MA 2: Ultrafast Magnetization I

Time: Monday 9:30–12:30 Location: HSZ 101

MA 2.1 Mon 9:30 HSZ 101

Theory of out-of-equilibrium electron and phonon dynamics after laser excitation in metals — •Ulrike Ritzmann[1,2,3], Peter M. Oppeneer[1,3], and Pablo Maldonado[3] — [1]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [3]Department of Physics and Astronomy, Uppsala University, Uppsala, Germany

Ultrafast magnetization phenomena are often described using the two-temperature model (2TM) to compute the electron and phonon dynamics after laser excitation. This model assumes that both subsystems are locally at thermal equilibrium. However, recent experiments show that this description is not sufficient to describe the out-of-equilibrium dynamics on ultrashort timescales. Here, we present a parameter-free microscopic out-of-equilibrium model to describe the ultrafast laser- induced system dynamics in various nonmagnetic and magnetic metals such as gold, aluminium, iron, nickel and cobalt. We report strong deviations from the 2TM on the picosecond timescale for all materials studied. Furthermore, we demonstrate the importance of the mode-dependence of the electron-phonon coupling for the relaxation process and reveal the significance of this channel in the lattice equilibration. The computed new behavior demonstrates that phonon-mode dependent dynamics have to be considered in the ps time range in order to describe properly the lattice heating process and the subsequent dynamics of the whole system.

MA 2.2 Mon 9:45 HSZ 101

Ultrafast spin momentum transfer in noncollinear spin valves — •Pavel Baláž[1], Karel Carva[1], Maciej Zwierzycki[2], Pablo Maldonado[3], and Peter M. Oppeneer[3] — [1]Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, CZ 121 16 Prague, Czech Republic — [2]Institute of Molecular Physics, Polish Academy of Sciences, Smoluchowskiego 17, 60-179 Poznań, Poland — [3]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden

Ultrafast demagnetization of metallic thin films induced by a femtosecond laser pulse is a well-known phenomenon studied since 1996. One of the possible mechanisms is superdiffusive spin-dependent transport [1] of hot electrons excited by the pump laser from the localized *d* band to the *sp* one above the Fermi level. Here, we generalize this model for the case of a magnetic multilayer with noncollinear magnetizations [2]. The spin-dependent transport through the interfaces between the layers is described by energy-dependent reflections and transmissions calculated ab initio using the wave function matching method [3]. A substantial effect of spin filtering and of non-collinear magnetic configuration on ultrafast demagnetization and spin transfer torque is predicted for Al(3nm)/Ni(5nm)/Ru(2nm)/Fe(4nm)/Ru(5nm) spin valve.
[1] M. Battiato et al., Phys. Rev. Lett. 105, 027203 (2010). [2] P. Baláž et al., J. Phys.: Cond. Matter 30, 115801 (2018). [3] M. Zwierzycki et al., Phys. Rev. B 71, 064420 (2005).

MA 2.3 Mon 10:00 HSZ 101

Ultrafast magnetization dynamics of ferromagnets on thin metal films — •Jonas Hoefer, Martin Stiehl, Christopher Seibel, Laura Scheuer, Simon Häuser, Sebastian T. Weber, Sanjay Ashok, Philipp Pirro, Burkhard Hillebrands, Benjamin Stadtmüller, Bärbel Rethfeld, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger-Strasse 46, 67663 Kaiserslautern, Germany

After the first observation of the ultrafast demagnetization process of ferromagnetic thin films, huge efforts were devoted to reveal the microscopic mechanism governing the ultrafast optically induced loss of magnetic order in ferromagnetic materials. It was soon realized that spin transport from a ferromagnetic into a non-magnetic metal can severely increase the speed of demagnetization of magnetic materials. So far, experimental studies focused on bulk-like non-magnetic thin films acting as a sink for the injected spins. In our study, we particular address the correlation between the demagnetization dynamics of a thin magnetic film and the thickness of a non-magnetic gold film underneath. Using time-resolved all-optical pump-probe MOKE experiments, we investigated the demagnetization time of a permalloy/gold bilayer systems for various Au film thicknesses. We find significantly longer demagnetization times for thin Au thicknesses compared to bulk-like Au films. These results will be discussed via theoretical model simulations describing the non-equilibrium dynamics of the optically excited spin carriers and their coupling through the interface.

