Chapter 6

Solid-State Dynamics and Education

(http://www.eduphys.ethz.ch/)

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6.1 Ultrafast demagnetization processes observed with free electron laser radiation

Y. Acremann, A. Fognini, Th. Michlmayr, U. Ramsperger, and A. Vaterlaus

Conventional manipulation of the magnetization involves magnetic field pulses, created by current flow through wires. Today such current pulses are typically limited to timescales of tens of picoseconds and faster manipulation of the magnetization requires a different approach. One of the forefront areas in modern magnetism is the use of ultrashort infrared or optical photon pulses to manipulate the magnetization. Since optical photons trigger the sample through electronic excitations, the fundamental questions revolve around the processes and timescales associated with energy and angular momentum transfer between the three fundamental thermodynamic reservoirs of the sample: the electronic system, the spin system and the lattice. In the past, typical experiments involved optical pump-probe schemes where the laser pump excitation is probed at variable delay time by a second laser pulse.

By probing the results of optical excitations of magnetic samples via the magneto-optic Kerr-effect or x-ray circular magnetic dichroism, surprising phenomena have been observed. One phenomenon is the ultrafast loss of the spontaneous magnetization in Ni and Co after infrared pumping on the 10 - 100 femtosecond time scale. Another is ultrafast all-optical magnetic switching using circularly polarized photons. The pathway of the angular momentum from the spin system to the lattice as well as the role of the optical pump pulse is not understood.

Free electron laser radiation offers new possibilities to investigate dynamics in solids. We are preparing two experiments to investigate ultrafast magneto-dynamics in ferromagnetic solids. The first approach is based on spin polarized photoemission. The most direct way to measure the magnetization of a ferromagnet is by detecting elastically emitted photoelectrons and determining their spins. If the photon energy is sufficient the detected spin polarization of all the valence electrons only depends on the magnetization and is independent of the band structure. Therefore we will be able to directly measure the magnetization of the laser-excited sample. We successfully applied for beamtime at the free electron laser in Hamburg (FLASH) and are currently developing the experimental setup. This involves the design of the electron optic system, the vacuum chamber (including in-situ sample fabrication) as well as the integration into the data acquisition system at FLASH. The same experimental setup will be used in a laser based experiment at ETH.

The second experiment is targeted towards the nanostructure of the laser generated excitations. The coherence properties combined with the extreme peak intensity of FEL radiation offers the unique opportunity of single shot imaging with nanometer scale spatial resolution. We are involved in a collaboration with SLAC (Stanford) to image the magnetization distribution of a ferromagnet during and short after a pump laser pulse. Our contributions are in the aspects of laser to FEL synchronization, consulting in sample fabrication issues as well as software development. The first beamtime has been scheduled for July 2010.

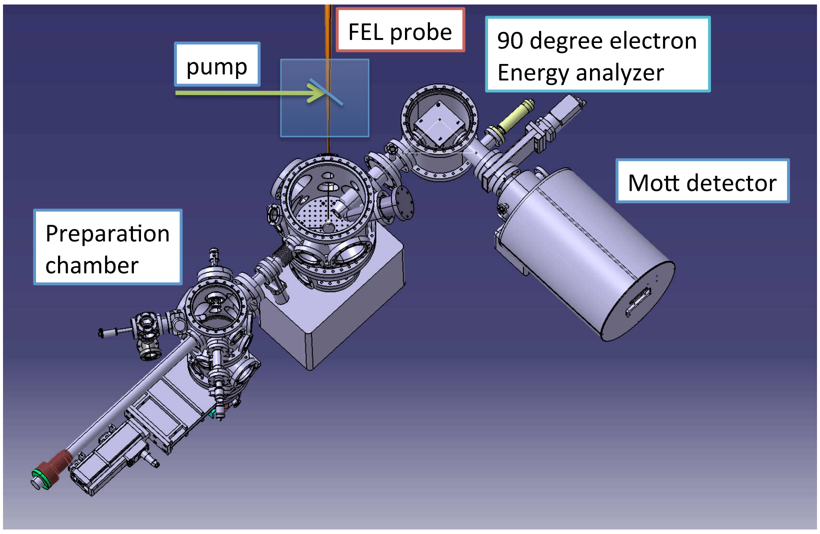

Figure 6.1: Experimental setup for the spin and time resolved photoemission experiment at the free electron laser in Hamburg (FLASH). The sample will be prepared in situ and transferred to the measurement chanber. There the 800 nm pump beam will excite the magnetization which will be probed by the FEL beam at 7 nm. Photoelectrons will be energy analyzed and their spin polarization detected by a Mott polarimeter.

