LASERLAB-EUROPE

The Integrated Initiative of European Laser Research Infrastructures V

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Deliverable Type		
R	Document, report	OTHER
DEM	Demonstrator, pilot, prototype	
DEC	Websites, patent fillings, videos, etc.	
OTHER		
ETHICS	Ethics requirement	
ORDP	Open Research Data Pilot	
DATA	data sets, microdata, etc.	
Dissemination Level		
PU	Public, fully open, e.g. web	PU
CO	Confidential, restricted under conditions set out in Model Grant Agreement	

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1 Introduction to Laserlab-Europe

Laserlab-Europe is the European consortium of major national laser research infrastructures, covering advanced laser science and applications in most domains of research and technology, with particular emphasis on areas with high industrial and social impact, such as bio- and nanophotonics, material analyses, biology and medicine.

Recently the field of advanced lasers has experienced remarkable advances and breakthroughs in laser technologies and novel applications. Laser technology is a key innovation driver for highly varied applications and products in many areas of modern society, thereby substantially contributing to economic growth. Through its strategic approach, Laserlab-Europe aims to strengthen Europe’s leading position and competitiveness in this key area. It facilitates the coordination of laser research activities within the European Research Area by integrating major facilities in most European member states with a long-term perspective and providing concerted and efficient services to researchers in science and industry.

2 Objectives of the Foresight Workshop

Lasers and photonic-based techniques are omnipresent and indispensable in modern society and their role will even increase in the future. Foresight activities act as Laserlab-Europe’s “think tank”, aiming to anticipate future strategic scientific, technological and innovation-related challenges with regard to laser science, technology and applications, to adjust Laserlab-Europe’s strategic positioning within the European research landscape of photonic-related installations, clusters of infrastructures and societies, and to enhance the long-term sustainability of cooperation within the Consortium.

Due to constant and rapid scientific and technological developments, the significance of laser research and laser-based technology for science and our modern economy is continuously increasing, and we are witnessing a spectacular advance of sources which nowadays reach extreme intensities and unprecedented average powers, but also extreme wavelengths from the soft X-ray to the terahertz regimes. These developments fuel technological advances to address the grand challenges of our society, and they enable entirely novel research in widely varying areas ranging from bio-imaging to attosecond x-ray science, laser-based particle physics and to laboratory astrophysics. Beyond the light sources themselves, to take full advantage of these new opportunities, experimental methodologies and data extraction methods have to be adapted or developed.

The Foresight Workshop on Opportunities with Future Laser-based Technologies aimed to address the scientific possibilities that such sources and methodologies enable, in addition to their technological aspects. The workshop involved the relevant communities and facilities to investigate how the opportunities can most efficiently be met and exploited. How can they be used to develop new opportunities in industry and for society, and how can they be applied to tackle Grand Societal Challenges?

3 Foresight Workshop on Opportunities with Future Laser-based Technologies in Riga, Latvia

3.1 Format and programme

On 24 and 25 July 2023, the Laserlab-Europe partners gathered in Riga, Latvia, for the Foresight Workshop on Opportunities with Future Laser-based Technologies. The event was hosted by the University of Latvia. During both days, 54 participants from Europe and North America met on-site, around 20 joined online.

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A programme committee, representing the access and JRA activities of Laserlab-Europe, the Industrial Advisory Committee, and the expert groups of the network, identified the most relevant topics of this foresight workshop. Users, industrial representatives and representatives from relevant RIs outside Laserlab-Europe were actively involved in the programme setup. The members of the programme committee were:

- Luis Arnaut, CLL
- Cord Arnold, LLC
- Jens Biegert, ICFO
- Giulio Cerullo, CUSBO
- Dusan Chorvat, ILC
- Mattia Cipriani, ENEA
- Sylvie Jacquemot, LULI
- Antonio Pifferi, CUSBO
- Christophe Simon-Boisson, Thales

Based on thematic suggestions from the programme committee, session chairs have been identified among the Laserlab-Europe partners. They were asked to compose their sessions and invite speakers from industry and academia being at the top of their respective field to present concrete needs for further research and industrial collaboration.

In view of the venue in the Baltic region with strong photonics clusters and associations, in particular regional industrial representatives have been invited to present, exhibit, and participate to the Foresight Workshop.

