LASERLAB-EUROPE

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Report on study of high repetition-rate HHG or soft x-ray laser

Lead Beneficiary:

FVB-MBI, CNRS-CELIA

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Deliverable Nature	
R = Report, P = Prototype, D = Demonstrator, O = Other	R
Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

A. Abstract / Executive Summary

Two novel high repetition rate XUV/X-ray sources have been developed. A high repetition rate soft X-ray laser delivering coherent EUV radiation @ 18.9 nm has been commissioned, which will be used in user initiated imaging experiments. Furthermore, an optical system capable of collecting XUV radiation from a tight-focusing HHG setup has been developed, which will be used in pump-probe experiments.

B. Deliverable Report

1 Introduction

High repetition rate/high average power extreme ultraviolet (EUV) sources such as high harmonic generation (HHG) and plasma based X-ray lasers (XRL) are basic tools for imaging and spectroscopy in the lab. These sources are complementary to large scale facilities such as free electron lasers.

2 Objectives

LASERLAB-EUROPE participants will develop high average power coherent X-ray lasers and HHG sources operating in the EUV, which will then deliver photons to users.

3 Work performed / results / description

<u>X-ray laser</u>
MBI has developed a high repetition rate x-ray laser (XRL) operating in grazing incidence pump (GRIP) geometry. The two pump pulses are provided by a 100 Hz thin disk laser (TDL) chirped pulse amplification (CPA) system which has been described elsewhere (Tümmler, Jung et al. 2009). Shortly, the TDL system consists of a front-end with an Yb:KGW oscillator, stretcher and Yb:KGW regenerative amplifier followed by two regenerative amplifiers and one multipass amplifier. The output is divided into two pulses, and each of them is amplified in a regenerative amplifier to a level of 100 and 200 mJ respectively. Whereas the pulse from the first regenerative amplifier is compressed to a pulse with about 200 ps duration, the output of the second regenerative amplifier is given to a thin disk multipass amplifier which amplifies the pulse to an energy up to 400 mJ. It is compressed in a grating compressor to about 2 ps pulse duration. The long pulse is focused by a cylindrical and a spherical lens onto the target at normal incidence giving a line focus of about 30 μm in width. The generated plasma column will then be heated by a short pulse focused according to the GRIP method by a spherical mirror into the preformed plasma. Using a Mo target narrowband ($\lambda/\Delta\lambda > 10^4$) EUV radiation is emitted at 18.9 nm. A gain-saturated operation of the Mo XRL was achieved with only 300 mJ pump energy (Stiel, Jung et al. 2014). Using a newly developed pump scheme (Banici, Cojocaru et al. 2012) with one long and two short pump pulses the output energy of the XRL can be increased above the 100 nJ level (Laserlab user access experiment together with D. Ursescu INFLPR, Magurele).

<u>HHG sources</u>
Thanks to numerous improvements done on high repetition rate intense lasers (see the JRA Eurolite section), high repetition rate lasers can now be used to initiate HHG. High repetition rate systems are however always associated to HHG in very specific conditions because of a low energy per pulse and a high average power. It is therefore necessary to perform HHG in the tight focusing regime (using short focal length and highly diverging beams) and to develop systems that can both collect highly diverging harmonic beams and support a high average power without damaging the XUV optics. CELIA has developed such a system to collect XUV harmonics with an acceptance angle of 35 mrad. By using specifically designed grazing incidence XUV beamsplitters with Nb_20_5 coating, they were able to reflect the XUV light with a high reflectivity (~30 %) while transmitting most of the fundamental light, thereby avoiding damages of the subsequent XUV optics. The high power imaging spectrometer that was developed used two reflections on a flat Nb_2O_5 beamsplitter and two reflections on gold

surfaces (one toroidal mirror imaging the source onto the detector or experiment and one grating for harmonic dispersion) leading to an estimated transmission efficiency of a few % in the 30 to 100 eV range. This versatile equipment, initially tested with harmonics emitted from a home-made 50 W Yb Laser at 100 kHz (see eurolite JRA, 50 W Yb Laser and HHG), could be adapted to several laser sources. By using a few-cycle post-compressed 2µm source for which the source divergence is a strong problem (collaboration Imperial College, London), CELIA could perform HHG and observe that 50 eV photons could indeed be efficiently detected. The XUV spectrometer developed for high repetition rate HHG can therefore be used with low pulse energy, withstand an average power as high as 50 W and recollect harmonics emitted in a wide solid angle.

