MA 2: Ultrafast magnetization effects and magnetization dynamics

Time: Monday 9:30–13:15 Location: H37

MA 2.1 Mon 9:30 H37

Ultrafast electron dynamics in the first-order phase transition of FeRh — •Federico Pressacco[1], Dmytro Kutnyakhov[2], Vojtech Uhlir[3], Jon Ander Arregi[3], Michael Heber[2], Steinn Agustsson[4], Davide Sangalli[5], Andrea Marini[5], Matteo Gatti[6,7], Guenter Brenner[2], Dmitry Vasilyev[4], Fausto Sirotti[6], and Wilfried Wurth[1,2] — [1]CFEL, Universität Hamburg, Germany — [2]DESY,Hamburg, Germany — [3]CEITEC BUT, Czech Republic — [4]JGU Mainz, Germany — [5]CNR-ISM,Roma, Italy — [6]École Polytechnique, CNRS, France — [7]European Theoretical Spectroscopy Facility (ETSF)

Time resolved photo-electron spectroscopy is one of the most powerful techniques to directly investigate the role of the electronic structure in phenomena such as superconductivity, and magnetization dynamics. It greatly benefits from recent developments of high repetition rate Free Electron Lasers (FLASH at DESY Hamburg) and advances in electron detectors such as momentum microscopes. Here we present a time-resolved study carried out at FLASH of the metamagnetic phase transition induced by laser excitation in FeRh with femtosecond resolution. We monitor the changes in the valence band related to the phase transition which at equilibrium takes place at 400 K from an antiferromagnetic to a ferromagnetic phase. The dynamics show a subpicosecond transition of the electronic structure to the FM, pointing to a primary role of the electronic system in triggering the magnetic phase transition. Ab-initio calculation of the non-equilibrium electronic structure show good agreement with the observed phenomena.

MA 2.2 Mon 9:45 H37

Ultrafast Demagnetization by Extreme Ultraviolet Light — •Leonard Müller[1,3], André Philippi-Kobs[1], Magnus H. Berntsen[2], Wojciech Roseker[1], Matthias Riepp[1], Kai Bagschik[1], Jochen Wagner[3], Robert Frömter[3], Miltcho B. Danailov[4], Flavio Capotondi[4], Emanuele Pedersoli[4], Michele Manfredda[4], Maya Kiskinova[4], Michal Stránský[6], Vladimir P. Lipp[1,5], Beata Ziaja[1,5], Hans Peter Oepen[3], and Gerhard Grübel[1,3] — [1]Deutsches Elektronen Synchrotron, Hamburg, Germany — [2]KTH Royal Institute of Tecchnology, Kista, Sweden — [3]Universität Hamburg, Hamburg, Germany — [4]Elettra-Sincrotrone Trieste, Basovizza, Italy — [5]Center for Free-Electron Laser Science, Hamburg, Germany — [6]Academy of Science of the Czech Republic, Prague, Czech Republic

One of the most intriguing topics within research on magnetism, ultrafast demagnetization [1], has greatly benefited from the advent of free-electron Lasers (FEL). Following a previous campaign [2], we report on a breakdown of the magnetic scattering cross section in Co/Pt multilayers for extreme ultraviolet (XUV) fluences $> 1\text{mJ/cm}^2$ defining the threshold fluence for FEL experiments where the FEL is meant to be a non-invasive probe. XUV-induced demagnetization is identified to be the major mechanism behind the breakdown. Besides revealing the existence of ultrafast demagnetization in the XUV regime, our results demonstrate that it proceeds much faster than the demagnetization when using IR radiation. [1] Phys. Rev. Lett. **76**, 4250 (1996), [2] Phys. Rev. Lett. **110**, 234801 (2013).

MA 2.3 Mon 10:00 H37

Magnetization dynamics due to femtosecond spin current pulses — •Karel Carva[1], Pavel Baláž[1], Ulrike Ritzmann[2], Pablo Maldonado[2], and Peter M. Oppeneer[2] — [1]Charles University, DCMP, Ke Karlovu 5, CZ-12116, Prague, Czech Republic — [2]Uppsala University, PO Box 516, 75120 Uppsala, Sweden

Ultrafast demagnetization induced by femtosecond lasers is accompanied by spin current pulses, which arise and decay on timescales unprecedent in spintronics. These originate from migration of nonequilibrium hot charge carriers in a magnetic layer excited to bands with higher mobilities by a laser [1]. These spin currents may exert torque on adjacent perpendicularly oriented magnetic layers [2]. First we calculate this torque, and model the magnetization dynamics described by the Landau-Lifshitz-Gilbert equation within macrospin appproach. We also find an optimal thickness of the excited layer that maximizes the torque [3].

