Magnetic Detection by Longitudinal and Transverse MOKE at Artemis

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Introduction

The understanding of ultrafast spin dynamics in ferromagnetic materials is attracting wide scientific interest owing to its potential applications for spintronics and high-density data storage [1]. Using laser sources is a very exciting approach as it can provide ultrashort pulses, which offer the possibility to explore the dynamics on ultrashort time scales. Photo-demagnetisation, where a femtosecond laser pulse induces demagnetisation in a sample on ultrafast timescales, is an effect that requires such an ultrashort source [2].

Artemis is a user facility based on an ultrafast TiSaph laser source dedicated to electron spectroscopy, imaging, and magnetic studies. Among the different approaches for magnetism detection, the Magneto Optical Kerr Effect (MOKE) is a very interesting technique for bulk characterisation of a sample and an element specific study of magnetic properties.

In effect, a MOKE measurement is about analysing the polarisation of a photon beam reflected from a magnetic sample. The reflected beam will have a change in intensity, in ellipticity, or in a rotation of the polarisation (the so called Kerr rotation) which depends upon the strength and direction of the magnetic field relative to the incident beam [3]. A pump - probe scheme can use these Kerr effects to look at the femtosecond changes in magnetisation induced by an ultrafast laser pulse.

Currently at Artemis, MOKE measurements known as Transverse MOKE (T-MOKE) can be made using the ToF chamber. In T-MOKE, the direction of magnetisation is perpendicular to the plane of polarisation, and the intensity of light reflected from the sample changes depending upon the magnetisation [4]. T-MOKE requires XUV photons, as the effect is due to a resonant excitation of shallow core electrons. This excitation is material and photon energy dependant [5], and so requires an ultrafast and tuneable XUV source.

The requirement for high energy photons and a complex detector makes T-MOKE difficult to use in an experiment. An alternative scheme for detecting changes in magnetisation uses light of optical wavelengths reflected off a sample magnetised parallel to the plane of polarisation. This Longitudinal MOKE (L-MOKE) is often performed with visible light and does not change dramatically with wavelength.

A detector using L-MOKE at optical wavelengths is relatively simple to set-up and is versatile, and can be used on a tabletop TiSaph source without the requirement for high energy photons. Comparatively to T-MOKE, which gives an element specific picture of the magnetic state, L-MOKE is a macroscopic measurement that yields information about the total demagnetisation of the sample. For example, when studying the time resolved dynamics using TR-ARPES it is important to have

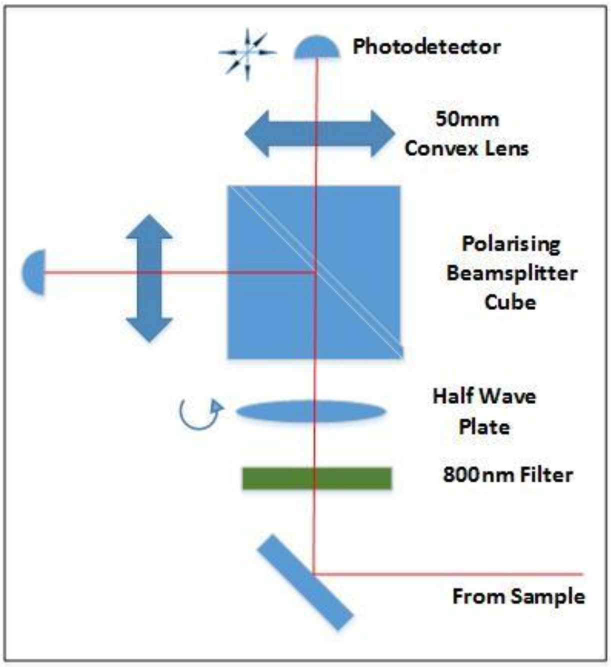

Figure 1: Diagram of L-MOKE optical setup installed after the experimental chamber. Both horizontal and vertical component of the laser field are measured simultaneously to extract the polarisation direction of the beam.

an estimate of the total magnetisation of the system, which is not usually accessible with ARPES.

Setup

The L-MOKE detector designed and built at Artemis uses 400nm light. This wavelength was selected as it was easily generated by frequency doubling the fundamental beam in a BBO crystal and could easily be separated from an 800nm pump beam using a filter. The detector can operate at different wavelengths by using appropriate coatings on the optics.

As shown in Figure 1, a band pass filter (green rectangle) is used to transmit 400nm, and to block any 800nm light. A half wave plate is mounted before the polariser to balance the signal into both photodiodes in order to detect very small polarisation variations. The most precise changes in the difference signal channel of the photodetector were visible when the initial signal was minimised.

The beam is then split by a polarising beamsplitter cube and the horizontal and vertical polarisation components are each focused into an optical fibre using a 50mm focal length lens. These fibres transport the beam to a Thorlabs PDB430A balanced photodetector which has a double diode and a fast difference signal output. A spectrum GMBH M2i.4961-Exp card running at 62.5MHz samples the different output voltages from the PDB430A photodetector.

The shot-to-shot amplitude of the photon pulses are measured along with the high frequency differential output. A LabVIEW program processes each pulse at 1kHz to calculate the integral of each pulse after the subtraction of a linear background to eliminate any low frequency noise. The pulses are then normalised to allow for variations in laser power.

