Element-selective ultrafast magnetization dynamics

Dennis Rudolf,[1] Chan La-O-Vorakiat,[2] Emrah Turgut,[2] Patrik Grychtol,[1,4] Roman Adam,[1]
Stefan Mathias,[4] Justin M. Shaw,[3] Hans T. Nembach,[3] Thomas J. Silva,[3] Martin Aeschlimann,[4]
Claus M. Schneider,[1] Margaret M. Murnane[2] and Henry C. Kapteyn[2]

[1] Peter Grünberg Institute, PGI-6 , Research Center Jülich, Germany
[2] Department of Physics and JILA, University of Colorado, Boulder, Colorado, USA
[3] Electromagnetics Division, National Institute of Standards and Technology, Boulder, Colorado, USA
[4] University of Kaiserslautern and Research Center OPTIMAS, Kaiserslautern, Germany (February 2012)

Application Note

Introduction

In the age of nano-science there is a demand for light sources in extreme ultraviolet (30-250 eV photon energy) and soft x-ray (250-10000 eV photon energy) spectral range which can provide chemical selectivity and spatial resolution on nm scale. On the other hand pulsed light sources enable time-resolved experiments. Laser-based high harmonics sources meet both requirements: their spectrum covers the relevant spectral range and they belong to the pulsed sources with shortest pulses in atto- to femtosecond range. Thus, high harmonic generation is a unique tool for studying electron and spin dynamics.

In our experiments we investigate magnetization dynamics of thin magnetic films on fs-timescale [1-3]. The materials we are interested in are alloys as well as multilayers. An important part of our experimental setup is the detector which is an Andor x-ray CCD detector iKon-L DO936N-MW-BN. It fulfills the requirements of a high sensitivity, good resolution and possibility of spectroscopic measurements employing fast vertical binning.

Experimental setup

Our experimental setup is based on the pump-probe scheme with 1,5 eV pumping and high harmonics probing pulses. The time delay between the two pulses can be adjusted by changing the relative optical path length (figure 1) which allows a time resolution of few tenths of femtoseconds.

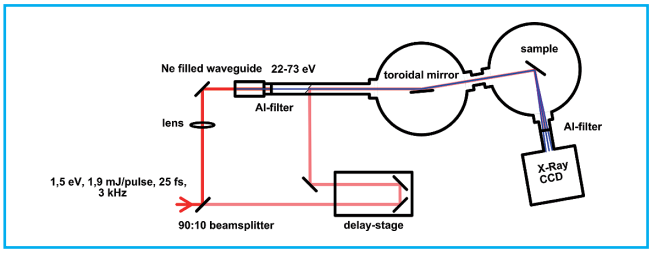

Figure 1 | Experimental setup: The 1,5 eV laser beam is devided into two beam paths which length can be changed in respect to each other. 90 % of the power is focused into a noble gas filled glass capillary where high harmonics are generated [4]. High harmonics are reflected from the sample under 45° and focused on the x-ray detector by a toroidal mirror. The other 10 % of the power is used to excite the sample.

High harmonics are generated in a Ne filled glass capillary under phase-matching conditions [4]. They are reflected from the sample and spectrally dispersed by a grating which is deposited on top of the sample. The beam is focused by a toroidal mirror on the x-ray detector. We are mainly working in the spectroscopy mode using fast vertical binning (figure 2).

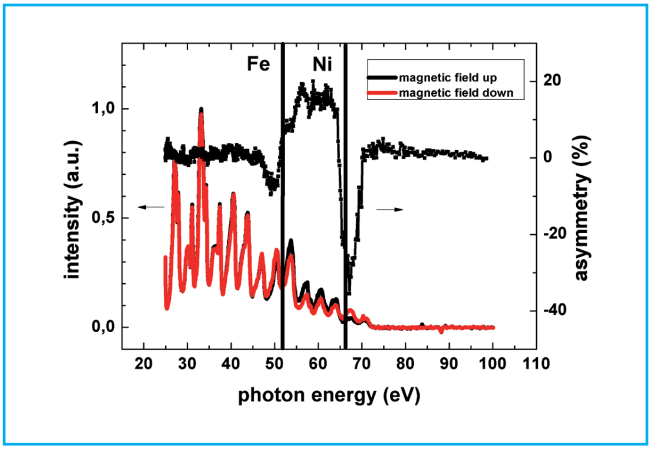

Figure 2 | High harmonics spectra for magnetic field up and down as well as T-MOKE asymmetry at the 3p absorption edges of Fe (52 eV) and Ni (66 eV).