Since the perturbation of magnetization is localized on the scale of several nm [4], we also perform a more accurate atomistic spin dynamics simulations to study the magnon dynamics induced by the spin current. In particular we investigate the induced magnon population, its subsequent temporal evolution on ps timescale, and the formation of standing waves in confined systems.

[1] M. Battiato, K. Carva, P.M. Oppeneer, PRL 105, 027203 (2010)
[2] A.J. Schellekens et al., Nat. Comm. 5, 4333 (2014)
[3] P. Baláž et al., J. Phys.: Cond. Matter 30, 115801 (2018)
[4] I. Razdolski et al., Nat. Comm. 8, 15007 (2017)

MA 2.4 Mon 10:15 H37

Dynamics of laser-excited nickel: an ultrafast look at the lattice side — Daniela Zahn[1], •Thomas Vasileiadis[1], Tim Butcher[2], Yingpeng Qi[1], Hélène Seiler[1], Jan Vorberger[2], and Ralph Ernstorfer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

The behavior of ferromagnets after laser excitation is governed by the interplay of electrons, lattice and spins. In the case of 3d-ferromagnets, strong coupling between electrons and spins leads to ultrafast demagnetization on the femtosecond time scale [1]. Since the lattice drains energy from the electrons on similar timescales, it plays an important role in the magnetization dynamics. A method to study the lattice response directly is femtosecond electron diffraction (FED) [2]. We present FED results on nickel for a variety of excitation conditions. We compare the experimental data with ab-initio calculations of the spin-polarized electron-phonon coupling in combination with a two-temperature model. We find that the experimental results can only be described by the model if energy transfer to the spin system is taken into account.

[1] Beaurepaire et al., PRL 76, 4250 (1996).
[2] Waldecker et al., JAP 117, 044903 (2015).

MA 2.5 Mon 10:30 H37

Induced vs. intrinsic magnetic moments in ultrafast magnetization dynamics — •Simon Häuser[1], Moritz Hofherr[1,2], Simone Moretti[3], Nataliia Safonova[4], Henry Kapteyn[5], Margaret Murnane[5], Mirko Cinchetti[6], Daniel Steil[7], Stefan Mathias[7], Benjamin Stadtmüller[1,2], Manfred Albrecht[4], Ulrich Nowak[3], and Martin Aeschlimann[1] — [1]Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Mainz, Germany — [3]Universität Konstanz, Konstanz, Germany — [4]University of Augsburg, Augsburg, Germany — [5]University of Colorado, Boulder, USA — [6]Technische Universität Dortmund, Dortmund, Germany — [7]Georg-August-Universität Göttingen, Göttingen, Germany

Technologically important ferromagnetic alloys consisting of several magnetic sublattices exhibit often both intrinsic and induced magnetic moments. Here, we study the ultrafast response of the element-specific magnetization dynamics for thin film systems based on purely intrinsic (CoFeB) and partially induced (FePt) magnetic moments using HHG-TMOKE as an element-sensitive probe. In FePt, on the one hand, we observe an identical normalized transient magnetization for Fe and Pt throughout both the ultrafast demagnetization and the subsequent remagnetization. On the other hand, Co and Fe show a clear difference in the asymptotic limit of the remagnetization process in CoFeB. This observation is supported by calculations for the temperature-dependent behavior of the equilibrium magnetization using a dynamic spin model [1]. [1] Phys. Rev. B 98, 174419 (2018)

