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Lasers for Industry

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Laserlab Europe

Laserlab Forum

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Lasers for Industry

Broadband SRS image of human head and neck tumor tissue acquired with 10-ms pixel dwell time

Figure: CRI srl

In this Issue

Editorial


Sylvie Jacquemot

The intersection of science and industry has long been a place of opportunity. When researchers and businesses work together, they can accelerate innovation, turn promising ideas into real-world applications, and ensure that new technologies find their way from the laboratory to society.

In this issue of *Laserlab Forum*, our 'Industry Focus' highlights a range of successful partnerships between academic institutions and commercial enterprises. From co-developing advanced instrumentation to applying laser-based technologies in new fields, these examples show how cooperation can drive both scientific and economic progress.

We hope these stories inspire further dialogue and collaboration across sectors – for the benefit of science, industry, and society alike.

By the way, did you know that Lasers4EU provides transnational access not only to researchers, but also to industry and medical centers? Learn more on page 12!

I wish you an interesting reading!

Sylvie Jacquemot

News

Innovative target design leads to surprising discovery in laser-plasma acceleration

Using the CLF's Gemini Laser, scientists have developed a groundbreaking method for generating fast, bright proton beams using a high-repetition-rate laser-plasma accelerator and a stream of water.

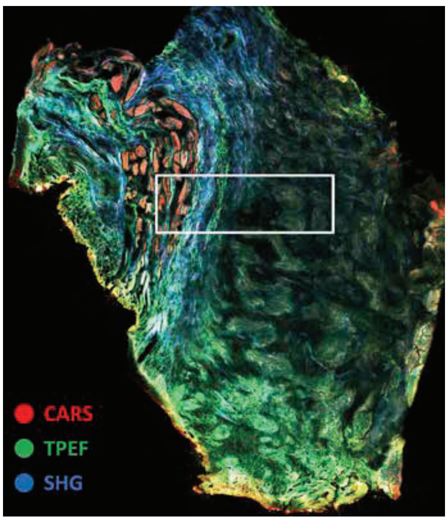
The Queen's University Belfast team tested a novel target, developed by researchers at SLAC, to tackle the inefficiency of replacing targets after each laser pulse. Published in *Nature Communications*, the study showed that replacing solid targets with a thin, self-regenerating water sheet not only solved the issue of frequent target replacement but also unexpectedly improved beam focus and brightness. When struck by the laser, the evaporated water formed a vapour cloud around the target, which interacted with the proton beam to create magnetic fields. Compared to similar experiments with solid targets, the water sheet reduced the proton beam's divergence by an order of magnitude and increased the beam's efficiency by a factor of one hundred. The proton beam exhibited remarkable stability, operating at five pulses per second over hundreds of Gemini laser shots throughout. The beam consistently delivered 40 Gray with each shot, a clinical dose used in cancer treatment. This innovation brings laser-driven acceleration much closer to practical use in medicine, materials science, and industry.

https://doi.org/10.1038/s41467-025-56248-4

With light and AI: Innovative technology for more precise cancer surgeries

Cancer surgery could become safer thanks to a new technology developed in Jena, Germany: An interdisciplinary research team has developed an innovative endoscope that can precisely identify and selectively remove tumour tissue – in real time during surgery. By combining state-of-the-art laser and imaging technologies with artificial intelligence, this approach opens up new possibilities for improving patients' chances of recovery.

A team at the Leibniz IPHT, in cooperation with the Friedrich Schiller University, the University Hospital Jena and the Jena-based com-



pany Grintech, has developed the new system that analyses tissue structure and chemistry with 96% accuracy, guiding surgeons during operations. An embedded femtosecond laser precisely removes diseased tissue while sparing surrounding healthy tissue, reducing the need for follow-up procedures. This "see and treat" approach merges diagnosis and therapy in a single device, potentially improving recovery outcomes.

https://doi.org/10.1126/sciadv.ado9721

Vacuum-ultraviolet attosecond pulses tracking ultrafast processes of natural systems

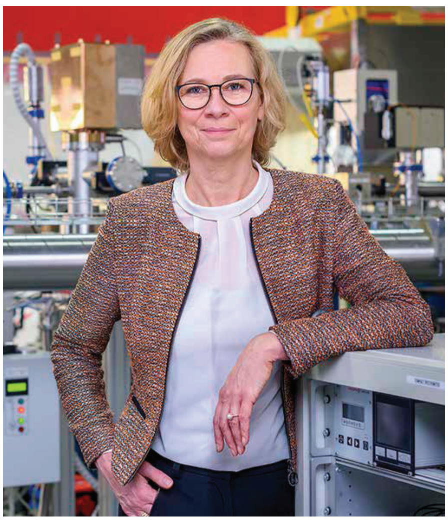
Researchers have developed a new technique to generate and characterise vacuum-ultraviolet (VUV) attosecond (10^{-18} seconds) light pulses using semiconductor crystals illuminated by strong laser fields. Published in *Nature Communications*, this breakthrough enables the study of ultrafast dynamics in natural systems in all states of matter.

The international team with researchers from ELI-ALPS, GTIIT, TU Wien, University Bordeaux–CNRS–CEA, FORTH and ICFO demonstrated that semiconductors illuminated by strong mid-infrared laser light emit vacuum-ultraviolet (VUV) attosecond pulses. They retrieved the pulses' temporal shape and measured their total duration. These unprecedented results establish the basis of a novel technique for probing the ultrafast changes that occur in most natural systems, preserving their bound state rather than inducing their ionisation.

https://doi.org/10.1038/s41467-025-56759-0

Britta Redlich appointed as Photon Science Director at DESY

Britta Redlich, former director of the Laserlab-Europe partner FELIX at Radboud University in Nijmegen (Netherlands) and Professor of experimental physics, assumed the role of Director of the Photon Science research division at DESY on 1 January 2025.



DESY, Jörg Müller

With extensive experience in laser and photon science, Redlich has played a key role in advancing free-electron laser research and high-field magnet laboratory developments. Throughout her career, she has actively contributed to international scientific collaborations, particularly within Laserlab-Europe she served in several boards including the management, access and networking board. From 2022 to 2024, she served as Chair of the General Assembly of Laserlab-Europe AISBL, helping to foster scientific exchange and to enhance access to state-of-the-art laser facilities across Europe.

