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Laserlab Europe

Laserlab Forum

Newsletter of LASERLAB-EUROPE:
the integrated initiative of European laser infrastructures funded by the European Union's Horizon 2020 research and innovation programme

Lasers Shaping the Nanoworld

Laser-produced plasma formed by the irradiation of liquid tin microdroplets by high-energy ns laser pulses.
Image: Tremani/ARCNL (from *Nature Communications 11: 2334, 2020*)

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In this Issue

Editorial

Sylvie Jacquemot

Following the examples of how lasers are providing valuable insights into matter at the nanoscale, that were presented in the previous issue of the Laserlab-Europe newsletter, the present issue focusses on how lasers allow fashioning materials, in terms of functionality or conformation, in order to drive forward nanotechnologies. Some of the advances detailed in the ensuing articles are directly contributing to Horizon Europe actions, such as clean energy or advanced computing, while others – related to innovative targetry – are enlarging the laser-plasma interaction capabilities of Laserlab-Europe facilities.

The issue also includes fresh news from the consortium and an attractive access highlight on a novel spectroscopy technique. I would like to spotlight more especially the launch of a series of online seminars entitled "Laserlab-Europe Talks". They aim at providing a platform for information exchange, bringing the Laserlab-Europe partners together around hot topics of global interest, thus increasing the visibility of the Laserlab-Europe activities and promoting them to a wide audience, from the academic community to the industrial and medical ones.

I wish you an interesting reading and a safe and happy New Year!

Sylvie Jacquemot

News

Laserlab-Europe AISBL elects Jens Biegert as new Executive Director and appoints new Board members

Jens Biegert

The General Assembly of Laserlab-Europe AISBL, the international not-for-profit association representing 45 leading laser research infrastructures in 22 European countries, has elected Jens Biegert from ICFO – The Institute of Photonic Sciences in Barcelona, Spain, as new Executive Director.

Jens Biegert is succeeding Claes-Göran Wahlström from the Lund Laser Centre in Sweden, who served as Executive Director since the creation of Laserlab-Europe AISBL in 2018 and who will continue as a member of the Management Board.

The General Assembly of Laserlab-Europe AISBL also renewed the Management Board members and User Representatives, with the election of Colin Danson, Cristina Hernandez-Gomez, Sylvie Jacquemot, Britta Redlich, Marc Vrakking, and Claes-Göran Wahlström to the Management Board and Helder Crespo, Susan Quinn, and Rosa Weigand as User Representatives.

The members of the General Assembly congratulate Jens Biegert and the Board members on their election and thank Claes-Göran Wahlström for his achievements and commitment in leading the Laserlab-Europe consortium.

NIF achieves breakthrough in laser fusion

Image: John Jett, LLNL

On 8 August 2021, an experimental campaign conducted in the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL) in the United States of America allows reaching a significant step toward ignition in delivering a neutron yield of more than 1.3 MJ. Such an achievement represents a 25X increase over the NIF's 2018 record yield and results from a deeper understanding of the physics involved and thus from several advances in the target design, as well as in target fabrication, laser precision and diagnostics, made over the last years. Details can be found in *Nature* 601: 542 (2022). Laserlab-Europe, which is – among other topics – investigating laser fusion energy, congratulates the LLNL and NIF teams.

Edited from NIF News

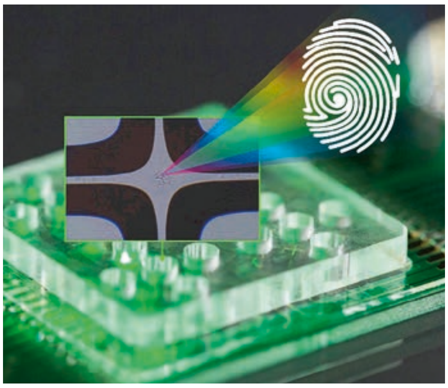
Leibniz Centre for Photonics in Infection Research Officially Launched

The German government is investing in a new Leibniz Centre for Photonics in Infection Research (LPI) in Jena. Aiming to revolutionise photonics in infection research and shorten product development times for the benefit of patients and physicians, the LPI officially started its build-up phase in March 2021.

The four LPI supporting institutions – Laserlab-Europe members Leibniz Institute of Photonic Technology and the Jena University, as well as the Leibniz Institute for Natural Product Research and Infection Biology and the Jena University Hospital – together aim to build up the LPI in the upcoming years. As a globally user open translational infrastructure, the LPI will be open in 2027 for anyone who seeks to bring an idea to life in the field of photonics for infection research.

In current projects, novel multimodal imaging techniques, point-of-care approaches together with the entire sample preparation as well as AI-based methods are being explored, which provide an important basis for the accelerated translation of fundamentally new solutions for the diagnosis, monitoring and therapy of infections, so that these can be rapidly transferred into routine application.

Image: Leibniz-IPHT



Raman Bioassay: Determination of a molecular pathogen fingerprint and its antibiotic resistance.

Explore the FELIX laboratory behind your computer

Take a look inside the FELIX building on the campus of Radboud University via a 360° virtual tour. The tour includes normally inaccessible zones such as the confined underground area where the invisible, super-intense laser light is made. You can zoom in on all the machinery and equipment. In short videos the staff tells you more about the instruments and the research performed. Access the virtual tour via *https://virtualtours.360totaal.nl/tour/hfml-felix*.

What is Laserlab-Europe?

Laserlab-Europe, the Integrated Initiative of European Laser Research Infrastructures, understands itself as the central place in Europe where new developments in laser research take place in a flexible and co-ordinated fashion beyond the potential of a national scale. The Consortium currently brings together 35 leading organisations in laser-based inter-disciplinary research from 18 countries. Additional partners and countries join in the activities through the association Laserlab-Europe AISBL. Its main objectives are to maintain a sustainable inter-disciplinary network of European national laboratories; to strengthen the European leading role in laser research through Joint Research Activities; and to offer access to state-of-the-art laser research facilities to researchers from all fields of science and from any laboratory in order to perform world-class research.

X-ray microscope for nanoscale virus imaging

Image: IST/IPFN

Marta Fajardo

The NanoXCAN project, co-ordinated by Marta Fajardo and a team of researchers from IST/IPFN, is one of the winners of the Pathfinder Open programme of the European Innovation Council (EIC). The NanoXCAN team intends to develop a nanoscale virus imaging X-ray microscope and the €4 million funding will be crucial to achieve this purpose.

The characterisation of viral structures and the identification of key proteins involved in each step of the cycle of infection are crucial to develop treatments. Yet imaging single viruses can only be performed in a few specialised centres in Europe, while every hospital could benefit from it. NanoXCAN proposes to develop a tabletop virus imaging X-ray microscope, with foreseeable impact as revolutionary as the invention of super-resolved fluorescence microscopy, paving the way towards the determination of the structure and dynamics of matter for a large community.

A new technique deepens insights into asthma

LaserLaB Amsterdam physicist Johannes de Boer, working with lung specialists from Amsterdam UMC, has developed a new technique for determining muscle thickness in the airways of asthma patients. It is a groundbreaking study that puts Amsterdam at the international forefront in this field.

“Stated simply, asthmatics have attacks of tightness in which the muscles around the airways contract, making breathing more difficult,” De Boer explains. “If you’ve had asthma for a long time, the effect is the same as regular visits to the gym: the muscles in the airway walls grow stronger, and therefore thicker, and the tightness experienced during an asthma attack becomes worse.”

