MA 17: PhD Symposium: Ultrafast spin-lattice interactions (joint session MA/AKjDPG)

The immensely fascinating field of magnetism research has branched into many lively communities such as spintronics, ultrafast demagnetization, all-optical switching, multiferroic materials, domain walls, magnetic textures and spin caloritronics just to mention a few. All of these hot research topics share that the relevant interacting magnetic moments are arranged within the framework of an atomic lattice which itself interacts with the spin system. The lattice thus does not only influence the geometrical arrangement of the magnetic moments but also serves as a major bath for energy, entropy and most importantly also angular momentum transfer within the studied systems. The symposium aims at exchanging ideas and at fostering the discussion about the effects of the spin- lattice interaction among various areas of magnetism research. We highly welcome contributions that explain basic mechanisms and results of the spin-lattice interaction from all communities. Spin-lattice interaction can be considered as one of the prototypical coupling mechanisms within correlated materials and the condensed matter research in general. It is a very timely topic as many applications in future information technology such as spintronic-devices, heat assisted magnetic recording, implementations of the Spin-Seebeck, all-optical magnetization switching greatly benefit from an understanding of this basic effect.

Organized by: Alexander von Reppert (U. Potsdam), Vivek Unikandanunni, (U. Stockholm), Kumar Neeraj, (U. Stockholm), Neha Jha (U. Greifswald), Tobias Wimmer, (Walther Meißner Institute München), Kamil Bobowski, (FU Berlin)

Time: Tuesday 9:30–13:15 Location: H 1012

Introduction by the organizers

Invited Talk MA 17.1 Tue 9:35 H 1012
Understanding spin and lattice interactions at ultrafast timescales — •Peter M. Oppeneer — Uppsala University, S-75120 Uppsala, Sweden

The interactions between spin moments and the crystal lattice are, in thermal equilibrium, responsible for a variety of phenomena, such as magnetostriction, magnetoelasticity, spin-reorientation transitions etc. In recent years these fundamental interactions are being probed on ultrafast timescales, which has led to discoveries of unexpected phenomena, as e.g. ultrafast demagnetization, breaking of exchange interactions, spin currents and all-optical switching. A characteristic feature of these discoveries is that an ultrashort excitation initiates highly correlated, out-of-equilibrium interactions of electrons, spins, and ions.

In this overview I survey the current understanding of ultrafast processes involving spins, phonons and hot electrons, aiming to go beyond a purely phenomenological picture and achieve atomistic theory. I shall address electron-phonon spin dissipation in the context of ultrafast laser-induced demagnetization, multiscale modeling of breaking of the exchange interaction, and helicity-induced all-optical switching. A second emerging area concerns ultrafast nonequilibrium energy flow between hot electrons and phonons; recent results emphasize that this flow proceeds in a manner different from the commonly used two-temperature model, and that therefore new theoretical modeling is required to capture the nonequilibrium electron-spin-lattice interplay.

5 minutes break

MA 17.2 Tue 10:25 H 1012
Magnetic and Structural Dynamics in Antiferromagnetically Coupled Fe/Cr Superlattices — •Daniel Schick[1,2], Daniel Bürgler[3], Niko Pontius[2], Stefan Eisebitt[1], and Christian Schüssler-Langeheine[2] — [1]Max-Born-Institut für Nichlineare Optik und Kurzzeitspektroskopie, Max-Born-Str.2a, Berlin, 12489, Germany — [2]Institut für Instrumentierung der Forschung mit Synchrotronstrahlung, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Str. 15, Berlin, 12489, Germany — [3]Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Straße 52428 Jülich, Germany

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 the initially FM 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.

Invited Talk MA 17.3 Tue 10:40 H 1012
Spin-Lattice coupling in ultrafast magnetization dynamics — •Bert Koopmans — Department of Applied Physics, and Institute for Photonic Integration (IPI),Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

Novel schemes for controlling the ferromagnetic state at the femtosecond time scale by pulsed laser excitation have received great current interest recently. Driving systems into the strongly non-equilibrium regime, it has been shown possible not only to fully quench magnetic order, and but even to reverse the magnetic moment by a single pulse.

In this tutorial I will start with a historical review of the field of fs control of the magnetic state by pulsed laser excitation, introduce some of the time-resolved experimental techniques, and discuss the key questions that need to be answered. Next, I will explain the role of spin-lattice coupling in the process of ultrafast loss of magnetic order, including the local dissipation of angular momentum via Elliott-Yafet spin-flip scattering. Also the importance of laser-induced spin currents will be emphasized. Experimental results on a variety of systems and materials will be compared to predictions by the so-called microscopic three-temperature model. The importance of tuning both spin-flip scattering and spin currents for establishing all-optical switching (AOS) of the magnetization will be highlighted. Some of our most recent experiments on AOS by single fs pulses in synthetic ferromagnetic systems will be discussed.

15 minutes break

Invited Talk MA 17.4 Tue 11:25 H 1012
The role of spin-lattice interaction in optical control of magnetism — •Alexey Kimel — Radboud University, Nijmegen, The Netherlands

The action of electric field of light on electronic dipoles, being the largest perturbation in physics of light-matter interaction, conserves the spin of electron. This is why experiments showing the possibility of ultrafast and efficient control of spins with the help of femtosecond laser pulses are among the most heavily debated topics in magnetism. In my talk I will review the progress in understanding of ultrafast laser-induced magnetization dynamics. In particular, I would like to discuss the roles of the spin-lattice interaction in heat-driven, heat-assisted, and heat-free mechanisms of optical control of magnetic order.