About Laserlab-Europe and Lasers4EU

Laserlab-Europe AISBL brings together 48 leading laser research infrastructures across 22 European countries. It promotes the development and application of advanced lasers and laser-based technologies through coordinated networking and joint research.
Our key initiative, Lasers4EU, is your go-to resource for having access to a vast network of 29 cutting-edge laser research infrastructures across Europe. Whether you are a researcher seeking specialised facilities for your scientific projects or an industry professional aiming to leverage state-of-the-art laser technology, Lasers4EU offers a streamlined platform to connect you with facilities best suited to your needs. Beyond access, we provide comprehensive training opportunities, equipping users with the skills and knowledge required to fully utilise these world-class infrastructures.

Multiphoton 3D lithography

Multiphoton 3D lithography (MP3DL) is an advanced additive manufacturing technique that uses non-linear light-matter interactions to create precise micro- and nanostructures. It enables free-form 3D architectures with sub-100 nm resolution, making it valuable for photonics, micro-optics, and biomedical engineering.

A recent interdisciplinary publication in the prestigious journal of *Nature Reviews Methods Primers* by researchers from Vilnius University's Laser Research Center, Laser Nanophotonics Group and Chemistry Institute together with their partners, provides a comprehensive overview of MP3DL, covering fundamental principles, experimental methodologies, material considerations, and applications. The study examines key factors such as laser parameters, photopolymerisation kinetics, and post-processing treatments like calcination and infiltration to enhance fabrication quality and reproducibility.

Notably, the research highlights the transformation of polymeric microstructures into inorganic frameworks, improving mechanical stability and optical properties. By refining structural characteristics through photopolymerisation and thermal treatment, MP3DL enables next-generation functional materials and structures.

https://doi.org/10.1038/s43586-025-00396-w

New chairman of the Access Selection Panel at Lasers4EU

Ingo Fischer has been appointed as the new chairman of the Access Selection Panel (ASP) at Lasers4EU. He has been involved in Laserlab-Europe since 2005 as a user, and has served as a user representative since 2015. In this context, he also joined the ASP, where he initially worked with Wolfgang Demtröder. With the launch of the follow-up project Lasers4EU in 2024, Fischer now succeeds Ludger Wöste as chairman.

Fischer is a professor of physical chemistry at the University of Würzburg, Germany. His research focuses on the photochemistry and chemical dynamics of reactive intermediates – including hydrocarbon radicals, hydrogen-bonded clusters, and biological molecules – as well as the study of complex reactions in solution using laser spectroscopy and synchrotron radiation.

Eleanor Campbell (University of Edinburgh) and Brigitte Cros (University Paris-Saclay) are serving as co-chairs of the ASP.

We thank Ludger Wöste for his commitment and work as former chairman of the ASP and congratulate Ingo Fischer on his new role.

ERC Grants

The European Research Council (ERC) promotes frontier research by awarding prestigious grants to outstanding researchers for projects of ground-breaking nature. Laserlab-Europe researchers have again been successful in the ERC's highly competitive selection process. Congratulations to the five scientists who were recently awarded ERC grants, three receiving a Starting Grant, and two receiving a Consolidator Grant.

Sven Askes (LLAMS): Heat in the driver's seat: Unlocking the full potential of pulsed photothermal catalysis


Peter Valckx

In his ERC Starting Grant project HEATPULSE, Askes aims to challenge the traditional approach for the use of catalytic reactors in the chemical industry. These reactors normally operate at a constant temperature, making them less controllable and less efficient. The researcher aims to change this by rapidly altering the temperature using short bursts of light and very small particles of materials that can efficiently convert light into heat. By precisely coordinating the timing of these light bursts to the speed of chemical reactions, he believes he can control the reactions better and enhance the energy efficiency.

Eva Pogna (CNR-IFN): Taming radiative heat emission with anisotropic and time-varying media

The ERC Starting Grant project TREAT, led by Eva Pogna, aims to advance our understanding of thermal radiation. TREAT will explore novel strategies for realising time-crystals and controlling near-field heat flow using a combination of ultrafast spectroscopy, thermal imaging and ultrafast near-field imaging in the mid-IR and THz ranges, applied to epsilon-near-zero and hyperbolic media. The project objectives include deepening our understanding of thermal emission and developing innovative strategies for thermal management, IR light generation, and energy harvesting.

Franco V. A. Camargo (CNR-IFN): Holographic nanoscale imaging via femtosecond structured illumination

Super-resolution fluorescence microscopy has triggered a revolution in the bio-imaging community by offering information on sub-diffraction spatial scales with the benefits of far-field techniques. However, reliance upon incoherent signals arising from bright states has severely limited their adaptation to the realm of ultrafast imaging. Franco V. A. Camargo's ERC Starting Grant project HOLOFAST will employ a new holographic approach to ultrafast microscopy to bring sub-diffraction limited spatial resolution to ultrafast timescales using nonlinear structured illumination, aiming for sub-10 fs temporal and ~10 nm spatial resolution.

Mikkel Brydegaard (LLC): Remote microscopy, nanoscopy and picoscopy by hyperspectral lidar

Within Brydegaard's ERC Consolidator Grant project, HyperSense, his group will develop four new prototypes of hyperspectral lidar (or laser radar). Currently lidar systems typically have a single or a couple of wavelengths. His new concept can provide lidar with hundreds of spectral bands which can be used to deduce micro-, nano- and picoscopic details of biological targets. Applications include classification of pollen on bees, virus in insects, hair growth on mosquitoes, navigation of midges, and diversity of zooplankton.

Christoph Heyl (DESY/HIJ): Gas phase sonophotonics


Christina Mänz

Heyl's ERC Consolidator project GASONIC is intended to leverage gas-phase light control mediated by intense ultrasound waves to other optical devices and adaptive control schemes, broadening the variety of applications of the innovative concept. These range from efficient light modulators and switches to all-gas-phase adaptive waveguide-like systems shaped by intense acoustic waves. Ultrafast optical switches and modulators are able to change key properties such as intensity and phase of ultrafast laser pulses. Thus, they are important building blocks for today's laser systems employed, e.g., for welding, machining, surgery and for scientific applications.

Lasers for Industry

At the crossroads of scientific discovery and industrial application lies a powerful catalyst for progress. In this issue of Laserlab Forum, our focus topic explores how laser-based technologies are advancing through dynamic collaborations between academia and industry. From developing cutting-edge instrumentation to pioneering new applications, the laser experts from Laserlab-Europe have driven many success stories.