On the first day, Laserlab-Europe's Executive Director Jens Biegert welcomed the attendees, emphasising the focus of the event on networking and exchange and possible future collaborations. He then left the floor to the chairs of the sessions on "Lasers for Clean Energy" and "Laser Science for Cancer Research" with short input presentations and fruitful discussions over the course of the afternoon. These sessions have been organised by the respective expert groups.

The second day in Riga was dedicated to the most promising laser-based technologies to open new fields of scientific, industrial and societal opportunities. After a welcome by Laserlab-Europe's project coordinator Sylvie Jacquemot (CNRS-LULI) and University of Latvia's Rector Prof. Indrikis Muiznieks, two successful collaborations of science and industry were presented by Dusan Chorvat (ILC) and Antonio Pifferi (POLIMI): the projects OPTIMAL[1] and fastMOT[2].

Three sessions addressed the following topics:

- environment & water (microplastics, nanoplastics and pollution)
- laser processing for materials structuring
- photoacoustics.

The sessions included diverse presentations from international representatives of science and industry and led to productive discussions and exchange on ideas for new projects.

At the end of the Foresight Workshop, the Biophotonics Laboratory and the Laser Centre of the University of Latvia were presented to the participants during lab tours.

3.2 Lasers for Clean Energy

Laser spectroscopy is of high importance in the investigation of the basic mechanisms occurring in advanced materials for the conversion of solar energy into electrical or chemical

[1] https://www.optimal-project.eu/
[2] https://fastmot.eu/

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energy and for understanding the operation and the degradation mechanisms in batteries. In addition, laser-assisted materials processing to structure and functionalise advanced materials also play an important role for use in clean energy applications and devices.

The session included presentations and discussions on:

- Lasers for battery research, Benedetto Bozzini (POLIMI)
- Dissipation-free optoeelectronics for future low-power consumption IT, Martin Schultze (TU Graz)
- Bioresins (bio-based materials) as renewable, green, and sustainable replacement for fossil plastics, Jolita Ostrauskaite (Kaunas UT), Darius Gailevicius (VULRC).

Discussions centred on the conclusions of the presented topics and the perspectives for joint efforts for funding from the EU for projects relevant to clean energy involving lasers:

Benedetto Bozzini (POLIMI) presented an overview on lasers for batteries, discussing the application of different advanced laser spectroscopies to study different problems related to battery operation and lifetime. He confirmed that a research scheme involving material processing by lasers and then employing advanced spectroscopy methods would bring added value and therefore could be considered for funding for a research project. He also stated the importance of establishing a strong link between the research community working on lasers, represented by Laserlab-Europe, and the research community working on batteries, represented e.g. by the consortium Battery2030+. In the discussion, among others, it was made clear that there is particular interest for proposal preparation targeting the EIC Pathfinder funding scheme for lasers for batteries research. A successful proposal would need to involve selected partners from Laserlab-Europe focusing on lasers for material processing/spectroscopy with other academic/industrial partners specifically focusing on battery research.

Martin Schultze (Graz University of Technology) presented his work on dissipation-free optoelectronics for future low-power consumption IT. He proposed that the topic of dissipation free optoelectronics based on the interaction of few-optical-cycle pulses with dielectrics could also be suitable for an EIC Pathfinder project, given its disruptive nature and its current low TRL.

Jolita Ostrauskaite (Kaunas University of Technology) presented her work in chemistry on bioresins, i.e. bio-based materials as renewable, green and sustainable replacement for fossil plastics. She pointed out that she needs collaborations with laser-assisted micro-nanostructuring experts and 3D printing experts for the development and fabrication of advanced bio-based materials. The topic of bioresins could also lend itself for a European proposal, once a suitable call has been identified.

The session was chaired by the Expert Group leaders Giulio Cerullo (POLIMI) and Panos Loukakos (IESL-FORTH).

3.3 Laser Science for Cancer Research

The Expert Group “Laser Science for Cancer Research” analysed potential contributions of laser research to the fight against cancer, also in the framework of the Mission on Cancer. Various synergies combining different expertise and advanced technologies were highlighted, also exploiting exciting local collaborations with clinicians and companies.

