Development and characterization of a reliable 13.5 nm EUV OAM carrying photon beamline

The Extreme UltraViolet (EUV) photon energy range (10-100 nm) is crucial for many applications spanning from fundamental physics (attophysics, femto-magnetism) to applied domains such as lithography and nanometer scale microscopy. However, there are no natural source of light in this energy domain on Earth because photons are strongly absorbed by matter, requiring thus vacuum environment. People instead have to rely on expensive large-scale sources such as synchrotrons, free electron lasers or plasmas from large lasers. High order laser harmonic generation (HHG), discovered 30 years ago and recognized by the Nobel Prize in Physics in 2023, is a promising alternative as a laboratory scale EUV source[1]. Based on a strongly nonlinear interaction between an ultrashort intense laser and an atomic gas, it results in the emission of EUV pulses with femto to attosecond durations, very high coherence properties and relatively large fluxes. Despite intensive research that have provided a clear understanding of the phenomenon, it has up to know been mostly limited to laboratories. Breaching the gap towards applied industry requires increasing the reliability of the beamlines, subjects to large fluctuations due to the strong nonlinearity of the mechanism, and developing tools to measure and control their properties.

CEA/LIDYL is a research laboratory dedicated to the study of laser-matter ultrafast interaction, with a major expertise in the study, development and use of EUV beamlines from HHG in gases, crystals and plasmas. Imagine Optic is a SME that designs, develops, manufactures and commercializes wavefront metrology and adaptive optics from the IR to the X-ray domains. CEA/LIDYL and Imagine Optic have recently joined their expertise in a join laboratory to develop a stable EUV beamline dedicated to metrology and EUV sensors[2]. The NanoLite laboratory, hosted at CEA/LIDYL, is based on a high repetition rate compact HHG beamline providing EUV photons around 40eV. Several EUV wavefront sensors have been successfully calibrated over the past few years. However, new needs have emerged recently, which require a significant upgrade and further developments of the beamline.

Objectives.

Objective 1: Upgrade of the EUV metrology beamline

Metrology and calibration of EUV detectors require a very stable photon source in terms of flux, pointing and spatial profile. Up to now, a close to perfect spherical wavefront is ensured by focusing the EUV radiation in a small filtering pinhole, at the expense of the flux. The first objective of the PhD candidate will be to implement a new geometry for the generation medium of the EUV source, switching from a gas cell to coupling the laser pulses inside a gas-filled capillary. This will provide a fixed point source with a high numerical aperture, while increasing the photon flux thanks to improved phase matching.

In parallel, there is a strong incentive to decrease the wavelength range of the beamline. Indeed, providing photons around 12-14 nm would enable the calibration of soft X-ray wavefront sensors without the need for expensive and hard to get synchrotron beamtimes. Moreover, 13.5 nm is one of the key wavelengths for lithography. Gaining access to this specific range would open up the possibilities for the join laboratory. Increasing the photon energy range for the beamline can be achieved by changing the nonlinear medium, at the expense however of a drastic loss of photon flux.

Instead, the student will implement a laser postcompression stage, which consists in reducing the pulse duration of the driving laser, thus increasing the laser intensity while reducing detrimental ionization effects. CEA/LIDYL laser group has a strong expertise in laser postcompression and will provide technical and numerical supports to the student[3].

Objective 2: Upgrading and testing the wavefront sensor for OAM characterization

Light can carry two angular momenta. The first one, the spin angular momentum, corresponds to light polarization. The second one, the orbital angular momentum (OAM), is experiencing a strong rise of interest in the EUV community with applications in chirality, spintronics, opto-electronics or orbitronics to name a few. This additional degree of freedom opens up new control routes with potential huge impacts to increase the speed and lowering the energy consumption of future electronics components. However, OAM is difficult to impart to EUV pulses, and most solutions result in non-perfect OAM modes[4,5]. We propose to implement OAM control on the HHG beamline, which has never been done for our guided geometry. Indeed, guided propagation could result in the coupling to higher propagation modes, potentially causing previously unknown effects on the OAM transfer to the HHG. The beamline will then be used to transfer the technology developed by Imagine Optic to characterize OAM from the visible range to the EUV.

Objective 3: Development of large numerical aperture measurement by wavefront switching

Past experiences in the join laboratory have shown that measurements are often limiting by the detector numerical aperture which is indeed higher than the source divergence. Imagine Optic has started to develop a solution based on the stitching of multiple overlapping acquisitions spanning the whole sensor aperture. The student will work with their software engineers to consolidate their algorithm needed to calibrate high NA wavefront sensors. A first demonstration on NanoLite beamline will consist in characterizing the quality of the focusing of the EUV beam by an off axis parabola. This will help to improve the alignment of this optic and enhance the beam's spatial properties[6].

Consistency with the Light in Paris call

CEA/LIDYL and Imagine Optic started the join laboratory NanoLite in 2020, with funding from the ANR LabCom program. While the initial project will end at the end of 2024, there is a shared desired to continue the development together. Both partners are currently in talks to renew the join laboratory agreement. CEA/LIDYL will maintain and upgrade the EUV beamline, while Imagine Optic has dedicated an engineer to the development of their EUV activities. This PhD project will be an additional step in the perpetuation of the join effort.

At CEA/LIDYL, the PhD work will be co-supervised at 75% by Dr. Willem Boutu (research director, HDR, ED 572 Ondes et Matière) and at 25% by Dr. David Gauthier (permanent researcher, ED 572 Ondes et Matière), while Guillaume Dovillaire will ensure supervision from the company side. The three of them share a long history of collaborative work, starting in 2010. NanoLite beamline is the result of the PhD work of a former student already following the same supervision scheme.

References:

1. Ferray et al., J. Phys. B 21, L31 (1988)
2. https://iramis.cea.fr/en/lidyl/dico/extreme-ultraviolet-metrology-the-nanolite-light-line/
3. Kaur et al., J. of Phys.: Photonics 6, 015001 (2024)
4. Pandey et al., ACS Photonics 9, 944 (2022)
5. Gauthier et al., Nature Communications 8, 14971 (2017)
6. Raimondi et al., J. NIMA 710, 131 (2013)