

An ultrafast x-ray detector system at an elliptically polarizing undulator beamline

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Abstract: An ultrafast x-ray detector system is under development at Lawrence Berkeley National Laboratory (LBNL) for application primarily to study of ultrafast magnetization dynamics. The system consists of a fs laser, an x-ray streak camera and an elliptically polarization undulator (EPU) beamline. Polarized x-rays from an EPU can be used to measure x-ray magnetic circular dichroism (XMCD) of a sample. XMCD has the unique ability to independently measure orbit and spin magnetization with sub-monolayer sensitivity and element specificity. The streak camera has simultaneously a sub-picosecond temporal resolution and a high spatial resolution. The combination of the streak camera and EPU allows us to study the transfer of angular momentum from spin to orbit to the lattice in the sample on an ultrafast time scale. We describe here the performance of the ultrafast detector, the laser and the x-ray synchronization system. The observation of the demagnetization process of different samples demonstrates the ability of the apparatus.

Keywords: ultrafast magnetism dynamics, XMCD, streak camera, photoconductive switch

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1 Introduction

The application of x-rays to study the microscopic structural details of molecules, liquids and solids has been a great success due to its short wavelength compared to laser photons. The use of x-rays to probe ultrafast phenomenon on a pico-second (ps) and femto-second (fs) scale level is currently a field undergoing intense development [1]. Two approaches can be taken to study ultrafast events using x-rays. In one of them, developing sources to have short pulses of x-rays such as free electron lasers and slicing sources provides the ultrafast temporal information. The other approach is to develop a detector fast enough to resolve the ultrafast details of the dynamical processes. This paper discusses the development of an ultrafast detector system used to obtain ultrafast temporal information from a relatively long pulse length x-ray source. The system consists of an x-ray streak camera, a fs laser and an elliptically polarizing undulator (EPU) beamline at the Advanced Light Source (ALS).

A streak camera is a detector that resolves the intensity of a photon signal as a function of time and space. Over the past decade, many different techniques have been developed in order to improve the temporal resolution of x-ray streak cameras [2-5]. The best resolution achieved so far in multishot accumulation mode is 280fs with ultraviolet (UV) illumination [6]. Polarized x-rays from the EPU beamline can be used to measure magnetic circular dichroism (XMCD) of a sample. XMCD has the unique ability to independently measure orbit and spin magnetization with sub-monolayer sensitivity and element specificity [7]. There is considerable interest in dynamical processes in magnetically ordered systems both from a scientific and a technological viewpoint. The combination of an x-ray streak camera with an

EPU beamline at a third generation x-ray source provides a powerful approach to the study of dynamics in magnetic materials.

2 Experimental setup

The ALS ultrafast x-ray detector system was located at the EPU beamline 4.0.2 and is being moved to the new EPU beamline 11.0.1. A schematic diagram of the experimental setup is shown in figure 1. The dashed-line box in the figure is the sample chamber which has typical pressure of $\sim 10^{-7}$ torr. Four photon beams go inside the chamber. An 800nm infrared (IR) laser beam with a duration of 50fs pulse duration is focused on the sample and initiates the dynamics. An x-ray pulse from the synchrotron with about 50ps passes through the sample and is detected on the streak camera photocathode. Two UV pulses with an accurately known separation in time hit the streak camera photocathode and are used to calibrate the detector.

Our streak camera consists of a photocathode, a pair of meander-type deflection plates, a photoconductive switch, magnetic lens and a position sensitive detector [8]. Photons interact with a transmission photocathode leading to emission of secondary electrons. These electrons are then accelerated in a high gradient field, 10kV/mm for a dc voltage and up to 25kV/mm for pulsed cathode voltage, established between the photocathode and mesh or slit anode. The accelerated electrons are then deflected by a time varying electric field, and a magnetic lens focuses the electrons to a position sensitive detector. The fast deflection is provided by a pair of meander strip lines. The meander lines are driven by voltage ramps with fast rise time through a photoconductive switch triggered by a high power laser. The photoconductive switch

is made of high temperature grown GaAs, and metallic contacts are evaporated over an implanted region doped with sulphur. Typically 70 μ J of 800nm laser light at 5 KHz is used to trigger the switch and achieve saturation. Operating in the saturation regime reduces the jitter due to laser pulse power fluctuation.

