetization precession in function of applied external magnetic field and Co-thickness (SRPT at 2.4nm).

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Notes:

First-principle calculations of spin dynamics in GdFe compounds

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Abstract:
First-principle atomistic spin dynamics (ASD) simulations are a promising tool to study theoretically ultrafast light-induced magnetization dynamics in a strongly non-equilibrium phase. In particular, at present first-principles ASD simulations are the only approach that has both the direct connection with first-principle electronic structure calculations and is feasible to study magnetization dynamics at critical temperatures. This is particularly important for the understanding of light induced magnetization dynamics in metals, where both thermal and non-thermal effects are present. Recent experiments with femtosecond circularly polarized laser pulses [1], show that full reversal of magnetization is found in ferromagnetic alloys of rare-earth and transition-metal atoms. Interestingly, the observed switching time strongly depends on the compensation temperature [2]. To develop a microscopic understanding of the dynamics across the compensation temperature, first-principle ASD simulations of rare-earth transition-metal alloys are highly desirable.
In this contribution we report on first-principle ASD simulations for a GdFe alloy, as a prototype model for the rare-earth transition-metal ferrimagnets. First-principle exchange parameters were obtained using the rhombohedral crystalline structure of GdFe3. Static characterization of this material shows the Curie temperature and compensation temperature in reasonable agreement with experimental data. In addition, studies of ferromagnetic resonance dynamics recover the ferromagnetic and exchange resonance modes. The ferromagnetic mode is seen to diverge around the angular momentum compensation temperature, while the exchange mode softens, but does not completely vanish. Hence the trends observed are the same as in experiments [3]. These findings indicate that the magnetization reversal across the compensation temperature in ferrimagnets involves rich dynamics, qualitatively very different from the reversal in ferromagnets.

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[1] C.D. Stanciu *et al.*, Phys. Rev. Lett, **99**, 047601 (2007)
[2] K. Vahaplar *et al.*, Phys. Rev. Lett, **103**, 117201 (2009)
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Notes:

Ultrathin cobalt/garnet films heterostructures for magnetization dynamics studies

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Abstract:
The aim of our research is to determine coupling between ultrathin Co films and Co-doped garnet films (YIG:Co). fs laser pulses driven large ultrafast photoinduced magnetic anisotropy and magnetization switching were observed in garnet films [1,2]. 6.5 μm YIG:Co films were grown by LPE and thinned by ion etching down to 1 μm. Au(4nm)/Co(2 and 6 nm)/YIG:Co heterostructure was obtained by ion-beam sputter deposition method. 20x20 μm Co pattern were fabricated by lift-off photolithography. Magnetic domain structure and magnetization processes were investigated by both magneto-optical Faraday and Kerr effects as a function of magnetic field applied perpendicular and in-plane of the sample. A strong influence of 2 nm Co film on the domain structure geometry, magnetization processes and coercivity has been found for garnet films thinner than 3.9 μm (see Fig.). The observed magnetization reversal process in the heterostructure could be explained by both the garnet magnetic anisotropy (cubic and uniaxial) and the garnet film coupling with Co layer.

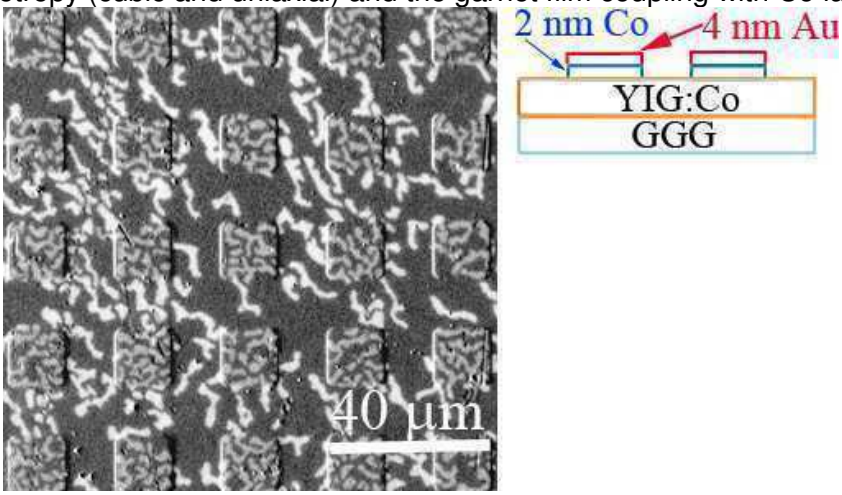

Figure: Influence of 2 nm Co film on domain structure of 2.5 μm YIG:Co film. Inset – scheme of the investigated heterostructure.

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Notes:

Investigation of Ultrafast Magnetization Reversal via a Nonequilibrium State

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Abstract:
The fundamental and practical limit of the speed of magnetization reversal is a subject of great importance for magnetic recording and information processing. Since the pioneering observation of subpicosecond demagnetization by a 60 fs laser pulse, femtosecond optical excitation seemed to offer new possibilities to control magnetization [1]. This was recently confirmed by the surprising observation of magnetization switching by a single 40 fs circularly polarized laser pulse [2]. To investigate the dynamics and mechanism of this laser-induced switching we have developed an ultrafast, single-shot pump-probe magneto-optical imaging technique.
The results show that circularly polarized subpicosecond laser pulses steer the magnetization reversal along a novel and ultrafast route, which does not involve precession but occurs via a strongly nonequilibrium state [3,4]. Although these experiments clearly showed the feasibility of ultrafast magnetic switching by circularly polarized subpicosecond pulses, we also investigated the following questions: How do the duration and the ellipticity of the excitation laser pulses affect the magnetization reversal? How strong should the light-induced effective magnetic field be? The answers give us a clearer picture of the balance between thermal and non-thermal contributions in this nonequilibrium process.
This work is supported by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) and EC FP7 contributions under grants NMP3-SL-2008-214469 (UltraMagnetron) and N 214810 (FANTOMAS)

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Notes:

Dynamics of Antiferromagnets and Ferrimagnets Driven by Ultrashort Magnetic Field Pulses

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Abstract:

So far, all-optical magnetisation switching has been demonstrated experimentally only in ferrimagnetic materials like GdFeCo or TbFeCo[1]. A reason for this restriction seems to be the antiferromagnetic coupling of the two sublattices in these materials, which may lead to completely different dynamics as compared to a ferromagnet, combined with a strong, ultrashort magnetic field pulse induced by the inverse Faraday effect[2]. Also the heating by the laser pulse is assumed to play a crucial role in this process and it was speculated that the special properties of the ferrimagnet close to the compensation point could be relevant.[1]
To understand the dynamics in these materials, we perform atomistic simulations of antiferromagnets as well as ferrimagnets, driven either by ac magnetic fields or by ultrashort magnetic field pulses. For an investigation of the dynamics of the (sub-lattice) magnetization we use generic classical Heisenberg models and solve the stochastic Landau-Lifschitz-Gilbert equation of motion for each atomistic moment numerically.[3]
For the ferrimagnetic model driven by ac fields we calculate the effective frequencies and damping parameters for both, the exchange mode as well as the ferromagnetic mode, and we compare with experimental findings [4] as well as analytical work. For the field pulse driven dynamics we investigate its dependence on the duration and the amplitude of the magnetic fields focusing especially on the possibility of ultrafast magnetic switching with or without thermal excitation.

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