6.2 Magnetic Properties of Gold-Capped and Uncapped Fe Layers on W-(110)

Th. Michlmayr, S. Miesch, A. Fognini, Y. Acremann, and A. Vaterlaus

Considering ultrathin layers of iron on tungsten W(110) as a sample for measurements at the free electron laser site FLASH in Hamburg requires elaborate studies of their magnetic properties beforehand. The FLASH experiments can be crucial for the understanding of ultrafast magnetodynamics processes such as the demagnetization of a magnetic structure within a few hundreds of femtoseconds time. The quest for answers regarding fundamental questions in solid state physic like this ultrafast spin angular momentum transfer to the lattice is assisted by preliminarily investigations in-house at the ETH Zurich. Thin film deposition - in the order of 5 to 25 monolayers (ML) - by molecular beam epitaxy (MBE) of iron on the clean and well ordered (110)-surface of a tungsten single crystal provides a reproducible sample with reliable qualities. Scanning electron microscopy with polarization analysis (SEMPA) and magnetooptical Kerr effect (MOKE) reveal that the coercive field -i.e. the smallest external magnetic field necessary to reverse the magnetization of the sample - for film thicknesses from 10 ML to 25 ML is almost constant and has a value between 15 Oe and 12 Oe. But it increases dramatically as the film thickness decreases. At a film thickness of 7 ML the necessary field is 72 Oe. A broad plateau in the coercive field dependency on the film thickness is very eligible. Exposed to air at atmospheric pressure the flimsy iron layer would oxidize within an instant and forfeit its ferromagnetic behavior. To prevent the iron film from oxidation the sample is covered with a thin layer of protective gold. This protection layer is also only a few monolayers thick. Beside this protecting property the gold layer also provokes a thickness dependent change in the coercive field of the underlaying iron film. For example a gold layer of 0.45 ML thickness leads to a change of the coercive field of +11 Oe but a gold layer of 0.73 ML changes the coercive field of the iron layer of only +4.1 Oe. And for gold layer thicknesses above 0.8 ML no changes are observed for the coercive field of the iron film. The gold layer does not provide a consummate protection against oxidation for all time. Namely the sample is still subjected to an aging process when exposed to air. An only 1.52 ML thick gold capping on 10 ML Fe on W(110) protects the sample in a way that still after 3 days on air the sample has a measurable coercive field but it increased to 125 Oe from former 42 Oe for the fresh sample. A 3.64 ML gold protection layer on 20 ML Fe on W(110) does a far better job because it has the effect that the coercive field only increased from 16 Oe to 19 Oe during exposing the sample to air for one day. Another characteristic of the sample one would like to know is the semi-static behavior of the coercive field. That is how the necessary magnetic switching field strength when applied as a single field pulse depends on the pulse length. The investigated pulse times would cover the scale from a few microseconds up to seconds.

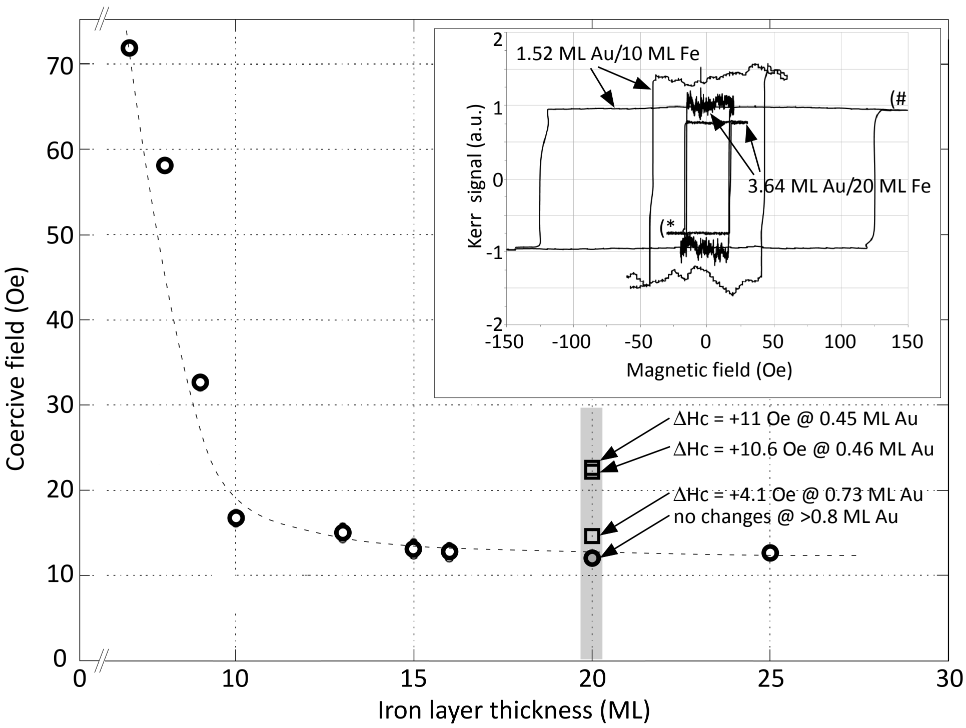

Figure 6.2: SEMPA and MOKE measurements of Fe ultrathin films evaporated on W(110). Open circles denote the coercive field for different Fe film thicknesses. For the Fe film thickness of 20 ML (gray bar) the effect on the coercive field by gold capping in the submonolayer scale is shown (open squares). The inset presents MOKE-hysteresis loops for gold capped samples on air with different exposing times that are three days (#) and one day (*).