Four delay stages are used in the setup for synchronization purpose. Delay stage 1 is used to synchronize the laser pulse with the x-ray pulse to find the best x-ray streak by changing the trigger time of the photoconductive switch. Delay stage 2 is used to vary the time delay of the IR laser pump pulses on the sample. Delay stage 3 is used to synchronize the UV pulses with the sweep voltage pulse. Finally, delay stage 4 is used to produce a temporal separation between two UV pulses and to calibrate the streak camera detector temporal scale.

3 Laser and x-ray synchronization

In the time-resolved pump-probe scheme, synchronization of the excitation pulse to the probe pulse is very important. In our case, since the pump (laser) and the probe (x-ray) are derived from independent sources and have different repetition rates, a sophisticated technique is desired. The synchronization system is diagramed in figure 2. It starts with the synchronization of the laser oscillator to the storage ring (shown as dashed-line box in figure 2). The basic idea is to vary the oscillator cavity length to frequency-lock and phase-lock its output to the synchrotron storage ring radio-frequency (rf) signal. The oscillator operates at 62.5MHz, 1/8th of the repetition rate of the storage ring. The signal from a fast photodiode in the oscillator is passed through a 500MHz bandpass filter and then sent to the mixer with the storage ring RF

signal. The output mixer signal is the difference in phase of the two signals. The stabilization box converts the difference signal into two dc output voltages, which drive the pico-motor controlled and piezo-controlled end mirrors of the oscillator cavity. The rough phase-lock is achieved by the pico-motor controlled mirror and the accurate phase-lock control is achieved by a piezo-controlled mirror over a range of $10\mu\text{m}$. The phase-lock error signal is monitored by an analog oscilloscope.

The synchronization of the laser amplifier output laser pulse (5kHz) to the storage ring electron bunches is achieved using a delay generator. The round-trip frequency of the storage ring is 1.52MHz (1/656ns). This frequency is counted down to 5kHz using a delay generator and then is used to drive the Pocket cells of the amplifier and the pump Q-switch. One of the challenges of the experiment is the loss of the x-ray flux inherent in the experiment due to the mismatch of the repetition rate of the storage ring and the repetition rate of the laser. The unwanted x-ray pulses are suppressed by a gated MCP detector. A higher repetition laser and less laser energy fluctuation per shot could improve the signal-to-noise and reduce the measurement time.

4 Results and discussions

Figure 3 illustrates the type of data that can be acquired using the apparatus. The top panel in fig.3 shows the measured x-ray and UV streaked images. Both the UV and x-ray pulse arrive at the same time at the photocathode of the streak camera. The x-ray pulse from the ALS storage ring is typically of the order of 50ps. The two UV pulses are used not only as time

calibration marks but also as time fiducial marks for data analysis. The overall temporal resolution of the detector system is about 1ps as tested using UV light illumination and is about 2ps using x-ray illumination. The resolution with x-ray illumination has been confirmed by measuring the sub-picosecond demagnetization of a Ni sample, which is instantaneous at this time resolution [9]. The photo-emitted secondary electrons for x-ray illumination have a wider energy spread than those emitted by UV light. This causes a bigger temporal dispersion in the streak camera for x-ray and causes a worsening of resolution compared to UV illumination.