MA 2.4 Mon 10:15 HSZ 101

Photon energy dependent fs-demagnetization dynamics of thin Ni films — •Martin Stiehl, Jonas Hoefer, Sebastian Weber, Sanjay Ashok, Moritz Hofherr, Ute Bierbrauer, Benjamin Stadtmüller, Bärbel Rethfeld, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Kaiserslautern, Germany

After the first observation of the ultrafast demagnetization process, a huge experimental and theoretical effort was devoted to reveal the microscopic mechanism governing the ultrafast optically induced loss of magnetic order in ferromagnetic materials. Almost all experimental fs-demagnetization studies so far employed fs light pulses of 1.55 eV to trigger the magnetization-dynamics. Hence, the role of the photon energy of the exciting light pulse has not been thoroughly investigated so far. Therefore, we have implemented an all-optical time-resolved MOKE setup with variable pump photon energy in the range of 1.55 to 3.10 eV. As prototypical system, we investigated the ultrafast demagnetization dynamics of thin Ni films on insulating and conducting substrates for various excitation photon energies. The characteristic parameters of the demagnetization process, i.e., the demagnetization time and the induced magnetization in the conducting substrate, are compared with simulations applying Boltzmann collision integrals including the density of states of Nickel to describing the non-equilibrium dynamics of the spin-carrying excited electrons.

MA 2.5 Mon 10:30 HSZ 101

Role of spin resolved charge and heat transport in ultrafast demagnetization dynamics — •Sanjay Ashok, Sebastian Weber, Christopher Seibel, Johan Briones, and Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS , TU Kaiserslautern, Kaiserslautern, Germany.

Starting from the itinerant picture of metallic magnetism (Stoner-model) and the ultrafast reduction of exchange-splitting [1, 2] the Thermodynamic μT-model [3] describes ultrafast quenching of magnetization by tracing the equilibration of chemical potentials and temperatures of spin-up and spin-down electrons and temperature of lattice separately.

In case of thin metallic ferromagnets, the laser pulse heats the material homogeneously, therefore transport effects can be neglected. However, for thicker films and bulk materials, transport effects become essential. Therefore, one needs to distinguish the role of heat and charge transport (caused by the inhomogenous heating) in demagnetization dynamics of thicker metallic ferromagnets.

We model the ultrafast demagnetization of thick magnetic metal using the Thermodynamic μT-model. In this talk we present results on spatial and temporal evolution of magnetization, distinguishing the role of various transport channels.

[1] S. Essert and H. C. Schneider, Phys. Rev. B 84, 224405 (2011).
[2] B. Y. Mueller et al., Phys. Rev. Lett.111, 167204 (2013).
[3] B. Y. Mueller and B. Rethfeld, Phys. Rev.B 90, 144420 (2014).

MA 2.6 Mon 10:45 HSZ 101

Influence of a non-magnetic substrate on optically induced transport in a ferromagnetic alloy — •Simon Häuser[1], Moritz Hofherr[1], Martin Stiehl[1], Jonas Hoefer[1], Martin Anstett[1], Gregor Zinke[1], Laura Scheuer[1], Sebastian Thomas Weber[1], Christopher Seibel[1], Daniel Steil[2], Stefan Mathias[2], Bärbel Rethfeld[1], Philipp Pirro[1], Burkard Hillebrands[1], Benjamin Stadtmüller[1] und Martin Aeschlimann[1] — [1]TU Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany — [2]Georg-August-Universität Göttingen, I. Physikalisches Institut, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Optical manipulation of magnetic materials on extremely short, sub-100fs timescales can be achieved either by generation and injection of optically induced (ballistic) spin currents or by direct excitation of the spin system, i.e., by the optically induced spin transfer (OISTR) ef-

fect. In this work, we aim to reveal the mutual interplay of these spin transfer effects on ultrafast timescales. Therefore, we investigate the ultrafast demagnetization of a thin Fe20Ni80 alloy on a non-magnetic Au substrate as well as the influence of the spin current into the Au substrate. As an element-resolved probe of the spin dynamics, we employ time resolved Kerr spectroscopy at the M-edge in transversal geometry to disentangle the spectroscopic signatures of the OISTR and ballistic spin transport in this material. Our results will be compared to the magnetization dynamics of a Fe20Ni80 film on an insulating substrate.