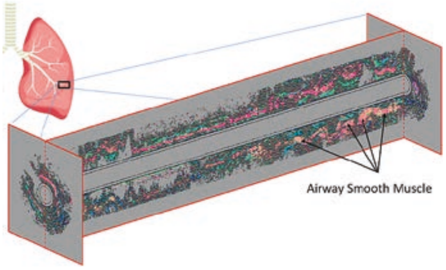


Image: LaserLaB Amsterdam

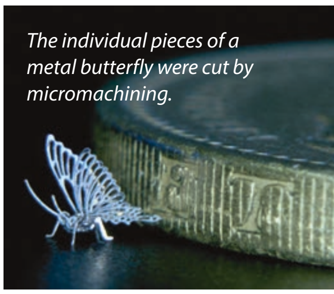
The new imaging technique known as polarization-sensitive OCT (Optical Coherence Tomography) can determine the thickness of muscle layers in asthma patients throughout the patient’s airways, without the need to take biopsies. This breakthrough in imaging technology will make it easier to identify the patients who will benefit most from treatment. The study was published in *Chest* (160: 432, 2021).

New Facilities at the CLF

The Central Laser Facility (CLF) has now made an exciting step forward with the completion of the Artemis laser facility upgrades. The new laboratories double Artemis’s floor space and enable it to host a new 100 kHz laser with 10x the energy efficiency of its predecessor, as well as a new vacuum beamline. Experiments with the 1 KHz beamline have resumed, the 100 KHz system is being commissioned with the first experiments planned for autumn 2022.

Furthermore, the new Scitech Precision laser micromachining laboratories were officially opened in November 2021. Scitech Precision Limited is a spin-off company born out of the CLF’s Target Fabrication group, which works to commercially produce laser microtargets for use in external laser facilities and offers a microfabrication service across many sectors. A new development lab is exploiting disruptive technologies for high repetition rate target fabrication.

Image: Scitech Precision Ltd

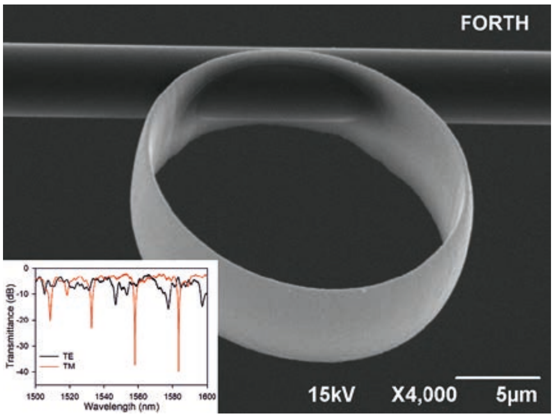


The individual pieces of a metal butterfly were cut by micromachining.

Lasers Shaping the Nanoworld

Lasers are perhaps the single best tools for interacting with nanometre-scale objects and physics. Offering great precision in terms of size, time and energy, lasers are facilitating ever-increasing control of both the physical shapes of specimens and the metaphorical landscape of this new frontier in technology.

Hybrid, micro-ring resonator devices photo-imprinted on optical fibres (ULF-FORTH, Greece)



SEM picture of a 20μm diameter MRR imprinted using MPL onto a 2.2μm diameter OFT. Inset: Transmission spectrum of this OFT-MRR for transverse electric (TE) and transverse magnetic (TM) polarisation states.

Integration and robustness are cornerstone characteristics for the fabrication of photonic devices in both planar and fibre geometries. This presents major challenges to the "Lab-in-a-Fibre" protocol, where multi-functional, miniaturised devices are implemented in microstructured optical fibres [1]. A great functionality optical element is the micro-ring resonator (MRR), while being used in routing and sensing photonic devices, realised in the integrated planar waveguide geometries. There are only a very few examples of MRR devices created on optical fibres, since the fabrication obstacles remain significant. This combination will allow the development of a new kind of photonic device combining the advantages of both the fibre and planar geometries, with connectorisation, miniature size, robustness and integration capabilities.

Researchers at ULF-FORTH have recently demonstrated a new type of miniaturised MRR device, directly imprinted onto micrometric optical fibre tapers (OFTs) [2] using sub-micrometre resolution multi-photon lithography (MPL). Using the three-dimensional character of the MPL [3] enabled the precise imprinting of MRRs with typical diameters of tens of micrometres and sub-micrometre transverse ring dimensions (see figure). These OFT-MRR photonic devices operate in the 1.5μm spectral band, with the OFTs drawn from standard telecom optical fibres, and exhibited light resonance with Q-factors up to ~10^4 (figure inset). This was achieved by tuning the MRR diameter and its waveguiding characteristics using 3D printing. OFT-MRRs were demonstrated in new ultrasensitive ethanol vapour sensors, readily achieving sensitivities better than 0.5ppm, by exploiting surface physisorption effects.

More complex OFT-MRR configurations include concatenated, scissor-shaped, or cross-coupled resonators, which were investigated for their gas pressure and nanoposition-sensing functionalities, based on modal hybridisation effects. Investigation of the opto-mechanical excitation of those MRRs for the colocation of light and acoustic modes has also been carried out. A fundamental objective of the approach is the use of the powerful MPL technique for rapid-yet-precise prototyping of high optical performance OFT-MRRs with good packaging and portability prospects, for translation into field applications. This design and fabrication approach aspires to set a paradigm for photonic components developed as part of Industry 4.0.

Vasileia Melissinaki, Odysseas Tsilipakos, Maria Kafesaki, Maria Farsari, Stavros Pissadakis (ULF-FORTH)

[1] S. Pissadakis, Microelectron. Eng. 217: 111105 (2019)
[2] V. Melissinaki et al., IEEE J. Sel. Top. Quantum Electron. 27: 1-7 (2021)
[3] M. Farsari, B. N. Chichkov, Nature Photonics 3: 450 (2009)

Shaken, not stirred: a recipe for spin switching (FELIX, the Netherlands)

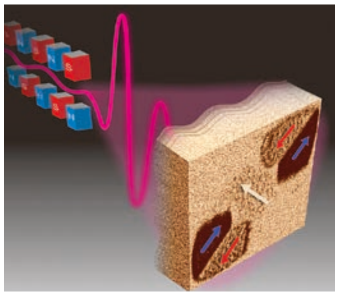


Image: A. Stupakiewicz

Four-magnetic-domain pattern switched by a FELIX pulse.

For the first time, an international team of scientists has demonstrated magnetisation switching triggered by the vibrations of a crystal lattice. Small perturbations can have a profound effect on macroscopic systems, an unfortunate example being the Broughton and Angers bridge collapses in the mid-1800s caused by the resonant vibrations of soldiers marching in unison. Similarly, in condensed matter systems, small excitations can have large repercussions on both ground and excited states.

Researchers from FELIX Laboratory and the University of Bialystok, in collaboration with scientists from the Institute for Molecules and Materials, Delft University of Technology, and the Max Planck Institute for Solid State Research, have found a way to convincingly demonstrate for the first time a constructive use of these excitations.