The following presentations were given by Laserlab-Europe partners:

- Development of devices with laser-fiber illumination for minimally invasive skin and mucosa characterisation, Janis Spigulis (ULLC)

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- Multimodal non-invasive non-contact time-resolved diagnostics tools, e.g. skin cancer, intra-operative, etc., Vanesa Lukinsone (ULLC)
- Monitoring and managing of cancer treatment, Antonio Pifferi (CUSBO/POLIMI)
- Microfluidic biochips & high resolution time lapse microscopy: application to cancer research, Felix Sima (INFLPR).

To summarise, the presentations and related discussions addressed three main domains:

Cancer diagnostics

Great emphasis was given to the unique advantage of photonics to detect endogenous biomarkers without the need of contrast agents. The complexity of approval for a new contrast agent and the extremely long time-to-market raises great interest in the wealth of information that can be retrieved non-invasively by photonics techniques by directly assessing a multitude of endogenous biomarkers. Great emphasis was raised on optical multimodality (e.g. fluorescence spectroscopy, time-of-flight assessment, Raman spectroscopy), which carry multiple and complementary information on tissue composition, tissue structure and microenvironment. Some tools can be designed also for non-contact real-time spectral imaging, permitting a simple investigation at the primary care physician without the need for a complex hospital structure. A prototype for real-time full-body scan of skin cancer lesions was shown – and demonstrated also during a laboratory visit.

Therapy monitoring

Photonics can provide real-time feedback to the efficacy of a cancer treatment, being sensitive to tissue alterations caused by the treatment or related photon emission. Often, cancer protocols are designed based on wide population statistics, which can miss differences in response due to individual variability. Viable and practical photonics tools to assist clinicians in finely tuning treatment on a personalised basis are most needed. Examples, including in some cases also preliminary clinical data, were discussed, namely: i) monitoring neoadjuvant chemotherapy in breast cancer to predict the therapy outcome and adjust the treatment strategy accordingly; ii) fibre-needle monitoring of minimally invasive interstitial thermal treatment (e.g. by radiofrequency, microwave, laser) as a guide to the surgeon to avoid over or under treatment; iii) monitoring of radiotherapy dose by detection of Cherenkov radiation.

Laser microfabrication for cancer research and personalised analysis

The extremely high versatility of laser microfabrication to realize complex microfluidic biochips is opening a novel paradigm for analysis of specific cancer cell populations, even taken directly from the patient. An example was discussed unveiling the basic mechanism of cancer cell extravasation and intravasation at the basis of the metastatic potential of cancer. This approach can lead also to the analysis of patients' cancer specimens, towards personalized treatment, also integrating the biochip with photonic sensors for additional on-line analysis.

The session was chaired by Antonio Pifferi (POLIMI).

3.4 Micro- and Nano-plastics in Water and the Environment

The first session of the second day consisted of three presentations, outlining the current technological state of the art, scientific challenges and expected new EU legislation in the area of micro- and nano-plastics in water and the environment.

- Analysis of nanoplastics in flow with spontaneous and stimulated Raman scattering techniques, Maximilian Huber (TU Munich)
- Advanced microscopy methods as a tool for visualisation of nano- and micro-plastics, Dusan Chorvat (ILC SCSTI)

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- MICREAUPLASTICS: upcoming technical & analytical requirements to analyse microplastics in drinking water in the EU, Eelco Pieke (Het Waterlaboratorium, Haarlem, NL).

Many groups in the world are studying the occurrence of microplastics in environmental compartments and other matrices, but there are no standardised methods yet and their toxicological effects are largely unknown. Even less is known about their smaller counterparts, nanoplastics, mostly because their detection (below the diffraction limit of visible light microscopy) is even more challenging.

Maximilian Huber (Technical University Munich) presented recent experiments, testing the options to detect and characterise nano-sized particles by means of Raman spectroscopy. He showed that by means of optical trapping (OT), nanoplastics can be kept long enough in the laser focus to be identified with conventional Raman spectroscopy. This method can be combined with a size-based separation method, such as field-flow fractionation. However, for the detection of nanoplastics without OT, a much faster technique is required. Maximilian Huber then showed results of a recent Laserlab-Europe access project carried out at LaserLaB Amsterdam. By means of Stimulated Raman Scattering (SRS), the measurement time could be reduced to tens of microseconds (instead of seconds), and untrapped nanoparticles could be detected on-the-fly, down to 100-nm diameter polymer particles. Such technological advances will be crucial for future research in the field of nanoplastics detection.