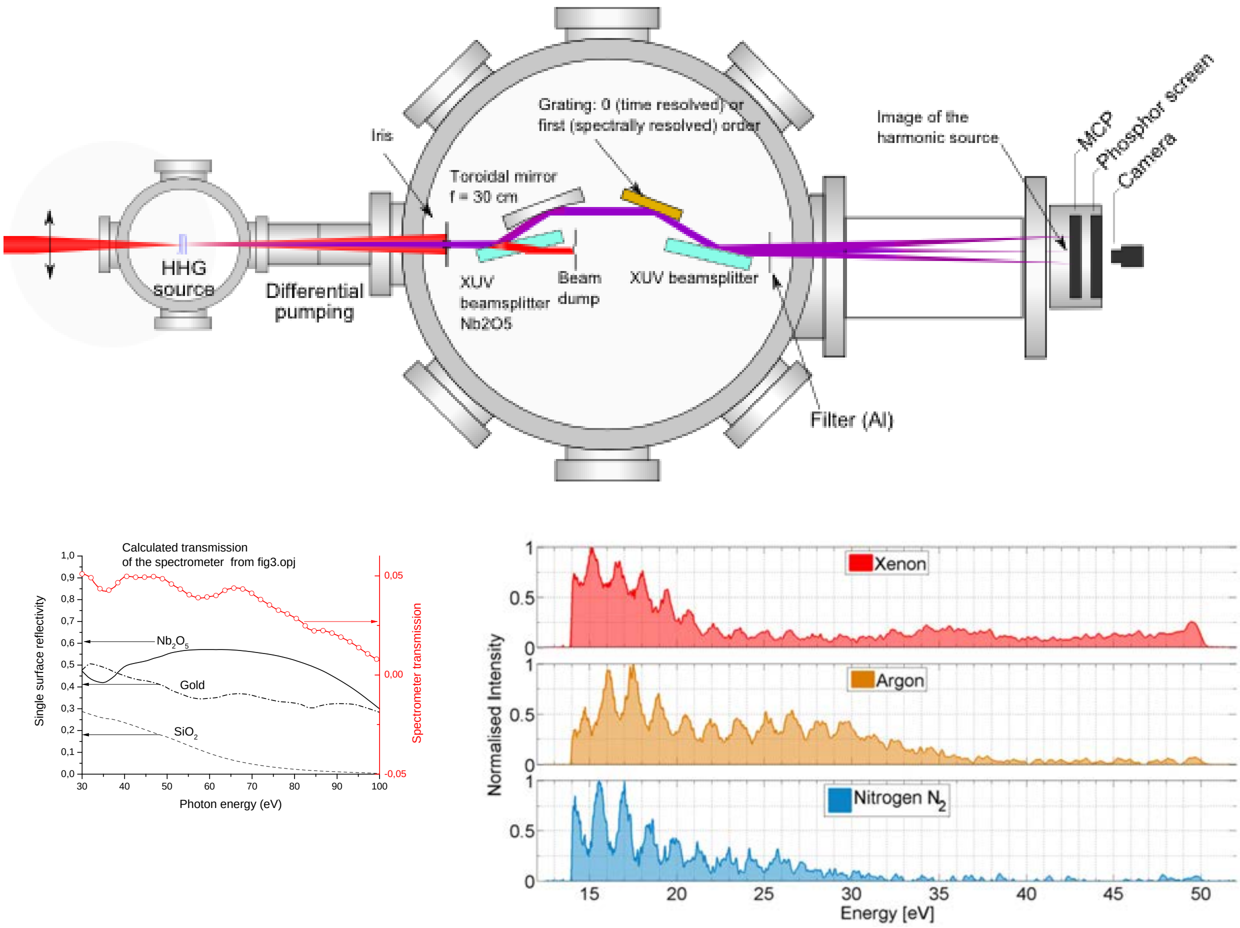

Figure 1: calculated transmission of the large angle XUV spectrometer and spectra measured after HHG with tightly focused 2µm fundamental beam (1 kHz rep rate).

In order to be able to perform HHG with a more traditional focusing geometry and to generate sufficient XUV fluxes to permit XUV-IR pump-probe experiments, MBI is developing two high repetition rate (100 KHz) OPCPA systems, operating resp. at signal wavelengths of 800 nm (515 nm pump) and 1.5 µm (1030 nm pump). The few-cycle, CEP-stable 800 nm OPCPA has been developed to an output power of 5W. The addition of a further amplification stage is expected to increase this output power further by a factor 3-4 in the near term, at which stage pump-probe experiments with an available COLTRIMS setup will become possible. It is foreseen that in the later stages of Laserlab IV this infrastructure can be offered to users. The 1.5 µm OPCPA has been developed to a signal power of 9 W. The addition of a further parametric stage is expected to increase this output power by a factor 5 in the near term.

4 Conclusions

Both the XRL at MBI and the HHG source at CELIA have been commissioned as a user station. One XRL user beamline was already put into operation and will be used for Fourier transform holography experiments in LASERLAB IV. The compact CELIA setup is also compatible with pump-probe experiments and CELIA is currently testing this possibility (collaboration F. Lépine et al., ILM Villeurbanne) as it will be very important for future experiments.

5 References

J. Tümmler, H. Stiel et al., "High-repetition-rate chirped-pulse-amplification thin-disk laser system with joule-level pulse energy," *Opt. Lett.* **34** 1378-1380 (2009).

6 Publications

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