The team used short, intense pulses from the FELIX free electron laser to show that "shaking" the atoms in a crystal for a short time can lead to a permanent switching of magnetisation polarity. The FEL is ideally suited to fit the resonance frequencies of the chosen lattice. Following the excitation, nonlinear interactions in the phonon system change the potential landscape of the magnetic system, forcing it to evolve into a peculiar four-domain pattern. "It has been discussed for years that such switching in principle could be possible, but has only now been realised, thanks to the high intensity and narrow bandwidth of the FELIX pulses" explains Andrei Kirilyuk.

Ultrafast modification of the crystal field environment has the potential to become the most universal way to manipulate magnetisation, and it could be a starting point for innovative IT concepts, such as ultrafast opto-spintronic devices.

Andrei Kirilyuk (FELIX)

A. Stupakiewicz et al., Nature Physics 17: 489 (2021)

Lasers for nanolithography (LaserLaB Amsterdam, the Netherlands)

In the past decades, technology has developed to a point where integrated circuits (ICs) – highly sophisticated man-made nanostructures – underpin household devices such as smartphones and drive progress in virtually every form of advanced technology. The semiconductor industry has been continuously innovating their production capabilities at a stunning rate, doubling the transistor density on an IC every two years (Moore's law). While this is an empirical observation, it is driven by a fascinating array of physics research. Particularly interesting is photolithography, in which light is used to image a mask onto a wafer. The mask contains the structures to be printed, while the wafer contains a photosensitive layer that gets exposed to the light in just the right places. After exposure, the wafer is processed to turn the printed structures into a final device. These steps are repeated many times to produce a modern IC.

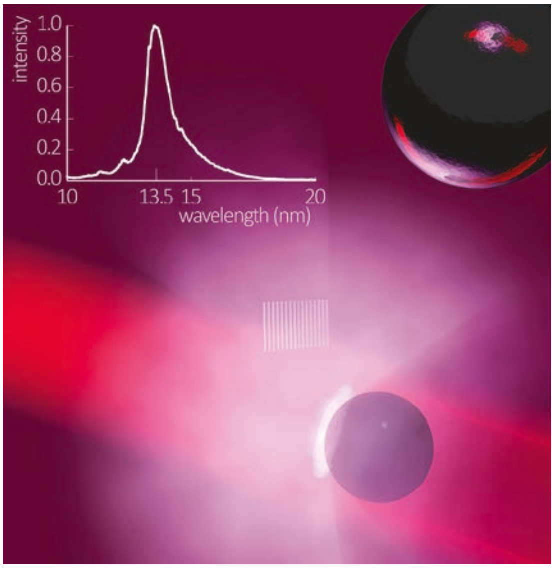


Image: Tremani/ARCNL, from *Nature Communications* 11: 2334 (2020)

LPP formed by the irradiation of liquid tin microdroplets by high-energy ns laser pulses. The hot, dense plasma generates extreme ultraviolet light near 13.5 nm, relevant for state-of-the-art nanolithography.

To successfully produce nanostructures with such a lithographic process is a daunting task, with a range of optical-physics-related challenges. The Advanced Research Centre for Nanolithography (ARCNL) in Amsterdam performs fundamental research with an application perspective into lithography. The ARCNL research programmes have close ties to Laserlab-Europe partner LLAMS at the Vrije Universiteit.

A large part of the research at ARCNL involves light and lasers. Next-generation lithography machines based on extreme-ultraviolet (EUV) radiation are becoming a reality, employing a laser-produced plasma (LPP) based source to produce EUV radiation. Such LPPs present a rich research area in which laser science, atomic spectroscopy and plasma physics come together. In addition to the light used for lithography itself, light also plays a crucial role in metrology: to print a nanostructure in exactly the right position with nanometre accuracy involves an array of laser-based measurements, including optical imaging, coherent diffraction, and ultra-broadband scatterometry. These techniques are fast, non-invasive and can reach sub-nanometre positioning resolution through phase-sensitive detection. Therefore, at ARCNL we have established research programmes including digital holographic microscopy, lensless EUV imaging, imaging in scattering media, and attosecond spectroscopy with high-harmonic generation sources.

Stefan Witte and Oscar Versolato (LLAMS/ARCNL)

F. Torretti et al., Nature Communications 11: 2334 (2020)

Using femtosecond laser pulses to modify bimetallic nanoparticles (CLUR, Spain)

Nanoscience and nanotechnology, in particular, the strong interaction of conduction band electrons of noble metal nanoparticles (NPs) with electromagnetic radiation, have great interest for catalytic, plasmonic and magnetic applications. This interaction gives rise to localised surface plasmon resonances (LSPRs), producing novel optical, electrical and magnetic properties. Silver has a higher plasmonic activity than gold, but its chemical instability is an important drawback. One promising strategy to overcome this is using Au-Ag alloys [1], but their controlled formation is not a trivial task.

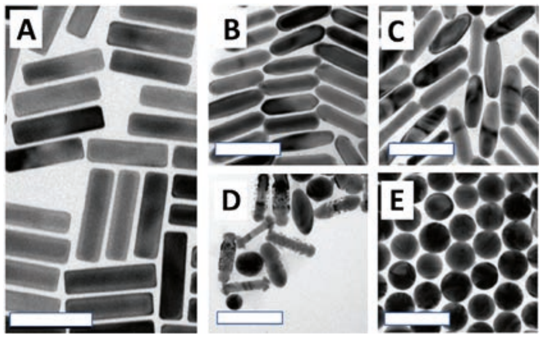


Image: CLUR

TEM micrographs before (A) and after irradiation with fluences of (B) 3.2 J/m², (C) 6.4 J/m², (D) 33.28 J/m² and (E) 92 J/m². Scale bars: 100 nm.

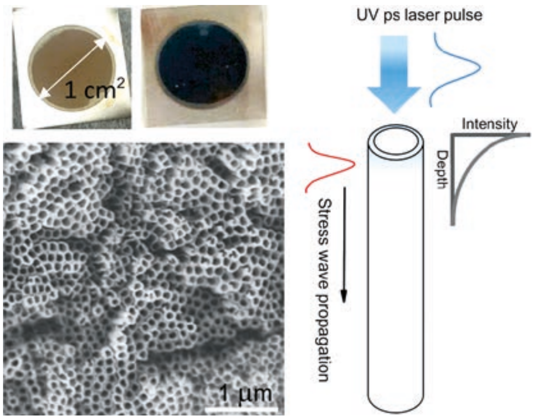
Scientists at the Center for Ultrafast Lasers (CLUR) have used a novel approach, based on the fabrication of Au@Ag core-shell structures via wet chemistry and their irradiation with 800 nm fs pulses to induce melting and alloying [2] (Figure A). The energy transferred to the nanostructure by the laser pulses thermally activates the Au and Ag atoms, which enhances diffusion and causes mixing and alloy formation. Both the deposited energy and the heat dissipation rate play an important role in the shape and distribution of the metals in the final alloyed nanostructure [2]. Hence, Au@Ag nanorods can be reshaped to produce diverse novel nanostructures just by controlling the pulse fluence and the surfactant concentration. At low fluences, the core-shell structure is maintained, and only slight reshaping is observed, mostly at the tips (Figure B). Increasing the fluence to 6.4 J/m^2 formed rice-like NPs, as well as other structures (Figure C). Partial alloying was confirmed by HAADF-STEM tomography and EDX tomography. This effect was more evident at 33.28 J/m^2 (Figure D), and at 92 J/m^2 (Figure E) we obtained completely alloyed NPs. This technique enables the partial or complete alloying of Au@Ag nanoparticles in a simple and reproducible manner, with potential applications in other heterostructures. The main requirements are the ability of such nanoparticles to absorb laser light (either via excitation of LSPRs or interband transitions), and the availability of fs-laser pulses with the desired wavelength and fluence. This methodology is expected to provide novel routes for synthesising colloidal bimetallic alloy nanoparticles with precise control over their size and composition.