The UK's Central Laser Facility: Open for business (CLF, United Kingdom)

The UK's Central Laser Facility (CLF, part of UKRI Science and Technology Facilities Council) is one of the world's leading centres for inter-disciplinary science and innovation using lasers, and is dedicated to supporting scientists and engineers from a range of disciplines to use laser-based technologies to address their research challenges. While the primary access to the CLF is by academics through a peer review process, the CLF also offers proprietary access to its facilities and expertise. A dedicated Impact, Partnerships and Innovation (IPI) group has been established to provide a range of services to commercial and other non-academic partners, and to explore collaboration opportunities to build meaningful and long-term partnerships. Within the IPI team is a group of scientists, each of whom specialises in a different area of science covered by the CLF, who are able to interact directly with industry and support clients every step of the way.

The industry programme at the CLF continues to grow and this year there has been an increase in the number of small and medium size enterprises (SMEs) accessing the facilities, many taking advantage of the exciting innovation funding calls supported by UKRI. One such scheme, the STFC Industry Impact Fund (I2F), has played an important role in facilitating SME access to the CLF.

Ongoing collaborations with both academia and industry have led to notable breakthroughs. Jim Thomas, with his spin-out company MetalloBio, has focused his research on unravelling the mechanisms of various antimicrobial complexes. This work is advancing our understanding of antimicrobial resistance and contributing to the development of a new generation of drugs. Jim Thomas accessed the CLF as an academic in previous years; he has since received I2F funding for MetalloBio to access the Octopus facility in 2024-25.

Another company, MetaGuideX, has been awarded I2F funding to enable access to both the STED (Stimulated Emission Depletion) and the ONI microscopes to investigate surface proteins present in extracellular vesicles. This research is aimed at improving the sensitivity of cancer assays, potentially enabling more accurate detection of cancer at earlier stages.

If you are interested in exploring options of working with CLF on your research projects, please get in touch via CLFindustry@stfc.ac.uk.

Claire Pizzey (CLF)

Fisher Studios. CLF, STFC, UKRI

CLF's Gemini Laser

Material processing with femtosecond laser in GHz-burst operation (CNRS-CELIA, France)

At the CNRS-CELIA (Centre Lasers Intenses et Applications) in Bordeaux University, the RAFALE facility has been installed for laser-matter interaction studies and material processing. This new facility is equipped with an industrial laser system that delivers femtosecond pulses in GHz-burst mode.

Material processing with femtosecond lasers in GHz-burst mode has attracted much attention in recent years. Bursts distribute the energy of a single femtosecond laser pulse across a large number of shorter sub-pulses that are emitted with very close temporal spacing (for example, nanoseconds) within a defined duration (a 'burst'). There is then a pause before the next burst is emitted. Using bursts of pulses, the interaction with the material is gentler and benefits can arise from the cumulative effects of multiple pulses, while unwanted non-linear effects can be avoided, thereby opening the door to new laser processing methods.

The RAFALE facility forms a key part of the TRICORN laboratory, a collaboration between CELIA, ALPhANOV (technology transfer centre) and Amplitude (laser manufacturer), and is open for access applications within the Lasers4EU and RIANA TNA calls. The facility is equipped with a TANGOR 100 industrial laser from Amplitude, that delivers 500 fs duration pulses at 1030 nm wavelength. The laser system can operate in three modes: standard single pulse mode at up to 2 MHz repetition rate; MHz-burst mode with an intra-burst repetition rate of 40 MHz and 2 – 32 pulses per burst; and GHz-burst mode with an intra-burst repetition rate of 1.28 GHz and 50 – 800 pulses per burst. The burst repetition rate can be varied up to 200 kHz. This laser system enables comparative studies across the three different laser-matter interaction regimes, without the need for realignment.

Three micromachining workstations can be served by the laser beam, either in Gaussian mode with microscope objectives for tight focusing or using a galvo scanner. Alternatively, Bessel-Gauss beam-shaping is available. The workstations feature granite bases and are equipped with motorized XY-stages for sample translation, offering high precision and stability. Side-view imaging is available for *in situ* observations.

Recent experiments performed at the RAFALE facility have demonstrated high aspect-ratio top-down drilling of glasses in GHz-burst mode. The resulting hole morphology is different from standard femtosecond laser drilling, featuring an almost cylindrical shape with glossy inner walls. The GHz-burst drilling mechanism was investigated by pump-probe imaging, leading to a better understanding of the process dynamics, which are plume-driven and based on controlled thermal accumulation.

Inka Manek-Hönninger (CELIA)

P. Balage et al., Int. J. Extrem. Manuf. 5: 015002, 2023

Hippolyte Jouanneau, John Lopez (CELIA)

NANOLITE: original solutions for optical metrology at short wavelengths (LIDYL, France)

NANOLITE , established January 2020, is a joint laboratory involving the CEA Laboratory Interactions, Dynamics and Lasers (LIDYL) and Imagine Optic, a company that specialises in wavefront sensing, optical metrology and adaptive

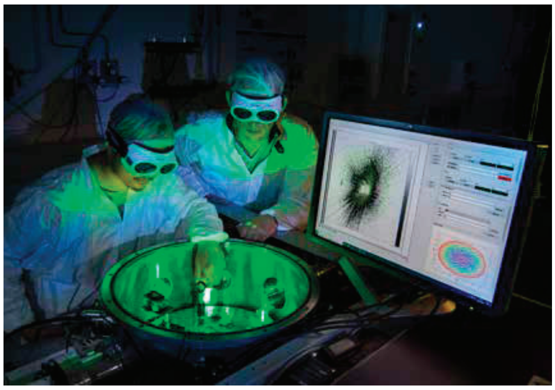


Image from M.J.A. Vink et al., Environ. Sci. Technol. 56, 15563–15572, 2022, used under Creative Commons license 4.0

optics. The laboratory's work is focussed on developing innovative optical metrology and imaging solutions at short wavelengths, in particular in the Extreme-UV range (EUV, typically between 10 and 100 nm).

NANOLITE is built around a new EUV source, which offers large photon flux, high stability and high beam quality, based on the use of a unique high-repetition-rate laser source. This high-performance beamline plays a key part in the development of advanced EUV metrology solutions. As well as serving as an ultra-precise calibration source for current EUV wavefront sensors and future developments, it will enable the development of "at-wavelength" metrology solutions, particularly for the qualification of X-ray and EUV (X-EUV) optics. Such optics, used for example in synchrotron beamlines, have to meet extremely demanding specifications in terms of surface quality and ideally require precise quality control before installation; however, this is not currently possible with the required level of precision, as measurements in the visible range are not sufficiently resolved. "At-wavelength" wavefront sensing in a configuration approaching the optics' final working conditions will lead to both better accuracy and more relevant results. Moreover, the NANOLITE beamline hosts the latest developments in ultrafast nanometric imaging, such as ptychography and coherent diffractive imaging. So far, NANOLITE has enabled "at-wavelength" calibration of several standard and large numerical aperture EUV wavefront sensors from Imaging Optic. Planned upgrades of the beamline will improve its stability and versatility, and will broaden the range of possible experiments.