6.3 Real World Physics

G. Schiltz, A. Lichtenberger, and A. Vaterlaus

The "filep" project "Real World Physics" was designed in order to illustrate selected concepts out of the physics 1 course for engineers in everyday life. Energy conservation and rotating reference systems were chosen as an example. In the framework of an E-Learning unit students described an everyday situation in which they observed the physical principle which was discussed in the physics course. They documented this situation with the help of pictures or short movies. In a report the observed effect was described and explained with the help of the theory, which was part of the physics curricula. The projects which were handed in ranged from the observation of a pendulum in a train running around a curve to a detailed consideration of energy conservation for a jojo. This second project turned out to be far from trivial, since the axis of rotation changes at the deepest point. In the end this group was able to simulate the measured movement of the jojo quiet accurately (Fig. 6.3). This work was counted as one experiment in the "Anfängerpraktikum".

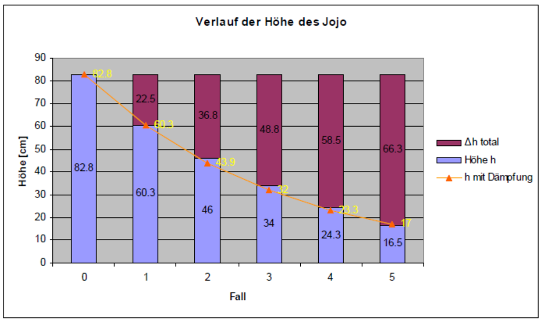

Figure 6.3: Measured and calculated maximal hights of the jojo for 5 initial swings. (source: F. Henschel and D. Heinzelmann, Physics 1, "Physik auf dem Pausenplatz")

6.4 E-Learning

G. Schiltz

6.4.1 Strategic activities

In 2009 the learning management system Moodle was introduced in 9 courses at the department. 5 introductory lectures (service and internal), 2 pedagogical lectures and 1 physics lecture with a total of 1Õ882 students were affected. Moodle was mainly used to support the course organization and to serve as a repository for course material. For some lectures, however, supplementary pedagogical scenarios, such as self-assessment tests, formative evaluations and collaborative tasks have been set up.

Figure 6.4: Moodle course

6.4.2 Filep projects

- "Real World Physics" (A. Vaterlaus) already launched in 2008 was successfully continued in 2009 (see above).
- "Brückenpodcast" (W. Wegscheider) was launched in 2009. This project aims at summarizing the physics introductory lectures by a weekly published podcast, including audio and visual material. Besides bridging the weekly lectures, students used the podcast episodes for preparing their exams. The podcast was first introduced in the physics lecture of G. Dissertori and has been positively evaluated within the project "Selbststudium an der ETH".
- "Erweiterte Physik-Vorlesungsexperimente" (B. Batlogg) could be reactivated in 2009. Jonathan Hanselmann, a teacher student from the department, was appointed at 50% to supervise the content production (videos and documentation).

Figure 6.5: Brückenpodcast on a mobile device

6.4.3 Promotion and Network

The e-learning activities pursued at the department have been communicated to a greater public and were abundantly discussed in the community at four different events (2 ETH-internal, 2 external).

6.5 Modern Physics for Schools

T. Michlmayr, T. Bähler, R. Mühlethaler, A. Vaterlaus

In an attempt to bring experiments which illustrate modern physical concepts to schools, the department of physics did purchase seven Scanning Tunneling Microscopes (STM) for the use in secondary level 2 (“Gymnasium”) classes. An introductory educational unit was prepared which gives an insight into the technique and the basic physical principles. A visit at a school normally compasses a introductory lesson with examples from research in solid state physics and two hours of practical work. The aim of the practical work is to image a surface (normally graphite) with atomic resolution. This does require a careful preparation of a tunneling tip and of the sample surface. Figure 6.6 shows a 1,5 nm by 1,5 nm STM image of a graphite surface imaged in a class room. In 2009 this educational program was used at six advanced trainings for practicing teachers, it was used in 11 classes at different schools, at the “Nacht der Forschung” and in two courses at the ETH in Zürich. In addition one STM was used during a “Maturaarbeit” and the whole program was presented at the general assembly of the ZHSF (Zürcher Hochschulinstitut für Schulpädagogik und Fachdidaktik).

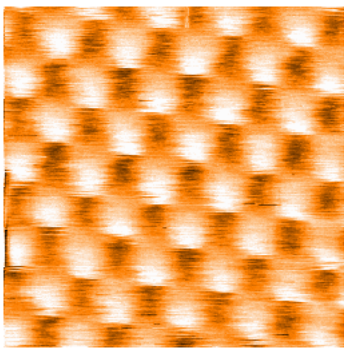

Figure 6.6: 1,5 nm by 1,5 nm STM image of a graphite surface imaged in a class room.