Luis Bañares (CLUR), Andrés Guerrero-Martínez (Universidad Complutense de Madrid) and Ovidio Peña-Rodríguez (IFN, Universidad Politécnica de Madrid)

[1] G. González-Rubio et al., Adv. Opt. Mater. 9: 2002134 (2021)
[2] G. González-Rubio et al., Science 358: 640-644 (2017)

Laser crystallisation of titanium dioxide nanotubular layers for photovoltaic applications (HiLASE Centre, Czech Republic)

Image: HiLASE



Left: Initial and laser-annealed TNT sample (1 cm^2) and its magnified view, demonstrating the absence of any signs of melting or deformation. Right: a schematic of the laser-induced solid phase crystallisation.

With the increasing world population, biocompatible and green-chemistry-based sustainable energy sources, air purification and wastewater treatment plants are increasingly important. Photocatalysts, particularly TiO_2, are of interest, for example in dye-sensitised solar cells or air and water purification. Most of these applications involve nm-scale TiO_2 structures. Anodic TiO_2 nanotube (TNT) layers are very promising, comprising several-µm arrays of nanotubes with a diameter of 90-100 nm.

Highly-ordered anodic TNT layers can be grown in fluoride-ion-containing electrolytes. However, the as-formed TNT layers are amorphous. For photocatalytic applications, the crystalline structure is a crucial parameter, with anatase being the typical preference. This is usually produced via thermal annealing, which is both time- and energy-consuming. Laser annealing is relatively quick and can offer localised annealing of TNT layers, but the resulting layers are usually molten on top.

The HiLASE Centre, in collaboration with the Centre of Materials and Nanotechnologies (University of Pardubice, Czech Republic) have achieved laser crystallisation of anodic amorphous TNT layers into the anatase phase [1]. The process takes around 14 minutes and the resulting anatase TNT layers do not show any signs of deformation or melting.

This was achieved with the combination of high energy per pulse, ultrashort pulse duration (~2 ps), and high repetition rate available on HiLASE Perla-C. The crystals formed via explosive solid-phase crystallisation, which is ignited by the laser-induced stress wave formed in the light absorption zone on the top of the TNT array, and which propagates one-dimensionally along the nanotubes. Careful analysis of the absorbed energy, initial temperature rise, and stress amplitude supports this crystallisation process.

The laser-annealed TNT layers were found to have a lower overpotential for hydrogen evolution (important for hydrogen-based electrochemistry) than oven-annealed TNT. XPS spectra similarly show a better surface stoichiometry. Photo-electrochemical measurements reveal that the laser annealed TNT layers contain more defects than the oven annealed TNT layers, resulting in lower photocurrent densities, a lower flatband potential and higher donor concentration.

The new process is fast and clean, avoiding oxidation of the underlying titanium substrate and allowing patterned crystallisation in localised areas. The new understanding of the high-power-laser crystallisation process opens methods for non-destructive laser annealing of other amorphous semiconductor structures.

Inam Mirza, Nadezhda M. Bulgakova and Tomáš Mocek (HiLASE Centre)

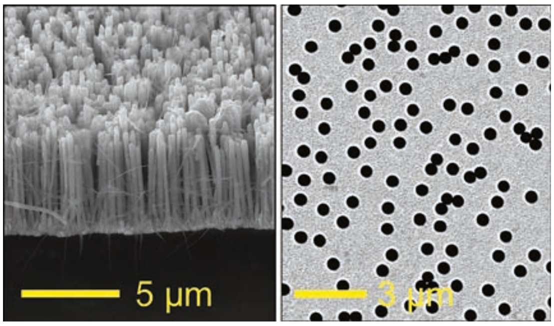
[1] H. Sopha et al., RSC Adv. 10: 22137-22145 (2020)

Nanostructured materials to improve the efficiency of laser-driven ion sources (LLC, Sweden)

Achieving a tunable, reliable source of ion beams would facilitate scientific, technological and possibly medical breakthroughs. For the past two decades, a particularly active research field has been the theoretical understanding and experimental control of ion beams produced by focusing an intense, ultrashort laser pulse onto thin solid targets.

A major challenge is to increase the conversion efficiency from laser energy to ions. For this, a well-established strategy consists of adding nanostructures to the surface of the irradiated target, typically a few-µm-thick metallic foil. Different shapes, sizes and arrangements of the nanostructures can favour the acceleration processes and in turn produce ion beams with higher energies when compared with simple flat foils.

In this context, recent studies of proton acceleration from nanostructured targets (see figure) have been performed at the Lund Laser Centre (LLC) in collaboration with researchers from Institut de la Recherche Scientifique INRS-EMT of Varennes (Canada) [1] and the University of Gothenburg (Sweden) [2]. Targets consisted of thin foils with the surface either covered with a forest of nanowires or perforated with nm-scale holes. Together with numerical simulations, the experimental results allowed exploration



Nanostructured targets used at LLC to accelerate proton beams. (Left) Cu nanowires grown by electrochemical deposition on 300 nm-thick Au substrates. (Right) 200 nm-diameter nanoholes in 100 nm-thick Au foil, realised with hole-mask colloidal lithography. Partially modified from [1] under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

of the role of different geometrical parameters, validation of the efficiency of the structures, testing of manufacturing inaccuracies, and better understanding of the conditions of laser-plasma formation that affect the final energy of the proton beam.

Besides target design, fabrication and metrology are crucial for achieving reproducible ion beams. At the laser intensities required for plasma acceleration (>10^{18} W/cm^2), targets are ablated and must be renewed after each shot, and their availability becomes even more relevant for the development of laser-driven sources with a high repetition rate (1-10 Hz). This clearly adds a challenge to the many different fabrication techniques (coating, lithographic, mechanical, chemical), which must deliver large quantities of targets with consistent structures. Realistically, there will be a trade-off between ion acceleration efficiency and cost-effectiveness.

For these reasons, ion acceleration from nanostructured targets joins expertise from the domains of laser-plasma interaction, photonics, materials science and nanoengineering. Innovative designs and high reliability remain key for pushing forward the understanding and optimisation of laser-driven ion sources.

Giada Cantono (LLC)

[1] S. Vallières et al., Sci. Rep. 11: 2226 (2021)
[2] G. Cantono et al., Sci. Rep. 11: 5006 (2021)

Ultrafast skyrmion reshuffling (MBI, Germany)

Smaller, faster, more energy-efficient: future requirements for computing and data storage are hard to fulfil and alternative concepts are always being explored. Particle-like magnetisation patches that form very small swirls in an otherwise uniformly magnetised material, called skyrmions, show great potential for novel memory and logic devices. Skyrmions are stable at room temperature, with diameters down to the 10-nm range. To be considered for practical application, however, fast and energy-efficient control of these nanometre-sized skyrmions is required.