Willem Boutu (LIDYL)

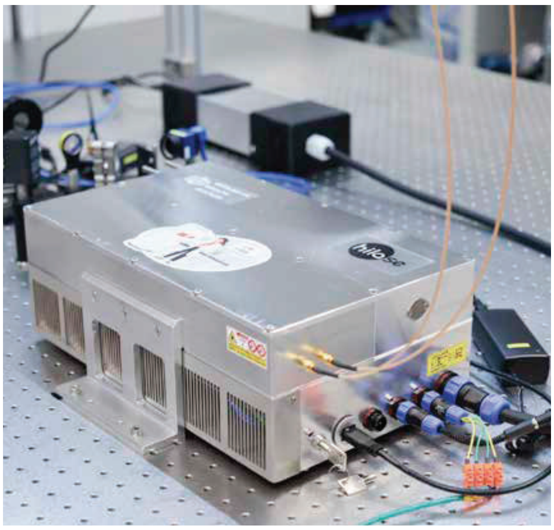
ESTER: A versatile laser platform arising from a Czech industry-research collaboration (HiLASE, Czech Republic)

Bridging the gap between cutting-edge laser research and practical application is a key mission of the HiLASE Centre. In line with its mission slogan, "Superlasers for the real world," HiLASE has teamed up with two Czech companies, Crytur and Lightigo, to co-develop ESTER, a new laser system tailored for industrial and scientific use.

The collaboration began when Lightigo, a producer of laser-induced breakdown spectroscopy (LIBS) systems, identified the need for a robust laser source that was compatible with its technology. A four-year project titled "Bromi" (Breakthrough optoelectronic materials for instrumentation, supported by the Technology Agency of the Czech Republic) was conceived, bringing together Lightigo with Crytur, opto-electronic solution specialists, and the HiLASE Centre, a state-of-the-art laser research facility. Using electronics developed by Lightigo, and mechanics, optical crystals and components by Crytur, HiLASE Centre researchers were able to develop ESTER, a unique air-cooled, diode-pumped laser system delivering nanosecond pulses of up to 70 mJ at 50 or 100 Hz repetition rate. Second and third harmonics are also available, providing additional versatility.

ESTER is an advanced solid-state Nd:YAG laser system designed for applications demanding precision. It offers outstanding beam quality and linear polarisation, and is air-cooled, suitable for use in a wide range of areas, including scientific research, industrial material processing, aerospace, defence systems and medical applications. Its robust design makes it an ideal solution for LIBS spectroscopy, LiDAR, target designation, or surgical procedures.

The ESTER advanced solid-state Nd:YAG laser system.

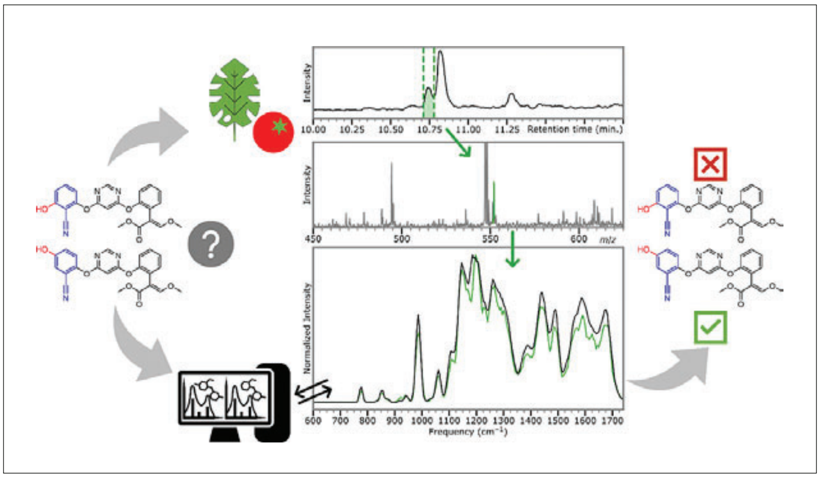


This successful partnership demonstrates how coordinated innovation across sectors can lead to competitive, real-world solutions grounded in advanced laser development.

Martina Rehakova and Sanin Zulic (HiLASE)

Unravelling the chemical structures of agrochemicals and related derivatives using infrared ion spectroscopy (FELIX, The Netherlands)

Agrochemicals typically undergo various chemical and metabolic transformation reactions in the environment, which result in a wide range of derivatives. These derivatives must be comprehensively identified to enable a complete assessment of their impact on the environment and human safety, and to address regulatory implications.



Schematic of the method showing the three combined techniques, from top to bottom: liquid chromatography, mass spectrometry and infrared ion spectroscopy

Most modern analytical methods, however, still struggle to differentiate closely related chemical isomers, which are often found at trace concentrations within complex sample matrices commonly encountered in environmental and dietary studies.

Researchers at HFML-FELIX (in the Netherlands) and Syngenta (in the United Kingdom) have introduced a novel method to facilitate the structural differentiation of derivatives of widely used agrochemicals, employing infrared ion spectroscopy (IRIS) in conjunction with the FELIX infrared free electron laser. The method combines mass spectrometry's selectivity and sensitivity with infrared spectroscopy for structural diagnostics, and demonstrates the exceptional potential for distinguishing even subtle structural variations in compounds at concentrations as low as one nanogram/millilitre.

The results achieved represent a significant improvement over alternative structure elucidation techniques, such as NMR spectroscopy, by reducing sample volume requirements and preparation complexity. A further advantage of the new method is the potential to integrate computationally predicted spectra with experimental IR spectra, to obtain structural assignments of unknown chemicals where reference standards are not available. Applying such an approach, based on quantum chemistry, could notably streamline product development and regulatory studies, by allowing targeted synthesis of reference compounds.

The researchers at HFML-FELIX and Syngenta are continuing to develop these IRIS methods with the aim of applying the technology in other areas of agrochemical study, for example to identify the molecular structures of production by-products, impurities, and other molecular unknowns of agrochemical interest.