One of the major applications of our ultrafast x-ray detector system is to study ultrafast magnetization dynamics. Studying magnetization dynamics at a sub-psec time scale is not only important in developing next generation ultra-high density magnetic data storage device, but also important for a fundamental understanding of the spin-orbit interaction and magnetic anisotropy [9-10]. An EPU beamline like BL4.0.2 and BL11.0.1 at the ALS provides the capability to easily change the polarization of the x-ray and enabling XMCD measurements [11]. By measuring the difference of a streaked x-ray image for left circularly polarized light and right circularly polarized light, a time resolved XMCD spectra can be obtained. Starting from the integration of the XMCD spectra, the spin momentum and orbit momentum of sample can then be determined using sum rules [7]. The bottom panel of fig.3 shows time-resolved XMCD spectra and spin momentum dynamics of Gd element in Fe/Gd multilayer sample. This allows us to study the transfer of angular momentum among spin, orbit and lattice in the sample on an ultrafast scale. A more detailed description of the experimental results can be found in reference [12].

In summary, an ultrafast x-ray detector system consisting of a streak camera, a fs laser and an EPU beamline has been developed at the ALS for the study of ultrafast magnetization dynamics. Element-specific spin and orbit momentum dynamics experiment for different samples such as Fe/Gd and Fe/Ni/Pt have been carried out.

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References

- [1] T. Pfeifer, C. Spielmann and G. Gerber, *Rep.Prog.Phys.*, 69(2006)443
- [2] C.Belzile and J.C.Kieffer, C.Y.Cote, T.Oksenhendle and D.Kaplan, *Rev. Sci. Instrum.*, 73(2002)1617
- [3] P.A.Jaanimagi, *Proceedings of SPIE*, Vol.5194, no.1, 2004, P171
- [4] J.Y.Liu and J.Wang, B.Shan and Z.H. Chang, *Appl.Phys.Lett.*,82(2003) 3553
- [5] M.M.Murnane, H.C.Kapteyn, and R.W.Falcone, *Appl.Phys.Lett.*, 56(1990)1948
- [6] Mahendra Man Shakya and Zenghu Chang, *Appl.Phys.Lett.*, 82(2005)041103

- [7] C.T.Chen, Y.U.Idzerda, H.J.Lin, N.V.Smith, G.Meigs, E.Chaban, G.H.Ho, E.Pellegrin, and F.Sette, *Phys.Rev.Lett.*, 75(1995)152
- [8] J. Feng, W. Wan, J. Qiang, A. Bartelt, A. Comin, A. Scholl, J. Byrd, R. Falcone, G. Huang, A. MacPhee, J. Nasiatka, K. Opachich, D. Weinstein, T. Young, H.A. Padmore, *Proc. SPIE* 5920, 592009 (2005)
- [9] E.Beaurepair, J.-C. Merle, A.Daunois, and J.-Y.Bigot, *Phys. Rev. Lett.*, 76 (1996)4250
- [10] S.-B. Choe, Y.Acremann, A.Scholl, A.Bauer, A.Doran, J.Stohr, H.A.Padmore, *Science*,304(2004)420
- [11] A.T.Young, E.Arenholz, J.Feng, H.A.Padmore, T.Henderson, S.Marks, E.Hoyer, R.Schlueter, J.B.Kortright, V.Martynov, C.Steier, G.Portmann, *Nucl.Instrum.Methods*, A467(2001)549
- [12] A. F. Bartelt, A. Comin, J. Feng, J. R. Nasiatka, T. Eimüller, B. Ludescher, G. Schütz, H. A. Padmore, A. T. Young and A. Scholl, *App. Phys. Lett.*, 90(2007)162503

Figure captions

Fig.1 Experimental setup of an ultrafast x-ray detector system

Fig.2 Schematic diagram of the laser and x-ray synchronization for an ultrafast x-ray detector system

Fig.3 Top: Measured x-ray and UV pulse streaked images; Bottom: Time-resolved XMCD spectra and spin momentum of Gd element in Fe/Gd multilayer sample