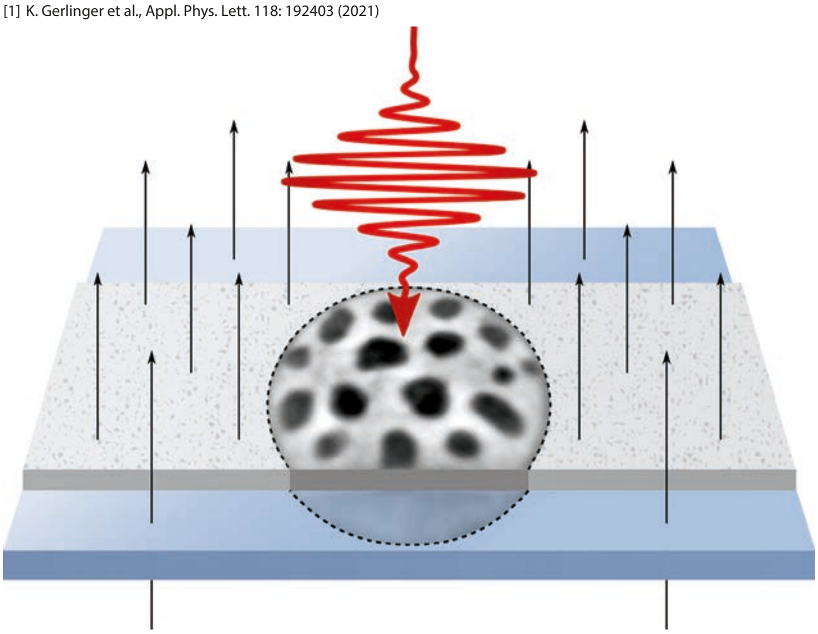
A team from the Max Born Institute, Helmholtz-Zentrum Berlin, Massachusetts Institute of Technology and others have investigated in detail how laser-based "skyrmion writing" can be controlled for use in devices. Sub-ps laser pulses, applied in the presence of an external magnetic field, can be used to write and erase them. This provides a faster and potentially more energy-efficient route than previous electrical methods. To image the skyrmions, holography-based X-ray microscopy was used, which can visualise the tiny magnetisation swirls.

There is a material-dependent window of laser intensities which permits the creation of a new skyrmion pattern which is completely independent of the previous magnetic state. Remarkably, the number of skyrmions created within the laser spot is not influenced by the laser intensity but by the external magnetic field, which can be precisely controlled. The strength of the external field therefore provides a "tuning knob" for the number of skyrmions created and even allows for annihilation of skyrmions [1]. The controlled creation or annihilation of single skyrmions within the laser spot was also demonstrated, representing the writing of a single bit.

The creation of a tunable skyrmion spot, independent of the prior magnetic state, is of interest for potential future devices since it could be used as a "skyrmion reshuffler" for stochastic computing. Stochastic computing represents numbers by strings of random bits with a given length, and with the probability of encountering "1" encoding the number value. Computations can then be carried out via logic operations between the individual bits within a string. However, completely randomised bit strings are needed in order to obtain correct results. The skyrmion reshuffling in this project was on the picosecond timescale, which is compatible with state-of-the-art computer clock speeds and is much faster than in previous efforts based on thermal diffusion (operating on the second-timescale).

Bastian Pfau and Rebecca Davenport (MBI)

[1] K. Gerlinger et al., Appl. Phys. Lett. 118: 192403 (2021)



A single laser pulse of appropriate intensity can create random skyrmion patterns, with density defined by an external magnetic field (arrows). This can be used as an ultrafast "skyrmion reshuffler" for stochastic computing. The dashed circle marks the field of view of the X-ray holography microscope used to see the magnetic skyrmions (appearing as black dots), 1 µm in diameter.

Microtargetry for the Nanoworld (CLF, United Kingdom)

The Central Laser Facility at the STFC Rutherford Appleton Laboratory has been supported by a Target Fabrication Group since its beginnings over 40 years ago. The targets that are supplied allow the exploitation of the facilities' high-power lasers to study fundamental physics such as shock propagation, particle acceleration and X-ray generation. Over the last decade this targetry has become more complex, with tolerances and specifications now regularly required at the nm level.

Images: CLF

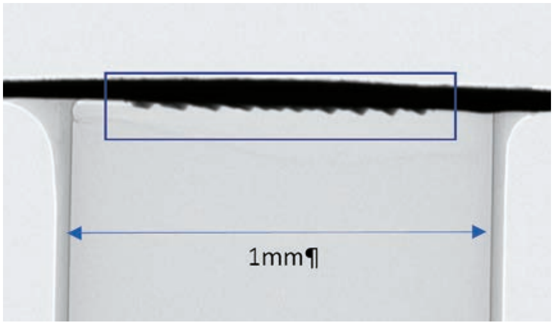


Figure 1: Structured foil as part of a complex RT target. The dual-mode structure can be seen on the rippled foil. The tube diameter is 1mm and the ripple target is highlighted.

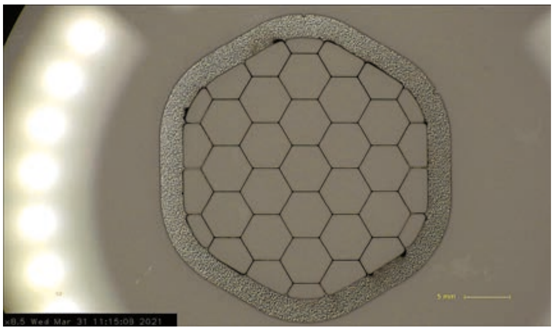


Figure 2: A niobium mesh micromachined using a 1033nm fs laser to provide a support for a thin film filter.

The dedicated team of scientists and engineers in the Target Fabrication Group are bringing capabilities on-line to meet these challenges and have recently invested in single point diamond turning (SPDT), advanced deep reactive ion etching for processing silicon wafers (DRIE), nanowire growth for increased laser absorption onto targets, and a suite of precision laser micromachining systems that are operated by its spinout company Scitech Precision Limited.

Targets that can be fabricated using these advanced capabilities include sine-wave 'rippled' structures for the investigation of Rayleigh–Taylor instabilities. The features have periods of a few tens of micrometres and amplitudes of approximately 5 micrometres with Figure 1 showing a complex dual mode structure. The structures are often part of a more complex assembly with the target in Figure 1 showing a tube containing microstructured plastic foam through which material from the ripple target propagates.

In addition to targets, complex structures such as fine meshes in hard-to-machine materials can be laser micromachined. The example in Figure 2 shows a niobium mesh supporting a thin-film filter for space applications. It was machined from a 50 micrometre foil with arm thicknesses as thin as 40 micrometres.

Targetry will be the limiting factor in fully exploiting the latest developments in laser technology, so the move to higher volume production is the challenge for the next decade.

Christopher Spindloe (CLF)

Femtosecond laser pulses modify the properties of 2D materials (Laserlab-NSC, Finland)

It is expected that 2D materials will become commonplace in electronic devices over the coming decade. One of the central obstacles to this development is modifying the properties of 2D materials to improve their performance.