Teun van Wieringen, Giel Berden, Jos Oomens, Jonathan Martens (HFML-FELIX) Agisilaos Chantzis, Simon Perry, Mansoor Saeed (Syngenta)

M.J.A. Vink et al., Environ. Sci. Technol. 56, 15563–15572, 2022

Lasers provide new insights for industrial plasmas (LLC, Sweden)

This research into industrial plasmas began through a collaboration with Siemens Energy within the Efficient Electric Combustion Technology (EFFECT) project, funded by the Swedish Energy Agency. The initial goal was to investigate plasma-assisted combustion in gas turbines using gliding arc discharges to improve combustion efficiency. However, early work quickly raised more fundamental questions such as: What radicals are formed in the arc? What are their lifetimes? How is the luminous arc connected to radical production? These questions redirected the focus of the research towards a deeper understanding of the underlying plasma chemistry and structure.

Gliding arcs is a robust plasma source that are promising for applications such as chemical conversion, pollution control, and materials processing, but their transient, filamentary, and three-dimensional nature makes them challenging to characterise using conventional diagnostics. To address these diagnostic challenges, an approach was developed that combined three-dimensional (3D) optical emission tomography with laser-induced fluorescence (LIF) and fluorescence lifetime imaging (FLI). Implemented at the Lund Laser Centre (LLC), as part of the EU-funded ERC LAPLAS project, this innovative setup provided *in situ* instantaneous access to both the global plasma topology and the surrounding reactive environment. Tomographic reconstruction revealed the 3D structure and position of the arc, while LIF-FLI delivered spatially resolved maps of hydroxyl (OH) radicals, collisional dynamics, and temperature, which enabled quenching-corrected fluorescence imaging.

Experiments were conducted in ambient air under varied flow conditions using a picosecond laser at 283 nm. Single-shot measurements resolved the plasma channel and OH distribution with sub-millimetre spatial resolution. The OH signal formed a hollow shell around the arc, dynamically shaped by turbulence and convection. Quenching-corrected data provided reliable relative OH number densities and showed how arc morphology controlled local reactivity zones.

This diagnostic approach will enable temporally and spatially resolved analysis of reactive species in harsh, luminous, and rapidly evolving plasma environments. By linking macroscopic arc structure to localised chemical activity, it can offer critical insights for the design and optimisation of plasma-based technologies.

Sebastian Nilsson, David Sanned, Adrian Roth, Jinguo Sun, Edouard Berrocal, Mattias Richter and Andreas Ehn (LLC)

S. Nilsson et al., Commun. Eng. 3: 103, 2024

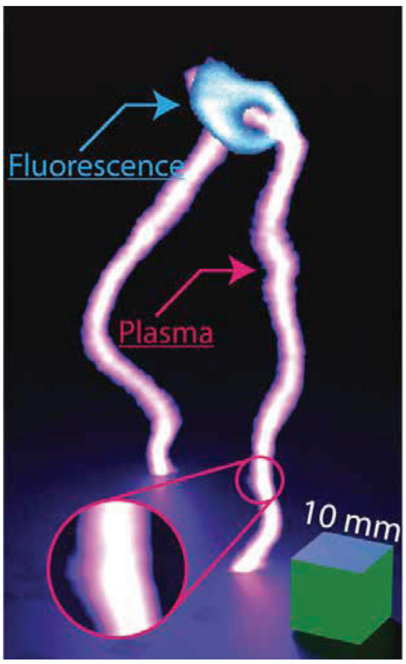


Image of laser-induced fluorescence of hydroxyl radicals combined with 3D plasma emission tomography in a gliding arc, a type of non-thermal plasma with significant potential in environmental and energy applications

A compact all-fibre laser system promises to revolutionise cancer diagnosis (CUSBO, Italy)

Stimulated Raman Scattering (SRS) microscopy is a powerful label-free chemical imaging technique, with a broad range of applications from life sciences to clinical diagnostics. Thanks to the vibrational coherence generated by the synchronised pump and Stokes pulses, SRS enables the non-destructive identification of chemical species in cells and tissues and the measurement of their concentrations, with high speed (pixel dwell times down to microseconds) and sub-micrometre spatial resolution. Currently, however, there are two drawbacks to SRS that limit its widespread adoption in mainstream biomedical applications: firstly, the complexity and high cost of a dual-wavelength excitation laser system; and secondly, the narrowband detection scheme, which measures one vibrational frequency at a time.

To solve both these problems, Cambridge Raman Imaging (CRI), a spin-out of Politecnico di Milano (CUSBO) and Cambridge University, has developed a compact, turnkey all-fibre laser system (STRALE – STimulated RAman LasEr – see Figure 1) designed for broadband SRS microscopy in the CH stretching region (2800 – 3100 cm^{-1}). The dual-wavelength laser, combining a narrowband (≈10 cm^{-1}) pump and a broadband Stokes pulse, is coupled to a scanning/descanning SRS microscope and a broadband detector with a custom-designed 38-channel high-

Figure 1: The STRALE compact, turnkey all-fibre laser system developed by Cambridge Raman Imaging for SRS microscopy

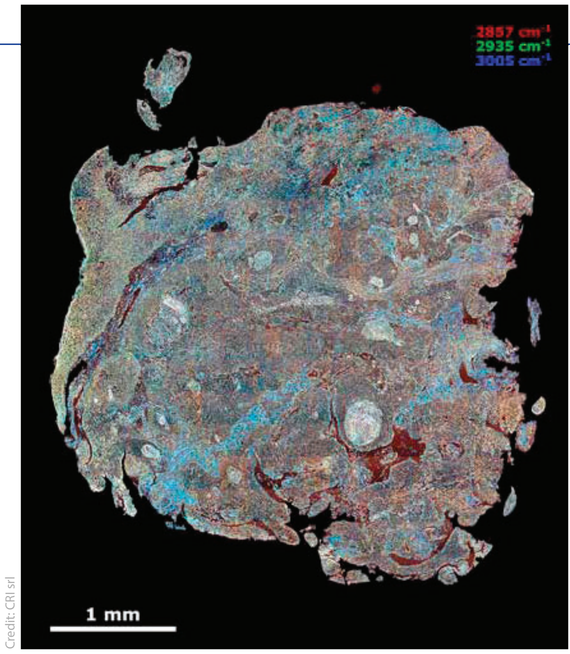


Figure 2: Broadband SRS image of human head and neck tumour tissue acquired with 10 μs pixel dwell time

frequency (1 – 10 MHz) lock-in amplifier, allowing sensitive parallel measurement of the weak SRS spectrum over the entire CH stretching region. The system is capable of measuring high quality SRS spectra of unstained cells and tissues with pixel dwell times ranging from 2 to 20 μs, as well as recording hypercubes of SRS spectra of ≈cm^2 clinical tumour biopsies (see Figure 2). As a result of its performance and ease of use, the fibre-based broadband SRS microscope is expected to have a disruptive impact on biomedical research, providing new insights into the cellular origins of diseases, and on medical diagnostics, enabling chemometric histopathology that provides both morphological and biomolecular data, allowing accurate tumour diagnosis and personalised treatment.