Dusan Chorvat (International Laser Centre in Bratislava) showed the results of several ecotoxicological studies with micro- and nanoplastics. They examined the responsiveness of the fluorescence of sweet water algae *Chlorella sp* and moss *Fontinalis antipyretica* to various nano/microplastic particles. MP optical properties and algae moss intrinsic fluorescence (e.g. chlorophyll) can be simultaneously monitored by spectrally time resolved microscopy techniques, Raman scattering, FTIR spectroscopy and mass spectrometry This means that algae and moss, when monitored with the appropriate optical techniques, can serve as biosensors of their environment, and thus improve our understanding of the interaction of living systems with micro/nanoplastic pollutants. It was found that the uptake and effects of nanoplastics are much greater than for the larger microplastics of the same polymer type. For certain studies, fluorescently labelled particles can be used, but for “natural” microplastics the further development of label-free methods will be crucial.

Eelco Pieke of Het Waterlaboratorium, Haarlem (NL), a commercial drinking water quality control laboratory, sketched how new legislation is in the making regarding microplastics in drinking water. Soon all EU member states will be required to collect and filter batches of >1000 L of drinking water by 1 January 2024, and analyse the residues on the filter (20 micrometer mesh) using a vibrational spectroscopic technique (FTIR or Raman) for identification at the individual particle level. Further details such as the number of measurement points (‘sources’) and number of measurements, measurement frequency, etc. have not yet been provided. If the first results will indicate that microplastic particles should be put on the ‘watch’ list, then this might be a great opportunity for instrument manufacturers.

The discussion at the end of this session was moderated by Freek Ariese (LaserLaB Amsterdam). It was noted that apparently our knowledge on (eco)toxicological effects lags somewhat behind our knowledge on environmental occurrence. As for the drinking water study, it is odd that the drinking water companies themselves have a say as to the analytical methods and the required specifications. The lower size limit of 20 micrometer may mean that the smaller-sized particles will escape detection and that probably soon a different strategy will be required.

Several ideas for future research projects involving laser spectroscopic methods for nano- and microplastics were suggested. Chip experts should get together to design chip-based microfluidic cells for more efficient detection in flow systems. This could involve a flow

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cytometry-type cell with hydrodynamic focussing and several detectors in series: scattering, fluorescence as well as Raman or SRS spectroscopy. Advanced data processing methods should be developed for such large, multimodal data sets.

3.5 Laser processing for materials structuring

The session consisted of four presentations, each followed by time with rich discussion and exchange with the in-person and online meeting attendees. The main topic addressed materials engineering by lasers, including specific aspects related to:

- Efficient laser nanostructuring for enhanced surface properties, Petr Hauschwitz (HiLASE)
- Laser shock applications: advances, challenges and new opportunities, Laurent Berthe (PIMM/CNRS-ENSAM)
- Laser material processing for biomimetic application, Stella Maragkaki (IESL-FORTH)
- Selective laser etching process and capabilities, Titas Gertus (Femtika).

The applications of shocks produced by laser plasma to increase the performances of materials, and their resistance to fatigue and corrosion were presented by Laurent Berthe (PIMM, ENSAM, Paris, France). Of specific potential interest for attendees, details of the capability of this technique for improving materials integrity and durability in extreme conditions (space, aeronautics, defense) and also in-bulk defect diagnostics have been presented and commented.

Titas Gertus (Femtika, Vilnius, Lithuania) reported on Selective Laser Etching (SLE) process capabilities by using multiphoton and selective laser etching techniques for enabling additive and subtractive manufacturing on a large and diversified range of materials (polymers, glasses, metals, ceramics, etc.). Remarkably, efforts are made today to boost the achievable resolution towards sub-micrometer scale and ever-increased system and device miniaturisation (including the description of a Liver-on-Chip device fabrication).