Researchers at Laserlab-NSC have shown that photons can be used to modify the electronic, optical, chemical, and mechanical properties of 2D materials. The key to successful laser-induced material modification is the combination of femtosecond pulses and fluences just below the ablation threshold. Two distinct processes were obtained using direct laser writing with femtosecond laser pulses.

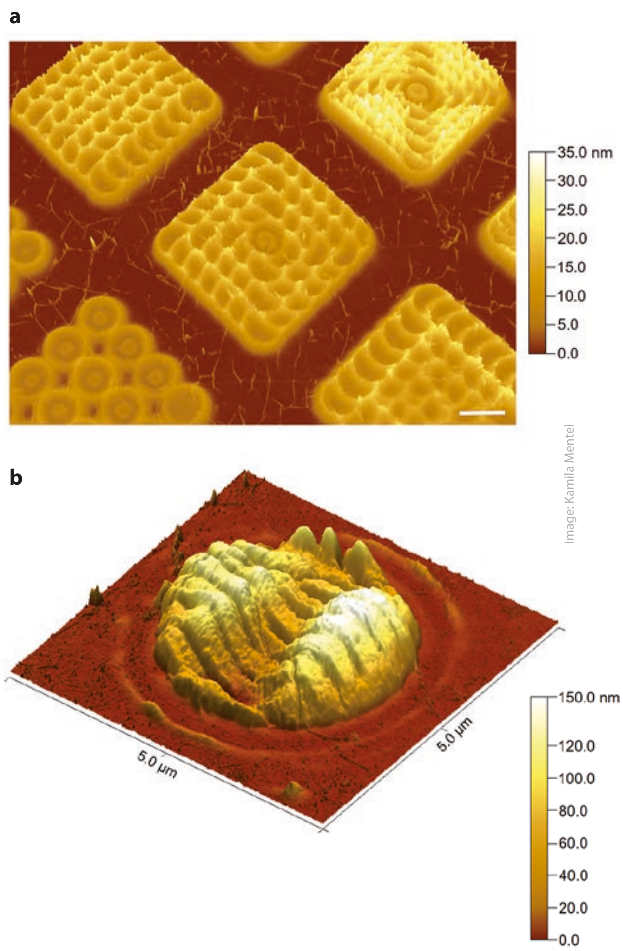


Image: Kamila Mentel

AFM images of laser-modified graphene. (a) 3D patterns prepared on monolayer graphene on Si/SiO_2 substrate. Scale bar 1 µm. (b) Laser-induced ripples on suspended monolayer graphene. The sample was fabricated by etching a round hole on a SiN membrane and transferring graphene onto it.

Irradiation of graphene under inert atmosphere forms localised defects, inducing strain and causing the graphene to bulge out of plane. This effect can be used to write 3D structures with sub-diffraction-limited features on graphene/SiO_2/Si [1] and other 2D materials, such as MoS_2 [2]. Higher doses lead to line defect formation and activation of luminescence via the formation of small graphene "islands", mimicking carbon nanodot material [3]. The rippling phenomenon induced on suspended graphene increased its stiffness by several orders of magnitude [4].

When specimens are irradiated under ambient atmosphere, the oxygen-containing groups are incorporated into the graphene lattice. This process enables the laser writing of oxidised areas on graphene. The oxidation opens a band gap, which is beneficial for electronic circuit fabrication. Additionally, the oxidised areas can be used for selective adsorption of molecules, as was demonstrated for protein immobilisation [5].

These methods provide a great toolbox for the optical writing of electronic circuits and device fabrication. Furthermore, the possibility to combine them with area-selective chemical functionalisation of 2D materials is promising for the development of biosensors and other devices.

Mika Pettersson and Kamila Mentel (Laserlab-NSC)

[1] K. K. Mentel et al., Nanoscale Adv. 3: 1431 (2021)
[2] M. T. Turunen et al., Adv. Mater. Inter. 8: 2002119 (2021)
[3] V.-M. Hiltunen et al., J. Phys. Chem. C 124: 8371 (2020)
[4] V.-M. Hiltunen et al., NPJ 2D Mater. Appl. 5: 49 (2021)
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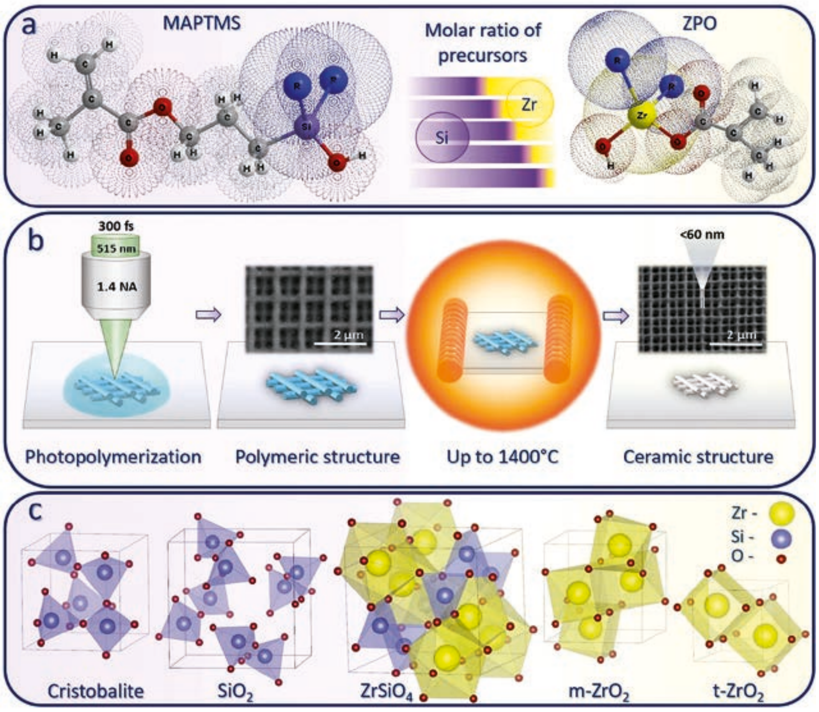
Laser nano-printing of 3D crystalline structures (VULRC, Lithuania)

A novel route for laser nano-printing of 3D crystalline structures has been developed, employing ultrafast laser lithography – used as additive manufacturing tool for producing true 3D nanostructures – and combined with high temperature thermal post-treatment, converting the printed material into a fully inorganic substance.

This inter-disciplinary experimental work was performed by a group of applied chemists and laser physicists at Vilnius University. They revealed the potential of tuning the sintered ceramic structure into distinct crystalline phases, including cristobalite, SiO_2, $ZrSiO_4$, m-ZrO_2, and t-ZrO_2.

In the systematic study, the starting model material was SZ2080™, and its derivatives containing variable fractions of Si and Zr were used to tune the resulting phases of the crystalline nanostructures. The laser fabricated and calcinated structures experienced downscaling in dimension towards 40-90% of their initial volume, yet perfectly preserving the designed 3D architectures, including porosity. The sintering process ensured complete removal of organic substances and re-arrangement of the material into glassy or crystalline ceramic matter. With more zirconium, the inorganic material is achieved at a lower temperature. The strong adhesion to the quartz or corundum substrates and high robustness in both high and cryogenic temperatures was validated by flushing the



A graphical summary showing: (a) raw organic and inorganic precursors and their molar ratios in synthesis (b) laser photopolymerisation and high-temperature calcination technology (c) resulting crystalline phase nano-lattices after calcination. These can all be observed and tuned depending on the treatment temperature and initial hybrid material compositions.