15 min. break.

MA 2.7 Mon 11:15 HSZ 101

Anomalous ultrafast optical demagnetization in stripe domain films — •Derang Cao[1,2], Roman Adam[1], Fangzhou Wang[1], Sarah Heidtfeld[1], Christian Greb[1], and Claus M. Schneider[1] — [1]Peter Grünberg Institute, Research Centre Jülich, 52425 Jülich, Germany — [2]College of Physics, Qingdao University, 266071 Qingdao, China

Recently, laser pump/resonant-X-ray-scattering-probe experiments showed that the regular stripe domain (SD) pattern in CoPd films changes into a labyrinth domain structure after laser pulse excitation [Phys Rev B. 2015;91(5):054416]. This observation leads to an assumption that the films with different SD may exhibit different ultrafast demagnetization response on ultrafast time scales. If this is a case, clarifying the interaction mechanism between the domains and sea of spins on ultrafast time scales may contribute strongly to the understanding the mechanisms of ultrafast spin dynamics.

In this work, a train of 80-fs optical pulses has been used to induce a partial quenching of the magnetization in a wedge Ni80Fe20 film (thickness varying from 25 to 370nm). The magnetization distribution along the wedge direction shows thickness-dependent in-plane or out-of-plane orientation. The magnetization dynamics measurements show substantially faster magnetization recovery of films with SD compared to the homogeneously in-plane magnetized films. We expect that an additional anisotropy introduced in the local region by the SD allows for faster magnetization recovery.

MA 2.8 Mon 11:30 HSZ 101

Optically-induced spin dynamics in NiFe/Pd multilayers investigated using soft X-rays and THz radiation — •Sarah Heidtfeld[1], Roman Adam[1], Daniel E. Bürgler[1], Fangzhou Wang[1], Christian Greb[1], Derang Cao[1,2], and Claus M. Schneider[1] — [1]Research Centre Jülich, Peter Grünberg Institute, 52425 Jülich, Germany — [2]College of Physics, Qingdao University, 266071 Qingdao, China

In our earlier work we demonstrated that Pd in NiPd alloys exhibits a non-zero magnetic moment and shows transient demagnetization when excited with a train of femtosecond laser pulses [1]. Most importantly, we showed that ultrafast demagnetization depends on the Pd concentration and that the effect can be attributed to an increased spin-flip probability, which is proportional to the amount of Pd in the alloys. In our present work, we elucidate the role of super-diffusive spin currents in the process of optically inducing transient magnetization in metals close to the Stoner transition. We compare demagnetization times in NiPd alloys and NiFe/Pd multilayers by applying the time-resolved magneto-optical Kerr-effect (MOKE) using either visible or extreme ultraviolet (XUV) light. In addition, we analyze the generated spin currents flowing from the NiFe into the Pd layer by investigating THz radiation emitted from these ferromagnet (FM)/heavy metal (HM) double-layers due to the inverse spin Hall effect [2]. Our data provide further insight into the spin and charge dynamics in FM/HM multilayers. [1] S. Gang et al., Phys. Rev. B 97, 064412 (2018) [2] R. Adam et al., Appl. Phys. Lett. 114, 212405 (2019)

MA 2.9 Mon 11:45 HSZ 101

Spin Relaxation and Domain Wall Dynamics in Optically Excited Ferromagnetic [Co/Pt]3 Multilayers — •Fangzhou Wang[1], Roman Adam[1], Daniel E. Bürgler[1], Derang Cao[1,2], Umut Parlak[1], Sarah Heidtfeld[1], Christian Greb[1], and Claus M. Schneider[1] — [1]Peter Grünberg Institute, Research Centre Jülich, 52425 Jülich, Germany — [2]College of Physics, Qingdao University, 266071 Qingdao, China

