LASERLAB-EUROPE

The Integrated Initiative of European Laser Research Infrastructures IV

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Deliverable Type	
R = Report DEM = Demonstrator, pilot, prototype, plan designs DEC = Websites, patents filing, press & media actions, videos, etc. OTHER = Software, technical diagram, etc.	R
Dissemination Level	
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1 Introduction and objectives

Advanced laser sources and associated technologies enable a wide range of novel applications that have high industrial and social impact, such as bio- and nano-photonics, (bio)material analyses, (bio)medical diagnosis and treatment, communication and data processing. The objectives of this work package are to foster LASERLAB-EUROPE's relationships with industry and to implement supporting measures to promote the use of laser research institutes by industrial researchers, and to enhance technology and knowledge transfer to comprehensively exploit the innovation potential of participating research infrastructures.

Under Task 3 "Innovation Forum", exchange between stakeholders from academia and industry is facilitated through workshops where interaction of laser facilities with industry and medical centres is explored, and, when appropriate, co-located with LASERLAB-EUROPE topical events. The workshops address issues such as technology bottlenecks, opportunities for industry to engage in research at an early stage, opportunities for industry to use facilities to develop and test concepts, and discuss protection of intellectual property in the context of academic openness.

2 Work performed / results / description

We are currently witnessing spectacular advances in laboratory and facility-based X-ray sources that are enabling a wide range of investigations with unprecedented time resolution and element specificity. A LASERLAB-EUROPE foresight workshop "*Visions on Future Laser-based X-ray Science and Technology*" was held between the 19th and 20th November, 2018, at ICFO – The Institute of Photonic Sciences in Castelldefels (Barcelona), Spain – aiming to assess state-of-the-art technologies and discuss visions for future opportunities in laser-based X-ray science through development of technologies and novel methods for scientific investigation. Part of this workshop, a session on industrial perspectives, was dedicated to providing a platform to enable industry to learn about new research opportunities and to help facilitate engagement in ongoing research and examine technology bottlenecks, while disseminating recent developments within their companies and secure contacts for future collaboration.

The two-day workshop was attended by more than 80 participants, comprising leading scientists from Laserlab-Europe laboratories, other European and international institutions and representatives from industry. The event created a unique opportunity for interaction between academia and industry in the field of laser-based X-ray science and technology.

The workshop was divided into three main sessions, covering state-of-the-art scientific applications, sources, and the requirements of industry. At the end of each day, a round table session provided for lively discussions about opportunities for future collaboration and synergies between the communities as well as options for industrial involvement.

2.1 Applications and diagnostics

Two prospective industrial applications were discussed: **semiconductor manufacturing** and **medical imaging and radiotherapy**.

Semiconductor industry relies on soft X-ray sources for photolithography and XUV microscopy for metrology and inspection of printed devices and masks. Development of compact soft X-ray microscopy tools has the potential to provide accurate metrology and inspection systems, which will enable further reduction in the size of semiconductor devices. The present challenge in the semiconductor industry is to develop a compact high numerical aperture (NA) point scanning microscope with a resolution approaching 6 nm and an average power of 1 mW.

Summary of industry talks

"Soft X-ray Metrology for Semiconductor Manufacturing", Seth Brussaard, ASML, The Netherlands

ASML is the world's largest manufacturer of lithography systems and all leading chipmakers use ASML's technology to print their most complex structures. Accurate metrology during production has become an essential step in the manufacturing process. Increasing complexity and reduction of feature size has moved these devices beyond the limits of visible light metrology. (Soft) X-rays will extend the metrology capabilities to meet the demands of the semiconductor industry.

"High-resolution X-ray detection with pnCCD detectors", Robert Hartmann, PNSensor GmbH, Munich, Germany

X-ray techniques can deliver meaningful answers to fundamental questions in fields ranging from physics and chemistry, to material and life sciences. pnCCD detectors have high X-ray quantum efficiencies, are fast, have low-noise readout and are suitable for a wide range of applications including spectroscopic imaging, which makes them well suited for use as components of instruments at modern X-ray facilities.