3D nanostructures directly with liquid nitrogen down to -196°C for 10 min and letting it evaporate freely. No detachment, delamination, or fracture of the structures was observed. The process and outcome are summarised in the figure.

This approach achieved sub-60 nm individual 3D features without any beam shaping or complex exposure techniques, thus makes it reproducible with other laser direct writing setups. The principle is also compatible with commercially available platforms (including Nanoscribe, MultiPhoton Optics, Femtika, Workshop of Photonics, UpNano, MicroLight).

The validation of the combined laser manufacturing and thermal-treatment technique upgrades the widespread laser multi-photon lithography process to create a powerful tool enabling additive manufacturing of crystalline ceramics at unprecedented precision and three-dimensional flexibility. This breakthrough is a milestone significantly contributing towards advancing the field of future opto-electronics.

Darius Gailevičius and Mangirdas Malinauskas (VULRC)

[1] G. Merkininkaitė et al., Opto-Electron. Adv. 5: 210077 (2022)

Ghost spectroscopy: an efficient and high-resolution approach for absorption measurements using free electron lasers radiation

X-ray absorption spectroscopy (XAS) is one of the most powerful investigating tools of X-ray based science, facilitating access to the electronic and magnetic properties of condensed matter. Indeed, tuning the photon energy to a specific absorption edge allows, for instance, determination of the oxidation state of an atomic species, or combing core level resonance with light polarisation allows investigation of the spin degree of freedom in magnetic materials.

In recent years, the advent of X-ray and extreme ultraviolet (XUV) free electron lasers (FELs), which can produce ultra-short and ultra-bright coherent pulses, has boosted XAS spectroscopy into the ultra-short-time domain, preserving specific energy levels of an atom and allowing unprecedented resolution. Traditional XAS of a target is performed by scanning the central photon energy of a narrow linewidth X-ray source. For each photon energy, the total number of photons absorbed by the target is measured and the material absorption spectrum is recorded, changing the input photon energy in steps. However, most of the worldwide FEL facilities are based on the self-amplified spontaneous emission (SASE) process, which naturally produces stochastic broad-bandwidth radiation that fluctuates in either intensity or spectral content. The use of such radiation for time-resolved applications requires complex experimental setups involving monochromators or multiple spectrometers before and after the sample.

An alternative approach, based on ghost spectroscopy (GS), has been recently demonstated in a transnational access project at the FERMI FEL in Trieste Italy, supported by Laserlab-Europe. GS is directly derived from ghost imaging, a widely used imaging thechnique in which spatial properties are reconstructed by measuring the incident probe's transverse properties. In GS the randomness of spectral features recorded on the spectrometer are correlated to the intensity fluctuation recorded by the single-pixel detector (the so called "bucket detector") placed behind the sample to obtain its spectral response. The reconstruction of the spectrum by GS can be formulated mathematically across n different measurements with a spectrometer of m energy pixels and can record the input SASE spectrum as a linear matrix multiplication:

$$\mathbf{A} \cdot \mathbf{x} = \mathbf{T}$$

Where $\mathbf{T}$ is a length-n column vector in which each element is the bucket detector reading for each measurement $\mathbf{T}_i$, $\mathbf{A}$ is the $n \times m$ matrix containing the spectral information of the n shots, and $\mathbf{x}$ is the length-m row vector of the unknown variable to be reconstructed representing the sample spectral response.

Figure 1: GS experimental scheme.