Experiment

To test the viability of the L-MOKE detector, which was expected to have a very small signal, it was directly compared to T-MOKE measurements obtained with the ToF detector on a thin film iron sample. In this experiment, the sample was magnetised using three sets of coils. A large pulsed current was used to flip the magnetisation direction.

For T-MOKE XUV light was reflected into the ToF detector. Fine-tuning of the sample position and orientation was required to maximise the amount of XUV light reflected into the detector, and so maximise the size of the signal.

For L-MOKE 400nm light was used instead of the XUV photons, and the sample was rotated to direct the reflected beam out of a chamber window. The coils used to magnetise the sample were also changed so the direction of magnetisation was parallel to the plane of polarisation. The detector was then placed in the beam and aligned to maximise the input signal into the photodiodes without saturating the electronics. The difference signal was minimised through rotation of the waveplate.

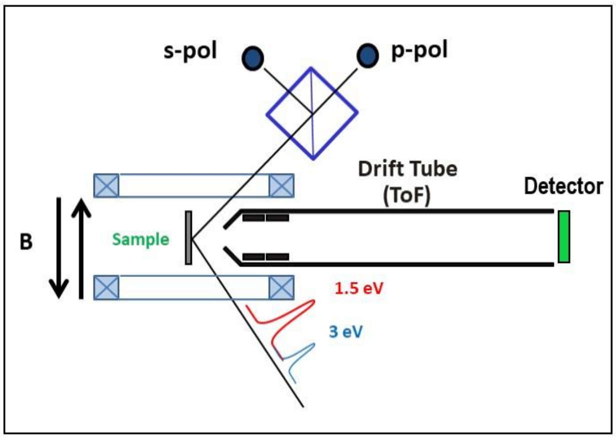

Figure 2: Experimental chamber geometry configured for measuring L-MOKE. T-MOKE measurements use XUV photons, and detect those reflected down the ToF tube.

Results

Scans were run for varying lengths of time, and an example of these results is given in Figures 3(b, d). The magnetisation direction was reversed periodically throughout these scans in order to eliminate any experimental asymmetry.

The T-MOKE signal was obtained by integrating over the photon peak at t = 0 in the ToF detector. Figure 3(b) shows a 20 minute scan with alternating magnetisations, measured using 52 eV electrons. An asymmetry of 8% can be seen at this energy. Figure 3(c) shows the strong energy dependence of the T-MOKE signal; by moving a single harmonic to either side the asymmetry is reduced to 3%.

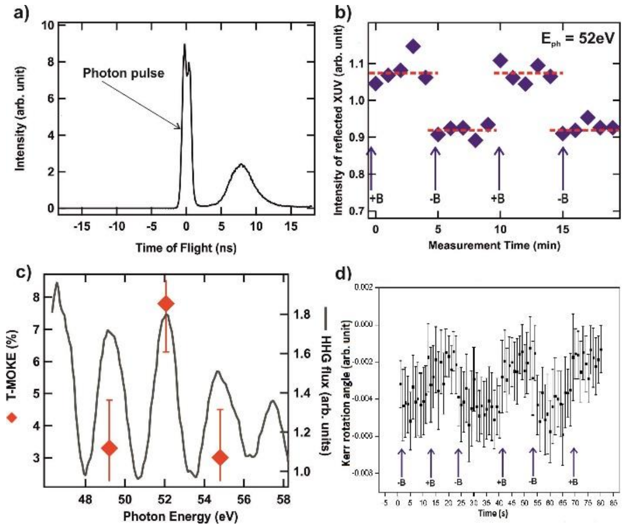

Figure 3: MOKE results. a) The XUV photon peak in the time of flight detector. The second peak is caused by electrons ionized by the XUV pulse. b) Asymmetry in the reflected intensity for positive and negative magnetisations using T-MOKE. c) Size of T-MOKE signal for different HHG harmonics. d) Kerr rotation for positive and negative magnetisations measured with L-MOKE.

Figure 3(d) shows the comparative results for L-MOKE, with an acquisition time of one second (1000 laser pulses) per data point. The difference between positive and negative magnetisations is small, only a few milli-radians. In this example the noise level is largely limited by the short acquisition time. A good signal to noise ratio is achieved when data is averaged over one minute.

Further development is planned to improve the L-MOKE noise level for the measurement of smaller signals in pump-probe experiments. An electronic method of pulse integration, as opposed to the software integration method, should greatly improve the signal sampled and reduce the noise level. Absolute calibration of the detector is under preparation in order to extract quantitative values.

Future experiments for time resolved demagnetisation studies will combine ToF-Spin and L-MOKE measurements to relate the changes in band structure to the demagnetisation.

Conclusion

On a thin iron film, a few milli-radian rotation of the polarisation was detected in a L-MOKE configuration and an asymmetry of 8% in T-MOKE measurements at 52 eV photon energy. Despite the smaller signal in L-MOKE, this technique remains a good diagnostic to complement the magnetic studies at Artemis. It is a convenient optical set-up that can be installed on any experimental chamber. There is ongoing development to optimize the electronics in order to improve the measurement noise level.

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