The laser plasma wakefield accelerator is a promising X-ray source for radiotherapy. The proposed combination of nanoparticles with X-ray activation could be used for tumour treatment. The X-ray therapeutic energy window for this application lies between 60 keV and 1 MeV. Short X-ray pulse duration (<10 ps) is important to ensure that the radiation dose is deposited within the lifetime of aggressive radicals. X-ray phase-contrast imaging, on the other hand, does not require short pulse duration. A LWFA betatron imaging source has been proposed for phase-contrast coherent tomography measurements. Ideally 10^{10} photons per pulse in a 10 mrad diverging beam over the 20-40 keV energy range is required.

Several examples of laser plasma EUV and soft X-rays applications were presented, including EUV tomography measurements. Ultrafast soft X-ray transient absorption spectroscopy using HHG source was also presented and discussed.

Development of X-ray optics and diagnostic systems are essential for the characterisation of novel X-ray sources. Examples of novel X-ray detectors based on pnCCD technology were presented. It was pointed out that there is a need for stable "turn-key" laser drivers for enabling the development of user-friendly and easily maintained laser-based X-ray sources.

It was suggested that artificial intelligence (AI) tools may deliver a substantial benefit for development of diagnostic equipment and provide necessary feedback in complex systems.

2.2 Academic-industrial partnership.

The present research funding landscape encourages engagement between academic and industrial partners. While basic research delivers unexpected advances in technologies, funding agencies tend to focus on, and mainly fund, applied research. Several routes exist to help translate innovation in research into industrial growth (e.g. Horizon 2020). It is important for academic communities build links with industrial partners and take advantage of these financial resources.

3 Industrial views on the progress of X-ray sources

There is keen interest in industry, particularly the semiconductor industry, in developing compact X-ray sources that can be implemented into existing products to extend their metrology and inspection capabilities.

X-rays can be produced using a wide range of techniques, for example high-harmonic generation, laser-plasma accelerators, capillary discharge X-ray lasers, laser plasma X-ray sources free-electron lasers etc. Industrial requirements for soft X-ray sources depend on the

specific imaging applications, and therefore must be examined on a case-by-case basis involving representatives from industry. However, due to weight and size constraints, it is foreseen that a key limitation in many industry sectors is the lack of turn-key modular X-ray sources with small footprints suitable for incorporating into existing products.

The majority of soft X-ray sources presented at the meeting have been validated in research laboratories and facilities, and are at a technology readiness level (TRL) of 4[1].

3.1 How to improve engagement with industry via LASERLAB-EUROPE

There are ranges of methods to transfer technology to businesses including direct cooperation, exploiting patents and through start-up companies. Laserlab-Europe will have an active role in linking industrial partners to research institutions and facilitate the transfer of technology through:

- Financial support for bi-lateral secondments between industry and research institutions.
- Proof-of-concept grants that target industrial applications.
- Review industrial design specifications of soft X-ray sources to identify key parameters.
- A pathway for research institutions to validate commercialisation plans to allow industry partners to assess and verify the technology more efficiently. This is would provide industry with necessary information to decide on what research and development of X-ray sources for a particular application to engage in.

4 Conclusions / Impact / Outlook

The workshop enabled an open discussion on advanced X-ray sources for research and industrial applications. The talks provided an overview of laser-driven X-ray sources and considered the needs and requirements of both academic and industrial research.

The discussion sessions clearly highlighted the challenges in developing appropriate technologies and indicated that there is a need for a review of requirements of all industrial sectors and academic research where X-ray sources are used as tools for advanced research. Future activities could include a review of sources and the requirements of industry and academia.

Visions for the future of bi-lateral technology transfer of X-ray sources: The X-ray source research community needs to develop a programme to address the grand challenges that are limiting the transfer of technology to industry. It is proposed that through laser lab some of these challenges can be targeted. Key themes of these industrial challenges include reliability of X-ray sources and formulating a pathway to miniaturise X-ray sources. There is large scope for industry to develop “in-house” research and development programmes to develop soft X-ray sources. This will benefit the scientific community and provide researchers with access to specialised engineers who can support investigations into improving stability of lasers and X-ray sources. Currently R&D of X-ray sources is mainly limited to research institutions.

[1] Horizon 2020 General Annexes TRL definition.