Giulio Cerullo (CUSBO)
Andrea Ferrari (University of Cambridge)
Matteo Negro (CRI)

Deep-UV Raman spectroscopy for sorting black plastic waste (LLAMS, The Netherlands)

Increasing the amount of polymer that can be recovered from waste would be a useful step towards achieving a circular economy, where plastics retain their value and quality. Currently, plastic waste is sorted in recycling factories using hyperspectral near-infrared (NIR) cameras. Correctly sorting black items (which account for about 15% of all plastic waste) is challenging with NIR, so recent investigations have been carried out to determine whether Raman spectroscopy could be used for that purpose.

Different polymer types have clearly distinct Raman spectra. For pristine plastics (without added pigments or dyes), most laser wavelengths can be used to obtain the Raman signal, but pigmented plastics often show a strong fluorescence background. In the case of black plastics, neither visible nor NIR lasers can be used, but good spectra were obtained in the deep-UV range with a 248.6 nm laser. Fluorescence from pigments (or dirt or food residues) may still occur at wavelengths above 270 nm, but the range below 270 nm is available for recording fluorescence-free Raman [1], as shown in Figure 1. Daylight or factory light would also not interfere with the measurements.

A semi-portable setup was built, based on a neon-copper (NeCu) laser (the same type of laser that was recently sent to Mars on board NASA's Perseverance rover). In order to collect sufficient Raman photons from objects with different heights, a stand-off geometry was designed, based on two parabolic mirrors (as shown in Figure 2). After initial optimisation at LaserLaB Amsterdam, the setup was taken to the NTCP recycling test facility in Heerenveen, Netherlands, and mounted above a conveyor belt. It performed well and proved to be relatively insensitive to height differences [2]. Despite the low power of the NeCu laser that was tested, black plastic objects could be identified within 0.1 s. Various waste items were identified as polyethylene, polypropylene or polyethylene terephthalate at different conveyor belt speeds and with differing object heights.

Based on these promising results, a follow-up project has recently been launched in collaboration with a start-up company (Veridis) to improve the design further. Amongst the avenues being explored is the use of a more powerful deep-UV laser. If successful, this technology will help to increase the percentage of recyclable polymer that can be recovered from household waste.

Liron Zada and Freek Ariese (LLAMS)

[1] S.A. Asher, C.R. Johnson, Science 225: 311-313, 1984
[2] Manuscript submitted: L. Zada, F. Ariese, J. Raman Spectrosc., 2025

Liron Zada at the NTCP recycling test facility in Heerenveen, Netherlands

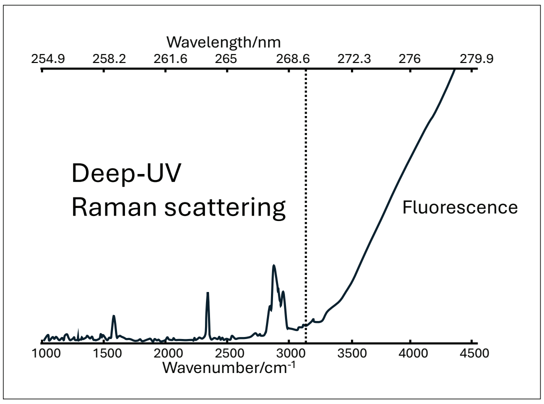


Figure 1: Raman spectrum of black polypropylene with 248.6 nm laser excitation (also showing signals for oxygen and nitrogen at 1555 cm^{-1} and 2331 cm^{-1}, respectively). The dashed line marks the approximate wavelength where the pigment's (carbon-black) fluorescence starts to become problematic.

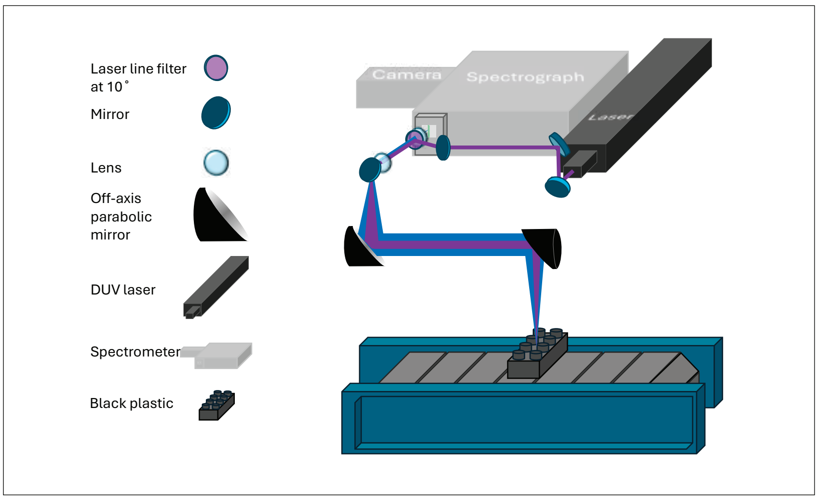


Figure 2: Illustration of the setup used for this study

Advanced micro-optics fabricated by multiphoton lithography for enhancing the lateral resolution in optical microscopy

Optical microscopy remains one of the most versatile tools for inspecting objects, organisms, or surfaces at the micro- and nanoscale, but its lateral resolution is fundamentally limited by light diffraction. Overcoming this limitation has become increasingly important in fields where fine spatial detail is critical, including nanotechnology and material and life sciences. Dielectric microspheres offer a promising solution. With support from Laserlab-Europe, a team of scientists has developed a new strategy for fabricating these structures via multi-photon lithography and integrating them into a micro-device that can be flexibly incorporated into any optical microscope.