MA 17.5 Tue 11:55 H 1012

Structural dynamics during laser-induced ultrafast demagnetization — •Emmanuelle Jal[1], Victor Lopez-Flores[2,3], Niko Pontius[4], Tom Ferte[5], Christine Boeglin[5], Boris Vodungbo[1], Jan Lüning[1,2], and Nicolas Jaouen[2] — [1]Sorbonne Universités, UPMC Univ. Paris 06, CNRS, LCPMR, 75005 Paris, FRANCE — [2]Synchrotron SOLEIL, Saint-Aubin, Boite Postale 48, 91192 Gif-sur-Yvette Cedex, FRANCE — [3]CSIC - University of Seville, Av. Americo Vespucio, 49, 41092 Seville, SPAIN — [4]HZB für Materialien und Energie GmbH, Albert-Einstein-Straße 15, 12489 Berlin, GERMANY — [5]Université de Strasbourg, CNRS, IPCMS, UMR 7504, F-67000 Strasbourg, FRANCE

I will present our investigation of the infrared laser-pulse-induced ultrafast demagnetization process in a thin Ni film, which characterizes simultaneously magnetization and structural dynamics [PRB 95 184422]. This is achieved by employing femtosecond timeresolved x-ray resonant magnetic reflectivity (tr-XRMR) as the probe technique. The experimental results reveal unambiguously that the subpicosecond magnetization quenching is accompanied by strong changes in nonmagnetic x-ray reflectivity. These changes vary with reflection angle, and changes up to 30% have been observed. By modeling the x-ray reflectivity of the investigated thin film, we can reproduce these changes by a variation of the apparent Ni layer thickness of up to 1%. Extending these simulations to larger incidence angles, we show that tr-XRMR can be employed to discriminate experimentally between currently discussed models describing the ultrafast demagnetization phenomenon.

5 minutes break

Invited Talk MA 17.6 Tue 12:15 H 1012

Driving magnetization precession by dynamical compressive and shear strain in a low-symmetry metallic film — •Alexandra M. Kalashnikova[1], Tetiana L. Linnik[2], Vladimir N. Kats[1], Jasmin Jaeger[3], Alexey S. Salasyuk[1], Dmitri R. Yakovlev[3], Andrew W. Rushforth[4], Andrey V. Akimov[4], Manfred Bayer[3], and Alexey V. Scherbakov[1,3] — [1]Ioffe Institute, St. Petersburg, Russia — [2]Department of Theoretical Physics, V. E. Lashkaryov Institute of Semiconductor Physics, Kyiv, Ukraine — [3]Experimentelle Physik 2, Technische Universität Dortmund, Dortmund, Germany — [4]School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom

We report on manipulating magnetocrystalline anisotropy via inverse magnetostriction on a picosecond time scale in a low-symmetry film of a magnetic metallic alloy galfenol (Fe,Ga). Two approaches are emploied, injection of a picosecond strain pulse into the film, and generation of a dynamical strain of a complex temporal profile in the film directly. In both cases the ultrafast change of magnetic anisotropy triggers magnetization precession owing to the mixed, compressive and shear, character of the dynamical strain emerging in the low-symmetry metallic film.

When optically-generated strain emerges abruptly in the film and modifies its magnetic anisotropy, it competes with heat-induced change of anisotropy. We show that optically-generated strain remains efficient for launching magnetization precession, when the heat-induced changes of anisotropy parameters do not trigger the precession any more.

Invited Talk MA 17.7 Tue 12:45 H 1012

Ultrafast Thermal Transport in Magnetic Heterostructures — •Richard Wilson[1], Michael Gomez[1], Jon Gorchon[2], Yang Yang[2], Charles-Henri Lambert[2], Sayeef Salahuddin[2], and Jeff Bokor[2] — [1]Materials Science and Engineering, University of California Riverside, Riverside, United States — [2]Electrical Engineering and Computer Sciences, University of California Berkeley, Berkeley, United States

Femtosecond heating of magnetic materials leads to a wide array of extraordinary thermally driven magnetic phenomena. Understanding and controlling ultrafast magnetic phenomena requires a detailed understanding of thermal transport in complex magnetic heterostructures. To achieve this understanding, we use a combination of TDTR and TRMOKE experiments to quantify thermal transport in magnetic heterostructures. We use ultrafast electrical or optical stimulus drive the heterostructures from thermal equilibrium. Then, we monitor tiny changes in optical and magneto-optic properties to monitor changes in temperature and magnetism. We interpret our data with spin and thermal transport models that quantify the diffusion of heat and spin across layers, as wells as energy flow between electronic-, vibrational-, and magnetic-degrees-of-freedom. Here, I discuss our recent efforts to understand ultrafast thermal phenomena in ferrimagnetic heterostructures. These experiments focus on both normal-metal/ferrimagnetic-metal heterostructures, e.g. Au/GdFeCo or Pt/GdFeCo, and normal-metal/ferrimagnetic-insulator heterostructures, e.g. Au/TmIG or Au/YIG.