In order to study the magnetization of different samples we are employing the transversal magneto-optical Kerr effect (T-MOKE). The reflectivity of p-polarized light which penetrates the surface near 45° angle of incidence depends on the orientation of the magnetization which is perpendicular to the plane of incidence in the T-MOKE geometry. The difference of the reflectivity for up- and down-magnetization normalized by the sum which is called magnetic asymmetry is directly proportional to the magnetization.

Results

We measured the T-MOKE asymmetry for a multilayer sample consisting of Fe and Ni layers (figure 2) and obtained layer selective signal at the Fe (52 eV) and Ni (66 eV) 3p absorption edges. In the next stage of the project the ultrafast magnetization dynamics will be studied. In the most optical pump-probe experiments

with magnetic materials, a pump-induced quenching of the magnetization within first 50 to 300 fs after excitation is observed [5]. The quenching even increases for higher pump fluence (figure 3).

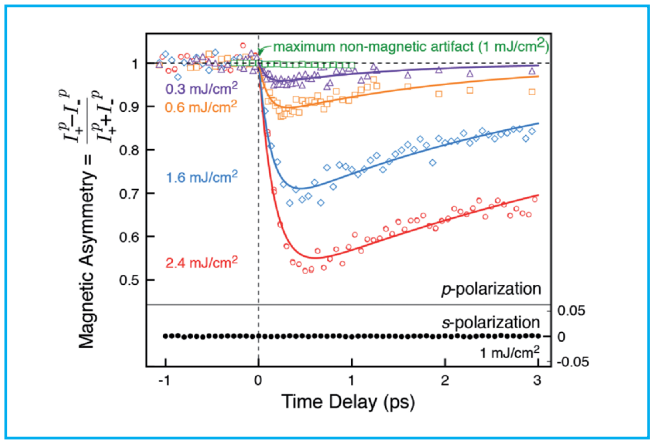

Figure 3 | Time-resolved magnetic asymmetry at the 3p absorption edge of Ni (66 eV) [2]. The pump beam fluence is increasing from the top to the bottom graph. For s-polarized light there is no magnetic asymmetry.

In a recent publication [2] we showed that the time-resolved T-MOKE asymmetry at 3p absorption edge of Ni is predominantly a magnetic signal which is not obvious due to creation of excited electrons on the fs- timescale. In this case the hot electron distribution almost doesn't affect the reflectivity which allows to extract the true magnetization dynamics.

Summary

In our resonant magneto-optical experiments employing high harmonics between 22 eV and 72 eV we can separate magnetic contributions from Fe and Ni layers. Time-resolved measurements of the magnetic asymmetry deliver insight into spin-dynamics on fs-timescale.

Application Note

References

[1] La-O-Vorakiat, C., Siemens, M., Murnane, M., Kapteyn, H., Mathias, S., Aeschlimann, M., Grychtol, P., Adam, R., Schneider, C., Shaw, J., Nembach, H. & Silva, T.; Ultrafast Soft X-Ray Magneto-Optics at the M-edge Using a Tabletop High-Harmonic Source Phys. Rev. Lett., 2009, Vol. 103, pp. 257402

[2] La-O-Vorakiat, C., Turgut, E., Teale, C.A., Kapteyn, H.C., Murnane, M.M., Mathias, S., Aeschlimann, M., Schneider, C.M., Shaw, J.M., Nembach, H.T. & Silva, T.J.; Ultrafast Demagnetization Measurements Using Extreme Ultraviolet Light: Comparison of Electronic and Magnetic Contributions, Phys. Rev. X, 2012, Vol. 2, pp. 011005

[3] Mathias, S., La-O-Vorakiat, C., Grychtol, P., Granitzka, P., Turgut, E., Shaw, J.M., Adam, R., Nembach, H.T., Siemens, M., Eich, S., Schneider, C., Silva, T., Aeschlimann, M., Murnane, M.M. & Kapteyn, H.; Probing the timescale of the exchange interaction in a ferromagnetic alloy submitted, 2012

[4] Kapteyn, H.C., Murnane, M.M. & Christov, I.P.; Extreme Nonlinear Optics: Coherent X Rays from Lasers Physics Today, 2005, Vol. 58(3), pp. 39-46

[5] Beaurepaire, E., Merle, J.-C., Daunois, A. & Bigot, J.-Y.; Ultrafast Spin Dynamics in Ferromagnetic Nickel Phys. Rev. Lett., 1996, Vol. 76, pp. 4250-4253

Contact

Dennis Rudolf
Peter Grünberg Institute (PGI-6 „Electronic Properties")
Research Center Jülich
52425 Jülich
Germany

Phone: +49 (2461) 61 2258
E-mail: d.rudolf@fz-juelich.de
Web: www.fz-juelich.de/pgi/pgi-6/EN/Home/home_node.html