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D11.2

Pilot experiment carried out in collaboration with a FEL user facility

Due date

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☒ P - Prototype, Demonstrator

☐ DEC - Websites, Patent filing, Press & media actions, Videos, etc

☐ O - Other

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☒ P - Public

☐ PP - Restricted to other programme participants & EC: (Specify)

☐ RE - Restricted to a group (Specify)

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INTRODUCTION

The recent development of Free Electron Lasers (FELs) opens the way for pump-probe experiments in the extreme ultra violet (EUV) and X-Rays regime. In particular, seeded FELs are the best candidates for experiments in which high wavelength purity and power stability is required, such as coherent non-linear experiments. In this case, the fine control of photon energy and polarization is the key for accessing the dynamics of core level electrons in solid state systems, thanks to the species selectivity given by the variable photon energy of FEL pulses.

In the framework of Four Wave Mixing (FWM) techniques, the transient grating (TG) approach is one of the most powerful experiments for dynamic studies of acoustic, magnetic and thermal degrees of freedom. Each contribution can be easily disentangled by changing the polarization of pump and probe beams, making this technique a unique tool for systems in which many different contributions give rise to the recorded signal.

An important aspect of TG is the possibility to access to various dynamical regime by changing the pulse sources. The induced transient grating period inside the sample, due to the interference between two pump pulses, depends from the angles between them and from their wavelength. Ranging from visible to EUV pulse energies, various spatial regime can be covered, accessing to very different dynamics. The comprehension of this dynamics requires a comparison between these excited regimes.

The main purpose of this deliverable is creating a connection with FEL community, in order to prepare a pilot experiment, showing how table-top based FWM technique, in particular TG, can be useful to a full comprehension of magnetic systems, based on the comparison between the regime covered by the FEL based TG.

The experimental solutions related to the optical setup and the first results, currently under analysis, are reported.

Experimental progress

Sample

The sample used for the experiments are amorphous ferrimagnetic thin-films of Ta(3)/Pt(3)/a-$Gd_{22-x}Tb_xCo_{78}$(10)/Pt(3) (thicknesses are in nm) heterostructures, deposited via sputtering onto MgO substrate.

TG setup

The laser source is a Yb:KGW fiber based laser (Pharos, Light Conversion), available at NFFA-SPRINT laboratory in Trieste, Italy. The laser source delivers pulses at 1028 nm, 300 fs and ≈ 5 nm bandwidth; the adjustable repetition rate is set to 100 kHz. The pump beams are obtained from the fundamental of the laser; the probe beam (514 nm, 250 fs) is obtained by second harmonic generation of the fundamental in a 2 mm thick BBO crystal. Energy is set to 30 nJ for each pump and 200 pJ for probe. The spot size is about 40 μm in diameter for pump and somewhat smaller for probe, giving a fluence on the sample 5 mJ/cm 2 for pump and 0.18 mJ/cm 2 for probe. The delay between pump and probe is controlled by routing the probe towards a corner cube retroflector mounted on a 500 mm delay line (maximum time delay ≈ 3.3 ns). The pump and the probe beams, red and green respectively in Figure 1, lie in a plane normal to sample surface. The polarization of both pump and probe pulses can be individually adjusted with half waveplates (not reported in Figure 1), in order to explore different dynamics. The various configuration are indicated as "XXXX", where the first two "X" describe the polarization for pumps (V for s polarization, H for p polarization), the latter indicate the polarization of probe and scattered beams, respectively.

The beams are overlapped on a dichroic mirror and focused onto a phase mask. The diffracted orders are focused on the sample by a pair of achromatic doublets (D1, D2) in confocal configuration. The first diffraction orders of the pump (m = ±1 in Figure 1) interfere on the sample, generating the TG. Briefly, the excitation mechanism involves absorption of the pump photons and subsequent thermal expansion, which generates a pattern of standing SAWs, given the stripy interference pattern.