MA 2.6 Mon 10:45 H37

Theory of ultrafast demagnetization in noncollinear spin valves — •Pavel Baláž[1,2], Karel Carva[1], Maciej Zwierzycki[3], Dominik Legut[2], Pablo Maldonado[4], and Peter M. Oppeneer[4] — [1]Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, CZ 121 16 Prague, Czech Republic — [2]IT4Innovations Center, VSB Technical University of Ostrava, 17. listopadu 15, CZ 708 33 Ostrava-Poruba, Czech Republic — [3]Institute of Molecular Physics, Polish Academy of Sciences, Smoluchowskiego 17, 60-179 Poznań, Poland — [4]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden

When a sample made of conducting metal is exposed to a femtosecond laser pulse, ultrafast demagnetization of the sample can be observed. One of the possible mechanisms is superdiffusive spin-dependent transport [1] of hot electrons excited by laser from the localized d band to the s one above the Fermi level. Here, we generalize this model for the case of a magnetic multilayer with noncollinear magnetizations. The spin-dependent transport through the interfaces between the layers is described by energy-dependent reflections and transmissions taking into account spin mixing. It is shown that laser-induced demagnetization of the multilayer depends on the magnetic configuration. Moreover, the angular dependence of spin transfer torque [2] acting on the magnetizations is estimated. [1] M. Battiato, et al., Phys. Rev. Lett. 105, 027203 (2010). [2] P. Baláž et al., J. Phys.: Cond. Matter 30, 115801 (2018).

MA 2.7 Mon 11:00 H37

tuning femtoseconds magnetization dynamics of FePt by Mn doping — •Yuting Liu[1], Ute Bierbrauer[1], Cinja Seick[2], Moritz Hofherr[1], Nataliia Safonova[3], Manfred Albrecht[3], Daniel Steil[1], Benjamin Stadtmuller[1], Stefan Mathias[2], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS,University of Kaiserslautern, Germany — [2]Institute of Physics, University of Gottingen, Germany — [3]Institute of Physics, University of Augsburg, Germany

Understanding the ultrafast response of magnetic materials after interaction of fs light pulses provides abundant topics for fundamental science, as well as new opportunities for ultrafast manipulation of magnetization in storage devices. In this work, the ultrafast magnetization dynamics of Mn doped FePt prepared by a rapid thermal annealing (RTA) process have been studied by employing the magneto optical Kerr effect using visible as well as fs-XUV radiation. The speed of demagnetization and degree of quenching can be tailored by Mn doping. In particular, we find a local minimum of the demagnetization time constant with increasing strength of the optical excitation, i.e., with increasing laser fluence, leading to an unusual camel-like demagnetization vs. quenching curve in this material system. These results provide a prominent example in which way the implantation of magnetic impurity atoms into a magnetic host material can severely alter and manipulate the ultrafast magnetization dynamics of complex materials.

15 min. break

MA 2.8 Mon 11:30 H37

Ultrafast terahertz-driven spin switching in an antiferromagnet — •Stefan Schlauderer[1], Christoph Lange[1], Sebastian Baierl[1], Thomas Ebnet[1], Christoph P. Schmid[1], Anatoly K. Zvezdin[2,3], Alexey V. Kimel[4,5], Rostislav V. Mikhaylovskiy[5], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Prokhorov General Physics Institute and P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow 119991, Russia — [3]Moscow Institute of Physics and Technology (State University), Dolgoprudny 141700, Russia — [4]Moscow Technological University (MIREA), Moscow 119454, Russia — [5]Radboud University, Institute for Molecules and Materials, Nijmegen 6525 AJ, The Netherlands

Switching magnetization with maximal speed and minimal energy loss is essential for future information processing and data storage. Here, we use intense THz pulses with meV photon energies to switch electron spins between two states separated by a potential barrier, in the fastest and least dissipative way, and we reveal the corresponding temporal and spectral fingerprint. This goal is achieved by coupling the locally enhanced THz electric field of custom-tailored antennas with antiferromagnetic $TmFeO_3$. Within their duration of 1 ps, single-cycle THz pulses abruptly change the magnetic anisotropy and trigger a large-amplitude ballistic spin motion. A characteristic phase flip, an asymmetric splitting of the magnon resonance, and a long-lived offset of the Faraday signal hallmark coherent spin switching into adjacent potential minima.