The application of laser fabrication for biomimetic application was detailed by Stella Maragkaki (IESL-FORTH, Heraklion, Greece). In particular, the Laser-Induced Self Assembled Structures (LIPSS) technique provides a unique and controlled way for structuring materials at the mesoscopic scale (100’s nm spatial scale) with myriad of potential applications in industry, optics or medicine (tribology, anti-reflection coatings, hydrophilic/hydrophobic/anti-bacterial surfaces, etc.) attracting additional interest of the audience. New opportunities and challenges permitted by the control (and shaping) of the polarisation of the laser beam writing tool were also detailed.

Complementary to the other presentations, Petr Hauschwitz (Hilase Centre, Prague, Czech Republic) presented laser (ns-kW class laser and thin-disk laser technology) and system design (beam shaping) routes to move towards efficient nanostructuring of large surfaces. This is a pre-requisite for further industrialisation of those laser-based techniques (with required TRL factor upscaling) which are needed to address the constraints of cost and speed of processing to pass into the industrial market.

Providing an opportunity to gather industrials and scientists with a large and diversified expertise, the session sparked curiosity and vivid attention of the audience as demonstrated by the large number of questions following the presentations. Originally, it also brings together academic and industrial partners with diverse and complementary expertise and maturity on a specific topic, as here focused on surface materials engineering. The session could be followed up to continue identifying and solidifying well-focused topics for future all-winning collaborations, which would combine partners from academia, industry and medical centers.

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The session was chaired by Andrejus Michailovas (Chief Scientist at EKSPLA) and Olivier Uteza (CNRS-LP3).

3.6 Photoacoustics

Photoacoustics, also named “optoacoustics”, can be broadly defined as the science of light-to-pressure conversion and its applications. The first observations on the generation of sound when modulated light is absorbed by a material were reported, and patented, by Alexander Bell in 1880 who created a device he called the “photophone”. The availability of pulsed lasers, the fabrication of sensitive pressure sensors and the development of materials that efficiently convert pulsed laser light into broadband and high-intensity photoacoustic waves, transformed the field and motivated the use of photoacoustics in countless systems and applications.

The session on photoacoustics was organised in view of the following objectives:

- Building a broad-based interest group in photoacoustics involving researchers from Laserlab-Europe affiliated laboratories
- Identifying competences and opportunities for the advancement of photoacoustic-based solutions to cancer, climate change, water quality or sustainability
- Encourage a team to design a promising EC proposal.

The workshop included contributions from key opinion leaders in various areas of photoacoustics, namely:

- Photoacoustic spectroscopy sensors for environmental monitoring applications, Vincenzo Spagnolo (Polytechnic of Bari)
- Three-dimensional thermophotonic super-resolution imaging in biomedical and manufacturing applications by spatiotemporal diffusion reversal methods, Andreas Mandelis (University of Toronto)
- Application of acoustic phonons reaching MPa peak pressures, Keith Nelson (MIT).

The industries working in the field were represented by an SME (Carlos Serpa, LaserLeap Technologies) and a multinational (Jithin Jose, FUJIFILM-Visualsonics). The first focused on the application of photoacoustic waves to permeabilise biological membranes or to change the properties of surfaces, whereas the second reviewed preclinical and clinical uses of photoacoustic tomography and its bottlenecks.

The session was attended by representatives of the vast majority of Laserlab-Europe affiliated laboratories. The stimulating discussions during the workshop will be continued online and an expert group will likely be constituted to explore opportunities in the landscape or EU project calls.

The session was chaired by Luis Arnaut (Coimbra Laser Lab).

4 Conclusions and outlook

The Foresight Workshop has been a great occasion for different disciplines to meet and exchange about ongoing research and research needs in the various topics covered by Laserlab-Europe. On-site and online participants discussed on the feasibility of ideas and how to implement them in future collaborations and potential EU funded projects.

The timing of the workshop has been challenging in terms of availability of speakers, exhibitors, and attendees in general. Nevertheless, a strong panel has been set up by the session chairs.

From industrial participants, the feedback has been shared that a stronger participation of industry and end users would be needed to better incorporate research needs in future

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developments as well as in EU projects with higher TRL. In addition, academic presenters should present new technologies or developments that strongly serve the EU's societal, environment, and economic needs as well as solve existing industry problems.

This feedback and the discussions initiated will be taken back for follow-up events.

Workshop impressions

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