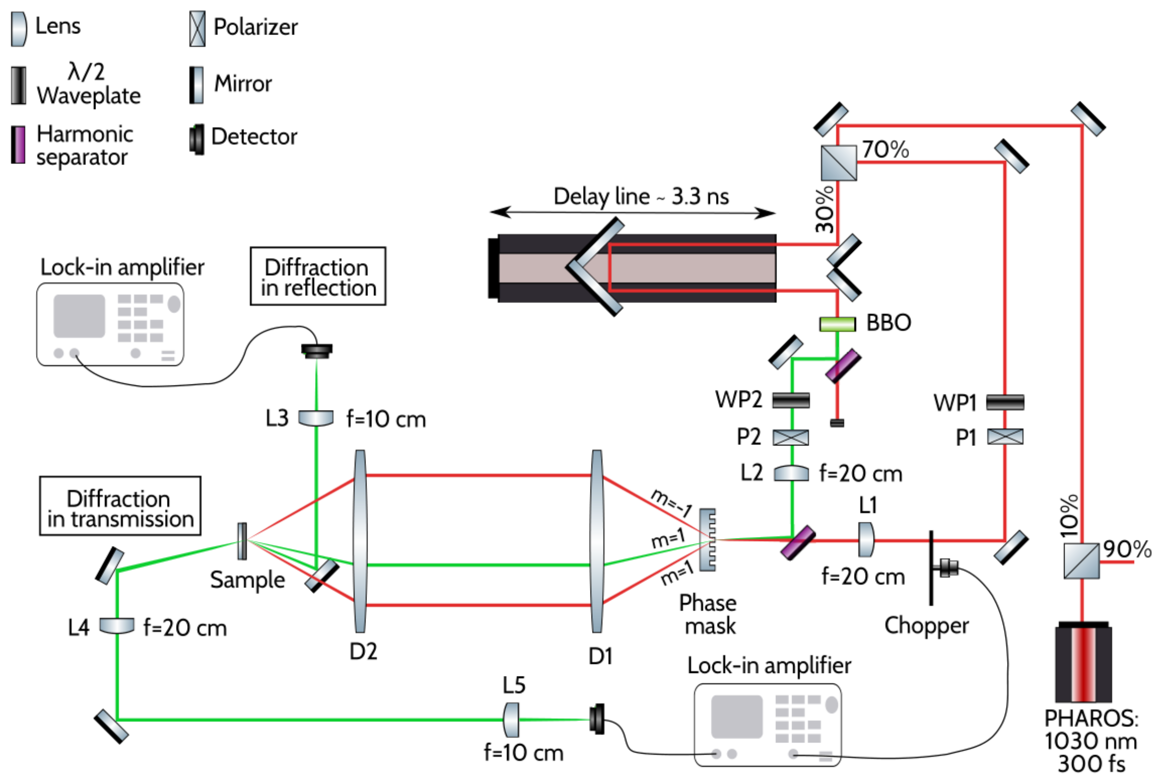

Figure 1: Pulsed TG setup scheme in reflection and transmission geometry. The laser source is the PHAROS, which generates 300 fs pulses at 1030 nm. Just 10% of its output is actually used. A second beamsplitter splits the beam again and the 30% of it passes through the delay line and across the BBO crystal. The harmonic separator provides a pulsed probe with a wavelength of 515 nm. Attenuation of the two beam is possible thanks to the waveplates (WP1, WP2) and the polarizers (P1, P2) placed on each branch. Both pump and probe are then focalized with plano-convex lenses (L1, L2) on the phase mask and diffracted. Two identical doublets (D1, D2) in confocal configuration recombine them. One of the first orders of the 515 nm is used as the probe. The pump consists in the two first diffraction orders of the 1030 nm. All other diffraction orders are stopped by a beam blocker.

Out-of-plane magnet

The magnetic analysis of the samples requires the use of an out-of-plane magnetic fields. Due to the setup geometry, a special magnet has been realized. It is based on four N52 NdFeB magnets, displaced as reported in Figure 2a. The magnets have a dimension of 3x1.2x1.2 cm, with a separation of 1.8 cm. The chosen values in separation guarantee a magnetic field of 220 mT in the centre, and enough space for overlapping the beams on the sample. The field map is reported in Figure 2b. The sample is inserted in the centre of the magnets, with the surface oriented orthogonally to the field line (out-of-plane configuration). The beams come from the right, and the induced grating is parallel to the sample surface.

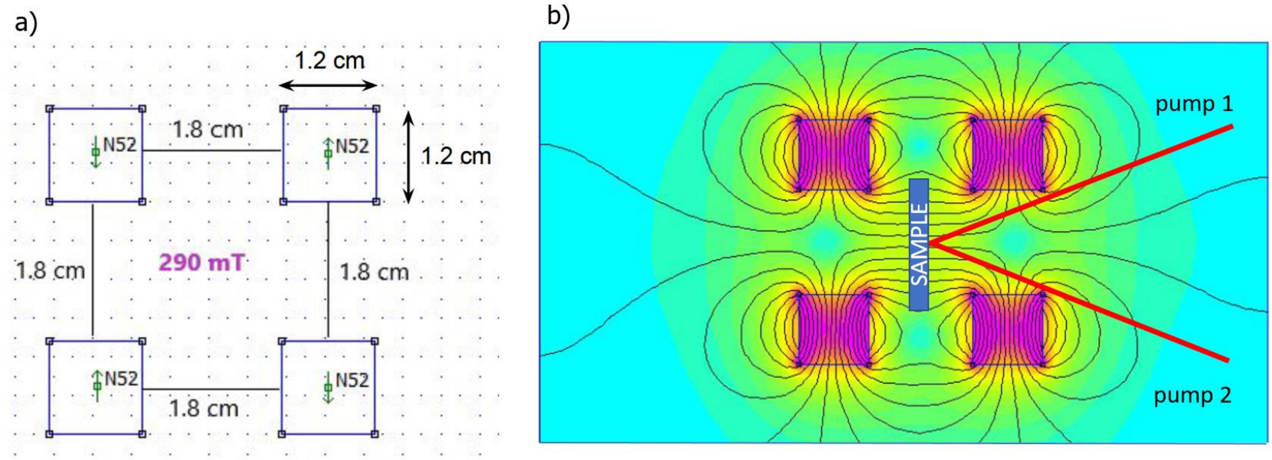

Figure 2: a) magnet orientation and displacement; b) field map and sample orientation.