MA 2.9 Mon 11:45 H37

Uncovering the magnetic origin of the contractive stress in laser-excited FePt by ultrafast X-ray diffraction — •Alexander von Reppert[1], Jan-Etienne Pudell[1], Steffen Zeuschner[1,2], Lisa Willig[1], Matthias Rössle[2], Marc Herzog[1], Fabian Ganss[3], Olav Hellwig[3,4], and Matias Bargheer[1,2] — [1]Institut für Physik und Astronomie, Universität Potsdam, Potsdam, Germany — [2]Helmholtz-Zentrum Berlin, Berlin, Germany — [3]Institut für Physik, Technische Universität Chemnitz, Chemnitz, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Here we present a systematic study of the previously observed contraction of laser-excited granular FePt by ultrafast X-ray diffraction. Double-pulse excitation experiments show that the contractive stress is suppressed when the FePt is transiently demagnetized and it recovers as the magnetization reestablishes. The saturation of the observed contraction in a fluence study and the timescale for the remagnetization in time-resolved MOKE measurements corroborate this finding. The comparison between the lattice response of continuous and granular FePt films shows that the in-plane geometry of the sample is crucial for the observed lattice dynamics, although we can exclude the anisotropic phonon and electron expansion coefficients as the only origin of the out-of-plane contraction. In this work we demonstrate how double-pulse excitation experiments can disentangle competing mechanisms at phase transitions, which are difficult to access.

MA 2.10 Mon 12:00 H37

Electron dynamics driving ultrafast magnetization dynamics in alloys — •Sebastian T. Weber[1], Benjamin Stadtmüller[1,2], Moritz Hofherr[1,2], Martin Aeschlimann[1], and Baerbel Rethfeld[1] — [1]Department of Physics and Research Center Optimas, TU Kaiserslautern, Erwin-Schroedinger-Strasse 46, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany

Irradiating ferromagnetic films with an ultrashort laser pulse leads to a quenching of the magnetization on a subpicosecond timescale [1]. Our spin-resolved Boltzmann description allows to describe the out-of-equilibrium electrons and their microscopic collision processes [2].

Recent experiments in an exchange coupled ferromagnetic Fe-Ni alloy (Permalloy) have revealed element-specific dynamics right after the optical excitation [3]. To reveal the mechanisms responsible, we have set up a model to trace the spin-resolved electron dynamics in dependence on both magnetic sublattices of the alloy. Our results show the influence of the involved coupling mechanisms on the different relaxation processes.

[1] E. Beaurepaire *et al.*, PRL **76**, 4250 (1996)
[2] B. Y. Mueller *et al.*, PRL **111**, 167204 (2013)
[3] S. Mathias *et al.*, PNAS **109**, 4792 (2012)

MA 2.11 Mon 12:15 H37

Stroboscopic imaging using Lorentz TEM at radio frequencies — •John H. Gaida, Marcel Möller, Sascha Schäfer, and Claus Ropers — 4th Physical Institute, Georg-August-University, Göttingen, Germany

Lorentz microscopy is a widely applied technique for the nanoscale mapping of magnetization structures. Its time-resolved implementation offers fascinating prospects for a spatiotemporal imaging of ultrafast magnetism.

The Göttingen Ultrafast Transmission Electron Microscope (UTEM) is a recently developed instrument to study ultrafast structural, electronic and spin dynamics, driven by optical pump pulses or radiofrequency currents [1].

In this contribution, we present stroboscopic Lorentz microscopy with photoelectron pulses at high MHz-repetition rates. We use a permalloy ($Ni_{80}Fe_{20}$) nanoisland as a model system to benchmark the new instrument by mapping time-resolved current-driven vortex gyration. The trajectory of the vortex core is tracked with a high precision of better than 3 nm, which allows us to identify subtle deviations from an idealized gyrotropic motion. Systematic deformations of the elliptical orbit and a changing angular velocity indicate the influence of pinning centers on the trajectory. Our method can help in the design of nanoscale magnetic materials by time-resolved imaging of the dynamics of magnetic quasiparticles such as vortices or skyrmions with high spatial and temporal resolutions.