To enhance resolution in optical microscopy, various super-resolution strategies have been developed to overcome the diffraction limit [1]. Many of these approaches, however, rely on complex optical setups or fluorescent markers, which limit their applicability in specific use cases. In contrast, the use of dielectric microstructures has shown considerable potential as a simple, efficient and cost-effective approach to improving the imaging performance of the final focusing element in optical microscopes. These structures are particularly appealing due to their ability to generate 'photonic nanojets' (PNJs) – narrow, high-intensity light beams that emerge on the shadow side of micro-scale particles when illuminated. While the physical origin of PNJs is still under investigation, in practical terms they can be regarded as focal regions with characteristics that may enhance resolution beyond the diffraction limit [2].

The technique that uses dielectric microstructures – particularly microspheres – is commonly referred to as microsphere-assisted microscopy (MAM), where an enlarged (virtual/real) image is formed by the sphere (see Figure 1), effectively increasing the numerical aperture of the imaging system [3].

A key bottleneck to advancing MAM lies in the handling, controlling and positioning of commercially available dielectric particles, which limits flexibility in sample characterisation over specific areas. Moreover, limited geometry and size particles are available, hindering a deeper understanding of the PNJ phenomenon and, consequently, its broader application in MAM.

Figure 1: Microspheres can generate a jet-like feature, known as a photonic nanojet, which enhances lateral resolution. This effect is exploited, for instance, in microscopy, where the use of microspheres to further focus light is referred to as microsphere-assisted microcopy.

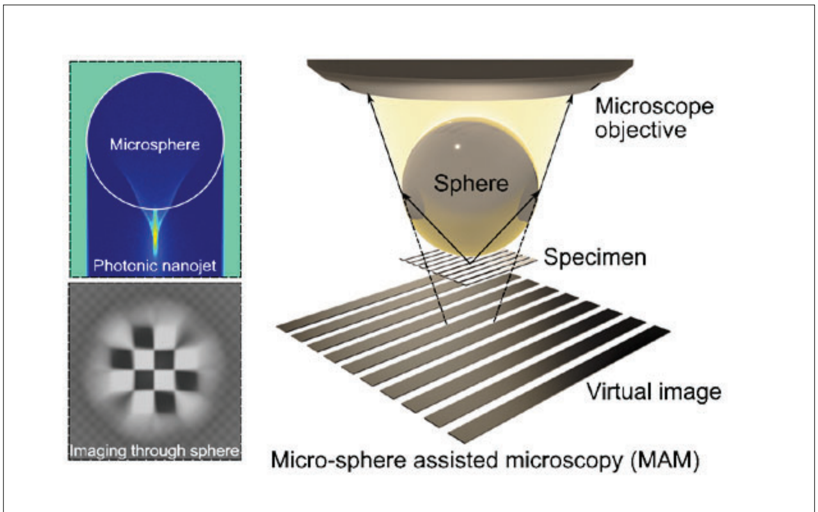


Image adapted from G. Zyla et al. Light: Advanced Manufacturing, 5:19, 2024

Multi-photon lithography (MPL) offers a promising solution to these challenges, as it enables the structuring of matter in three dimensions (3D) at the micro- and nanoscale [4], allowing polymeric microspheres to be manufactured, rather than having to rely on those commercially available. In its simplest form, the MPL process involves the nonlinear, quasi-simultaneous absorption of two photons upon threshold excitation, triggered by laser radiation that is highly confined in space and time. This locally initiates a photochemical reaction in a photosensitive material – typically via radical polymerisation [5].

To realise this process, MPL employs tightly focused ultrafast laser radiation, often using oil-immersion microscope objectives to generate a small ellipsoidal polymerised feature known as a voxel (volume pixel). This voxel is typically confined to the focal volume, enabling high-resolution, maskless 3D printing by assembling individual voxels through controlled steering of the laser focus at a fixed laser intensity. Exposure paths are usually pre-defined by slicing a computer-designed model into layers, each comprising a hatching pattern of lines spaced at a fixed distance.

For MAM, the ellipsoidal shape of a single voxel poses a challenge for fabricating microspheres with the near-perfect geometry and high surface fidelity required for resolution enhancement via the PNJ phenomenon. The nonlinear nature of MPL, however, enables modulation of voxel size through rapid control of the laser power, which can be achieved using an acousto-optic modulator (AOM), commonly integrated into MPL setups as a fast shutter. This means that local adjustments to feature precision can be made even during the printing of a single structure – particularly important at the top and bottom of a sphere, where the curvature is steepest (see Figure 2 (left)). In addition to improving feature resolution, this approach allows the use of dry-air microscope objectives, which are more practical, offering longer working distances than oil-immersion objectives.

Such improvements in MPL precision have been demonstrated within the framework of the Laserlab-Europe transnational access programme by a team of scientists from the Institute of Electronic Structure and

Laser – Foundation for Research and Technology-Hellas (IESL-FORTH), the University of Helsinki and Ruhr University Bochum. The work, carried out at the IESL-FORTH facility, combined rapid laser amplitude modulation with optimised hatching and slicing strategies – which further influence both structural roundness and fabrication speed – to successfully fabricate a microsphere with a diameter of 20 µm using a 20x objective lens (NA = 0.8). The resulting structure exhibited near-perfect geometric quality (λ/8) and exceptional surface smoothness (see Figure 2 (right)).

To enable its use in MAM applications, the microsphere was printed onto a coverslip featuring a central hole, which had also been processed by ultrafast laser radiation. This configuration allows light to be focused directly onto the microsphere, enabling the generation of a PNJ. Together, the coverslip and microsphere form a 3D micro-device, produced in just eight minutes, that can be flexibly integrated into any optical microscope.

To assess its performance, the 3D micro-device was incorporated into a Mirau-type coherence scanning interferometer (MCSI) to image features of a calibration grating with a period of 0.28 µm. The MCSI operated with white light centred at 600 nm and inherently achieved a lateral resolution of 0.5 µm using a microscope objective with an NA of 0.55. Upon integration of the 3D micro-device, the resolving power improved significantly, enabling clear visualisation of the grating features. This indicated that the printed microsphere effectively increased the system's numerical aperture – beyond 1 – surpassing the typical resolution limit of standard objectives used in the visible range, without compromising the MCSI's axial resolution.

The results of this transnational access project have recently been published in *Light: Advanced Manufacturing* [6]. The fabricated 3D micro-device demonstrated strong potential as a cost-effective, real-world solution for MAM. Further enhancements in lateral resolution appear feasible, as both the material properties – such as refractive index – and the geometry of the microsphere can be further optimised. Looking ahead, the unique capabilities of MPL may enable the fabrication of advanced micro-optical structures beyond spherical shapes, offering the possibility of tailoring lateral resolution enhancement for a variety of optical microscope platforms. This will support continued progress in MAM, and also contribute to a deeper understanding of the PNJ phenomenon.