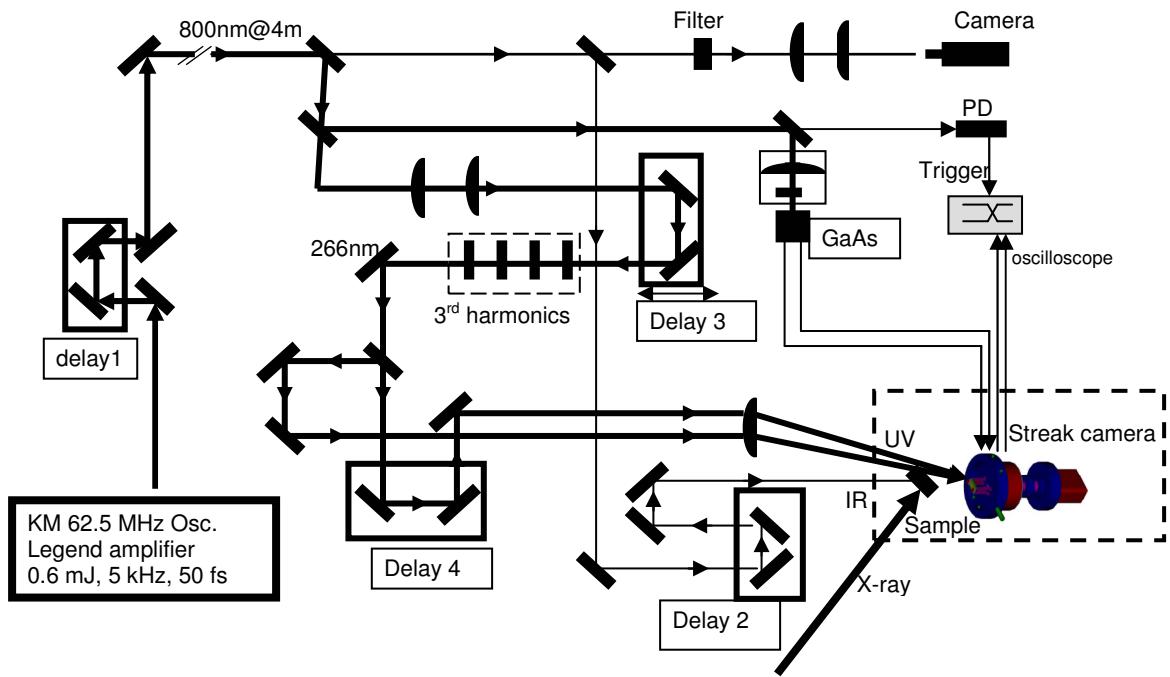


Fig.1

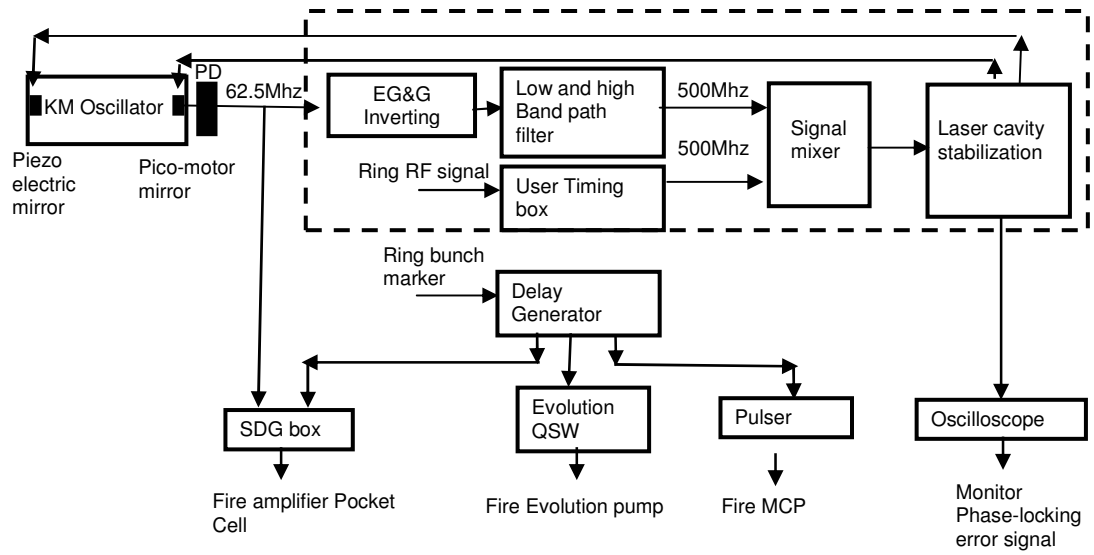