Earlier, we demonstrated [1] that the area of the laser-modified magnetization decreases with the reduced repetition rate at room temperature, but remains constant at low temperature. The strong temperature dependence indicates that thermally activated domain wall motion (TA-DWM) plays an important role in the spin dynamics triggered by a fs laser pulse. In this work, we investigate in detail the relaxation processes following the femtosecond excitation in out-of-plane (OOP) magnetized [Co(0.4 nm)/Pt(0.7 nm)]3 multilayers by performing time-resolved MOKE measurements at varying magnetic field and laser power. We determine the time scales relevant for intrinsic and extrinsic magnetization relaxation processes. Based on the recorded magnetization dynamics transients and assuming TA-DWM as an additional relaxation mechanism, we estimate a time-dependent domain wall velocity for magnetization relaxation. Our analysis contributes to an understanding of spin relaxation processes in OOP magnetized multilayers on the picosecond time scale. [1]U. Parlak, R. Adam, D. E. Bürgler, S. Gang, and C. M. Schneider, Physical Review B 98, 214443 (2018).

MA 2.10 Mon 12:00 HSZ 101

Laser excitation induced ultrafast demagnetization and perpendicular magnetic anisotropy reduction in a $Co_{88}Tb_{12}$ thin film — •Marcel Hennes[1], Alaa el dine Merhe[1], Valentin Chardonnet[1], Xuan Liu[1], Clemens von Korff Schmising[3], Benoît Mahieu[4], Michel Hehn[5], Gregory Malinowski[5], Flavio Capotondi[6], Emanuele Pedersoli[6], Emmanuelle Jal[1], Jan Lüning[1,2], and Boris Vodungbo[1] — [1]Sorbonne Université - LCPMR, CNRS, Paris, France — [2]Synchrotron SOLEIL, Gif-sur-Yvette, France — [3]Max-Born-Institut, Berlin, Germany — [4]Laboratoire d'Optique Appliquée (LOA), Palaiseau, France — [5]Institut Jean Lamour (IJL), Nancy, France — [6]FERMI, Elettra-Sincrotrone, Trieste, Italy

We use time resolved resonant magnetic x-ray scattering experiments, performed at the Co M- and Tb O-edge, to study laser-induced demagnetization effects in a ferrimagnetic $Co_{88}Tb_{12}$ alloy with magnetic stripe domain structure. We evidence an ultrafast decrease of magnetization on sub-ps timescales in the Co as well as in the Tb sublattice and we provide a quantitative description of the demagnetization behavior. Combining the femtosecond temporal with nanometer spatial resolution of our pump-probe experiments, we show that on ultrashort timescales (<1 ps), no detectable change in domain size and domain wall size occurs. However, we evidence a broadening of the domain walls, setting in after approximately 4 ps, which we attribute to a decrease of the uniaxial anisotropy due to energy transfer to the lattice.

MA 2.11 Mon 12:15 HSZ 101

Ultrafast demagnetisation and recovery of chiral magnetic domain walls probed by dichroic X-ray magnetic scattering — •Nico Kerber[1], Dmitriy Ksenzov[2], Frank Freimuth[3], Flavio Capotondi[4], Boris Seng[1], Joel Cramer[1], Hartmut Zabel[1,5], Yuriy Mokrousov[1,3], Mathias Kläui[1], and Christian Gutt[2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099, Mainz, Germany — [2]Department Physik, Universität Siegen, Walter-Flex-Strasse 3, 57072, Siegen, Germany — [3]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [4]FERMI, Elettra-Sincrotrone Trieste, 34149, Basovizza, Trieste, Italy. — [5]Department of Physics, Ruhr-University Bochum, 44780 Bochum, Germany

We employ pulses from a XUV free-electron laser and investigate time-resolved the evolution of the chirality of domain walls in magnetic thin film samples by an IR pump - X-ray magnetic scattering (XRMS) probe experiment. Using samples with interfacial DMI and perpendicular magnetic anisotropy exhibiting labyrinth-like domain patterns we measure in the same experiment both the dichroic signal related to the chirality of the domain walls and the sum signal related to the average domain magnetisation. We observe an ultrafast decrease of both signals in the subpicosecond regime with similar time constants. However, we find a significantly faster recovery of the chiral signal on the sub-ns timescale.