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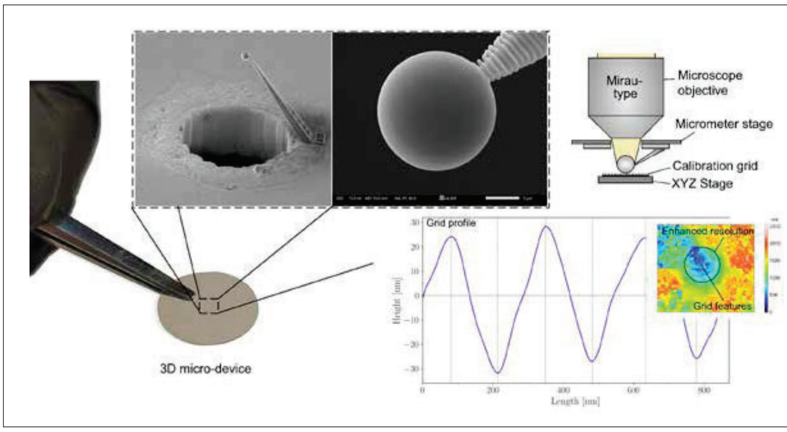

Image adapted from G. Zyla et al. Light: Advanced Manufacturing, 5:19, 2024

Figure 3: The 3D micro-device enables the integration of a microsphere into various optical microscopy setups, such as a Mirau-type coherence scanning interferometer, enhancing the lateral resolution of the entire imaging system to 0.28 µm – beyond the limits of conventional dry microscope objectives

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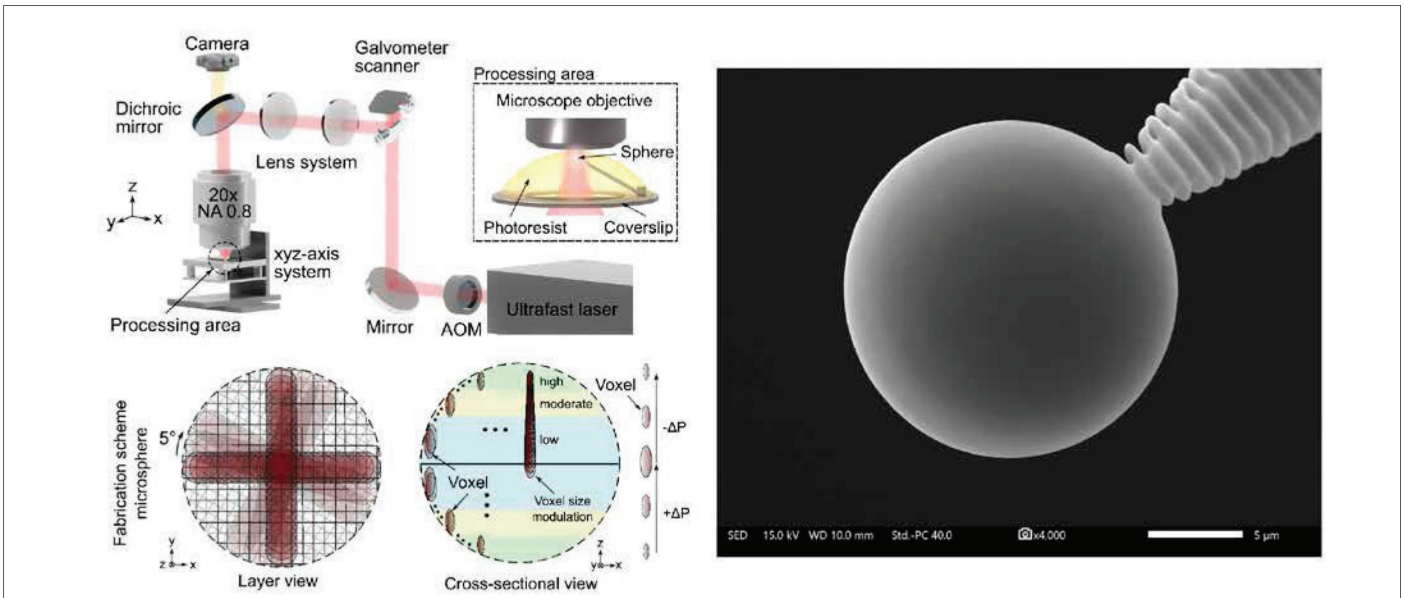

Image adapted from G. Zyla et al. Light: Advanced Manufacturing, 5:19, 2024

Figure 2: (Left) Optical setup for MPL and fabrication scheme for high-precision microspheres. A rotating hatching pattern (5° per layer) improved roundness, while advanced slicing with different step sizes (green: high, yellow: moderate, blue: low precision) optimised fabrication speed. Layer-specific power adjustments (ΔP) refined voxel size to improve precision during printing. (Right) SEM image of the resulting microsphere, with a geometric precision of λ/8.

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RIANA Laserlab-Europe & RADIATE users' meeting in nanoscience

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Bringing together experts, researchers, and professionals from both networks, the meeting aims to share knowledge, exchange ideas, present ongoing projects, strengthen collaborations within the scientific community, and explore future research opportunities. Keynote presentations and interactive sessions will allow for a dynamic exchange of expertise, reinforcing the commitment of both groups to scientific excellence. More information, including deadlines for abstract submission, can be found at:

https://radlas-iaba.cmam.uam.es/

How to apply for access

Interested researchers are invited to contact the Lasers4EU website at lasers4.eu/become-a-user/how-to-access/, where they find relevant information about the participating facilities and local contact points as well as details about the submission procedure. Applicants are encouraged to contact any of the facilities directly to obtain additional information and assistance in preparing a proposal.

Proposal submission is done fully electronically, using the Lasers4EU Proposal Management System. Your proposal should contain a brief description of the scientific background and rationale of your project, of its objectives and of the added value of the expected results as well as the experimental set-up, methods and diagnostics that will be used.

Incoming proposals will be examined by the infrastructure you have indicated as host institution for technical feasibility and for formal compliance with the EU regulations, and then forwarded to the Access Selection Panel (ASP) of Lasers4EU. The ASP sends the proposal to external referees, who will judge the scientific content of the project and report their judgement to the ASP. The ASP will then take a final decision. In case the proposal is accepted, the host institution will instruct the applicant about further procedures.

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