Results and discussion

The experiment has been realized in collaboration with the group TIMER from the FERMI FEL in Trieste. TIMER is a beamline dedicated to TG in the EUV regime, so the perfect candidate for the pilot experiments. Also the University of Ca Foscari (Venice) has been involved for their experience in magnetism.

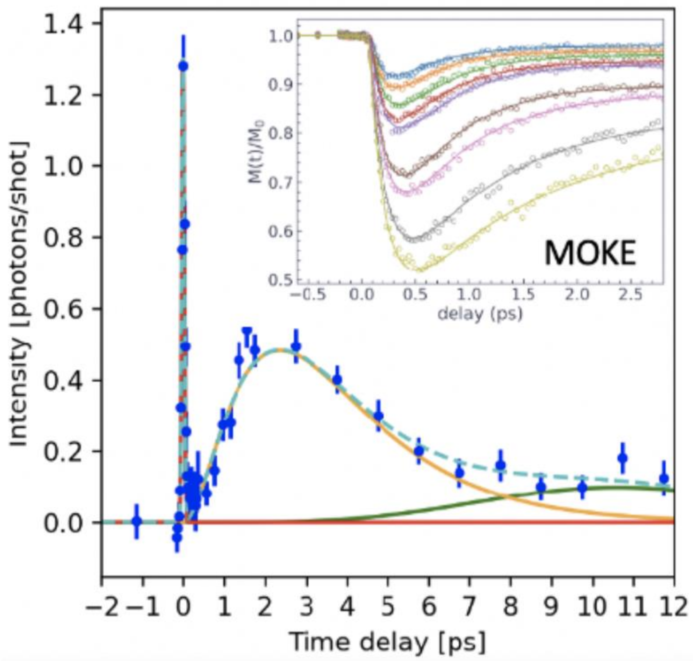

Figure 3: Time evolution of transient intensity grating showing the dominance of magnetic contribution (orange) to the total signal as compared to the reference electronic and elastic signals combined (red). Inset plot shows Magneto-Optical Kerr Effect (MOKE) measurements with demagnetization as a function of time for fluence between 0.5 mJ/cm 2 (blue) and 18 mJ/cm 2 (yellow).

The main purpose of the experiment is to compare the signals obtained at SPRINT lab with the ones performed at TIMER. The sample was already studied at FERMI in various polarization configuration (VVVV, VVVH, VHVH). The measured signal for VVVH, in comparison with MOKE experiments is reported in figure 3.

The rise of the signal, thanks to the crossed polarization of probe and scattered beams, can be attributed to a magnetic dynamics stimulated by an intensity grating (due to VV polarization of pump pulses). What is strange is the different time duration of the magnetic signal with respect to the one measured with MOKE experiment, which could be related to the same effect.

In order to better understand the nature of this dynamics, we have measured the same sample in the same polarization configuration, in order to compare the differences. From an experimental point of view, the most important difference between the two setups is the pitch of the induced grating (44nm for FEL, 4 microns for our TG setup). Considering that a lot of dynamics have a dependence from the pitch, making the same experiment with different pitch can allow to disentangle the various contribution (acoustic, magnetic thermal) from the signals, and make a correct comparison.

The raw data obtained in the VVVH are reported in fig.4.

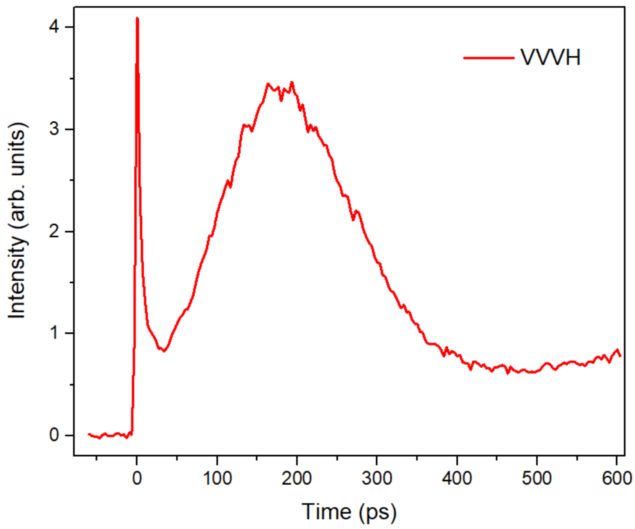

Figure 4: Time evolution of transient intensity grating from a table-top TG.

It is clear how the rise and the decay of the signal, associated to the magnetic degree of freedom, are really different in the two experiments, indicating a strong dependence from the grating spacing, and so from the dimension of the induced excitation. In order to better understand the complete dynamics of the system, all the possible polarization configurations have been measured, opening the way to a complete comparison between FEL-based and table top-based TG experiments.

The obtained results allow to better plan the other possible experiments on FEL sources, paying the way for a long collaboration with the FEL community.