[1] A. Feist *et al.*, Ultramicroscopy **176** (2016)

MA 2.12 Mon 12:30 H37

Linking spectroscopy calculations with the underlying time-dependent DFT electronic structure — •Voicu Popescu, Sergiy Mankovskiy, Jürgen Braun, Alberto Marmodoro, and Hubert Ebert — Department Chemie, Ludwig Maximilian University, Munich, Germany

Recent developments in time-dependent density functional theory

(TD-DFT) paved the way towards investigating and quantitatively interpreting, on *ab initio* level, the ultrafast demagnetisation processes in ferromagnetic systems caused by a strong laser pulse [1]. These time-dependent phenomena can in principle be monitored by standard spectroscopic techniques such as angle-resolved photoemission (ARPES) and/or magnetic circular X-ray dichroism (MCXD), with the latter having the additional advantage of being element-specific.

The present contribution tries to answer the question how much of information, and how accurately, do such spectroscopy experiments actually convey? We do this by calculating, within the framework of the spin-polarised relativistic Korringa-Kohn-Rostoker method, the ARPES and MCXD spectra for several transition metals employing the self-consistently determined TD-DFT potentials. We make a side-by-side comparison between the theoretically determined spectra and the time evolution of the underlying electronic structure and find that, while correctly reproducing the qualitative trends, quantitative estimations based on the MCXD sum rules have a limited range of validity.

[1] K. Krieger *et al.*, J. Chem. Theory Comput. **11**, 4870 (2015)

MA 2.13 Mon 12:45 H37

Long-distance ultrafast spin transfer processes through carbon chain structure — •Jing Liu[1], Georgios Lefkidis[1], Wolfgang Hübner[1], and Chun Li[2] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Northwestern Polytechnical University, Xi'an, China

Ultrafast spin flip and transfer processes between near magnetic centers have already been theoretically demonstrated on various realistic, or even synthesized molecular systems [1]. Motivated by the delicate spin interaction between the encapsulated magnetic atoms and the atoms of the cage of endohedral fullerenes [2,3] as well as the calculability of such large structures with high precision quantum chemical methods, we use C atoms as spin channels to optically transfer the spin over distances comparable to the actual CMOS scale.

First we transfer the spin across a finite 2D graphene sheet, on which we induce spin localization by attaching two Ni atoms on opposite sites. However, our to-date record distance of 4.428 nm is achieved over a 40-atom-long zig-zag carbon chain, again with two Ni attached. The spins of the two Ni atoms couple due the combination of local and global symmetry, with the nonlinear geometry of the chain (which gives rise to what we term dynamical Goodenough-Kanamori rules). The processes typically finish within 600 fs.

[1] D. Dutta, *et al.*, Phys. Rev. B **97**, 224404 (2018).
[2] C. Li, *et al.*, Carbon **87**, 153 (2015).
[3] C. Li, *et al.*, Phys. Chem. Chem. Phys. **19**, 673 (2017).

MA 2.14 Mon 13:00 H37

Effect of ultrashort laser pulse on the magnetic and chemical state of individual Co nanoparticles probed by X-PEEM — •Tatiana M. Savchenko, Michele Buzzi, Jaianth Vijayakumar, Martin Timm, Ludovic Howald, David Bracher, Carlos A. F. Vaz, Frithjof Nolting, and Armin Kleibert — Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen, Switzerland

The discovery of all-optical switching (AOS) in ferrimagnetic alloys such as FeGdCo using ultrashort laser pulses has stimulated immense activities in the field of magnetism. More recently, AOS was also observed in 3d transition metal thin film systems. In this work, we combine X-ray photoemission electron microscopy (X-PEEM) with X-ray magnetic circular dichroism (XMCD) and X-ray absorption spectroscopy (XAS) to observe the response of the magnetization and the chemical state of individual and well separated Co nanoparticles with sizes between 8 and 25 nm deposited on silicon wafers upon excitation with single 50 fs laser pulses with a wavelength of 800 nm. We find that the laser pulses with fluences up to about 7 mJ/cm2 have no noticeable effect on the magnetic state of the particles, irrespective of the laser polarization. At higher fluences, we find that the nanoparticles undergo a chemical reaction with the Si substrate and lose magnetic contrast. Calculations indicate that Rayleigh scattering significantly reduces the number of absorbed photons in a nanoparticle due to the large wavelength relative to its diameter. Thus, much higher laser fluences as compared to thin films together with laser transparent substrates are required to achieve all-optical switching in individual nanoparticles.