Fig.2

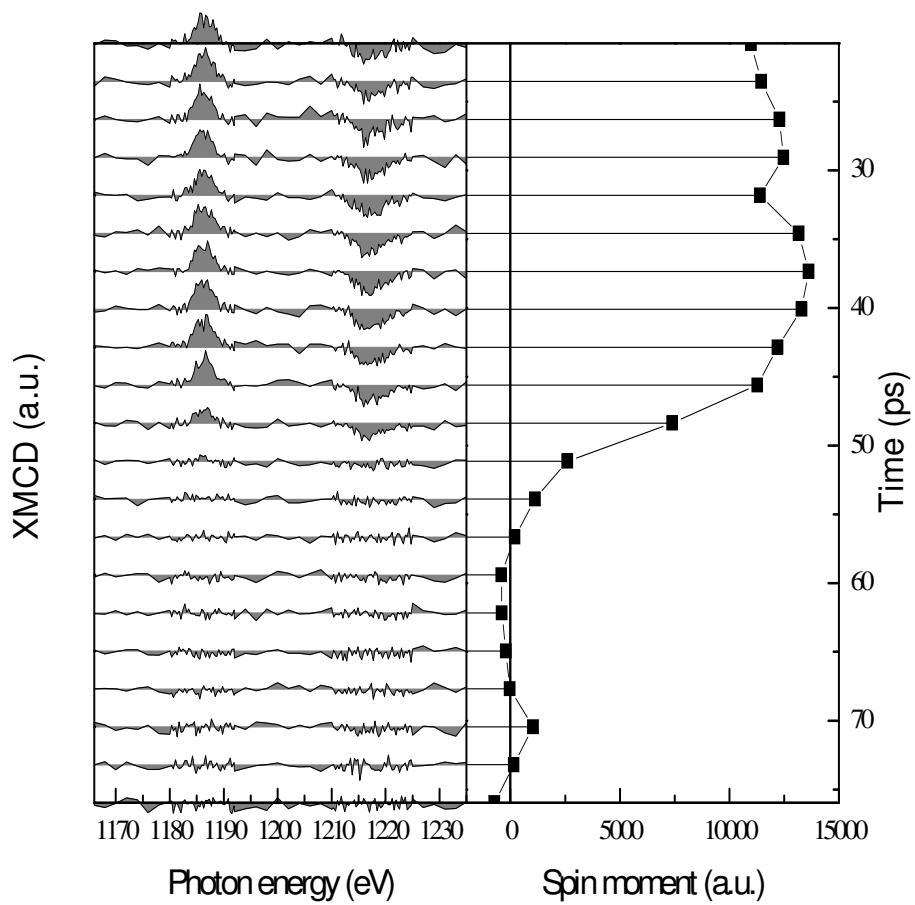
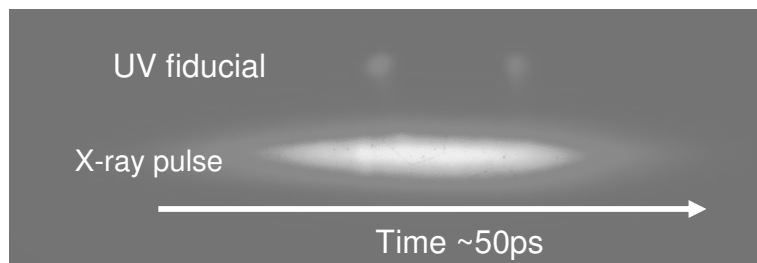


Fig.3