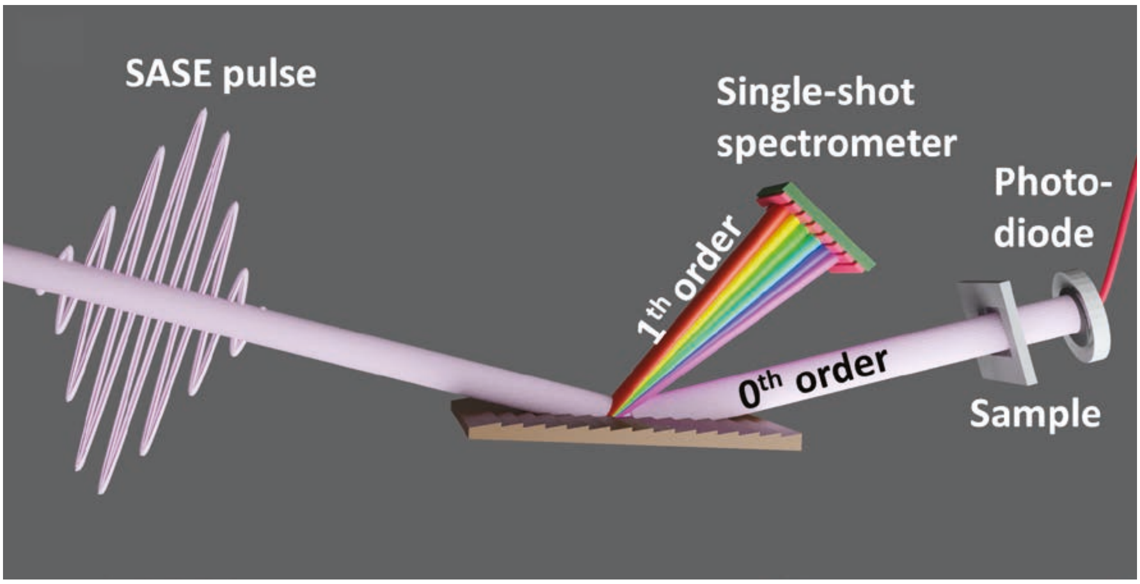


Image: Bar Ilan University

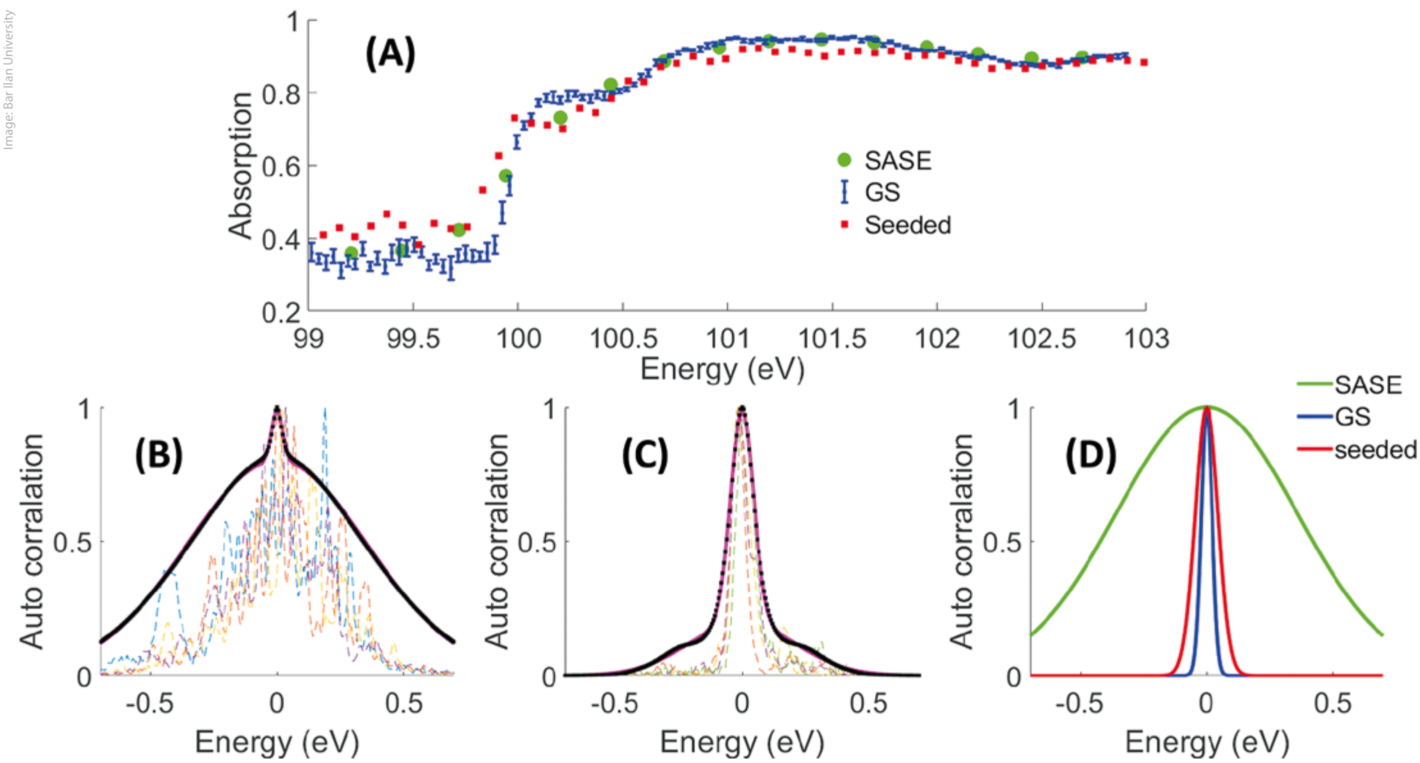
To demonstrate the GS approach, FERMI FEL was tuned both in SASE mode operation and, for comparison, in seeded mode. The pulse's central energy was varied between 99 eV and 107 eV for the measurements of the Si $L_{2,3}$ edges.

Figure 1 shows the scheme of the experimental setup. The energy spectrum of the radiation produced by the source was recorded in a shot-to-shot fashion by an online spectrometer placed before the sample. After focussing, the effect on the pulse intensity of the interaction with the crystalline Si sample was measured on a photodiode. Figure 2(A) shows the comparison of the absorption spectrum of the crystalline silicon reconstructed by GS (blue dots), with the spectrum achieved by scanning the FEL pulse energy in seeded emission mode (red squares), and in SASE configuration (green circles). Due to the narrow emission line, the resolution of the crystalline Si spectrum recorded using the FERMI source in seeded mode is higher with respect to the SASE mode, which can easily be understood by comparing the bandwidth of the emitted radiation in the different operation modes. Indeed, the average bandwidth of SASE emission is about 0.6 eV (Figure 2(B)), almost an order of magnitude larger than for the seeded case (0.075 eV, Figure 2(C)). However, the GS reconstructed Si spectrum has a higher resolution than the one recorded scanning the energy range in seeding mode. Indeed, as shown in Figure 2(B), a broadband single-shot SASE spectrum is formed by several narrow spikes (with a spectral width smaller than that of the seeded emission), which randomly fluctuates shot-to-shot, thus sampling the full bandwidth of the average SASE emission. These narrow features are the key parameter for the higher resolution seen with GS reconstruction. To be more quantitative, Figure 2(D) compares the spectral resolution of the three methods obtained by fitting the average spectral auto-correlation function (black curves in Figures 2(B) and (C)). The resolution of GS reconstruction is estimated to be about 0.035 eV, as the full width half maximum of the Gaussian fit of the narrow central peak in the auto-correlation function of Figure 2(B).

It is worth noticing that the results of this new experiment indicate clearly that GS provides a better resolution than the seeded configuration (and much better than the SASE case) but with the same number of scanning points as the SASE beam. As a consequence, the acquisition time compared to the seeded case is considerably shorter. The extension of this work to transient spectroscopy measurements, implemented by pump-probe approaches, is straightforward and the reduction in the measurement time for those experiments will be more significant since the typical durations of pump-probe experiments is very long.

Yishai Klein and Sharon Shwartz
(Physics Department and Institute of Nanotechnology and Advanced Materials, Bar Ilan University, Israel)

Figure 2: (A) Si absorption spectrum across the $L_{2,3}$ edge reconstructed using the GS approach (blue dots) and scanning the input photon energy setting the FEL emission in the SASE (green dots) and the seeded regime (red dots). In (B) and (C) the dashed lines are examples of a single shot spectrum in the SASE and seeded regimes respectively. The dark lines are the auto-correlation function in the SASE and seeded cases. The narrow central peak in the SASE auto-correlation function is a measurement of the average spike width under such a source emission mode. (D) Gaussian fits from the auto-correlation functions corresponding to the resolution of the three methods.



With governing structures in place, ELI ERIC makes strides towards user access

Since its establishment in April 2021, ELI ERIC has put in place important cornerstones for operations. The ELI ERIC governing and advisory bodies, General Assembly (GA), Administration and Finance Committee (AFC), and International Scientific Advisory Committee (ISTAC) held their first meetings and made key decisions on policies. The ISTAC is chaired by John Collier (CLF) and involves 14 prominent representatives of the community. ELI ERIC will also look to recruit a Director of Science this year.

A key achievement of 2021 was the approval of the User Access and Scientific Data Policies by the GA, which provide a framework for how access will be offered and scientific data handled. Access will be allocated on an excellence basis through peer-reviewed selection of proposals, part of which will be dedicated to mission-based access, a mode of access supporting research in thematic areas addressing innovation and societal challenges. There will also be the possibility of proprietary access.

Image: ELI Beamlines

In 2022, focus is on opening the ELI facilities for users with the launch of the user portal and first ELI ERIC peer-reviewed calls for proposals foreseen for mid-year. Enabling user access is the main mission of ELI and a critical milestone that will drive the scientific excellence of future research to be performed. Overall, activities in 2022 will concentrate on the further integration of the ELI ERIC facilities, in addition to expanding collaborations with the scientific community and strategic partners.

Alexandra Schmidli (ELI ERIC)

Launch of the "Laserlab-Europe Talks"

Laserlab-Europe is launching the "Laserlab-Europe Talks", a series of online seminars, lectures and panel discussions organised by our community on diverse topics of common interest. The events will provide a platform for regular information exchange and knowledge sharing.

The talks will take place bi-weekly on Wednesday afternoons at 16h00 CET and are open to all interested parties, from PhD students to experts in the field and industrial and medical partners as appropriate.

The first scheduled talks already illustrate the broad range of topics that Laserlab-Europe scientists are investigating:

- 9 February 2022, Multi-photon 3D lithography for sub-100 nm additive manufacturing of inorganics, Speaker: Mangirdas Malinauskas (VULRC)
- 23 February 2022, Next generation imaging and image-guided diagnosis and therapy for cancer
  - Time domain multiwavelength diffuse optics in breast cancer management, Paola Taroni (POLIMI)
  - Theranostics with photoacoustic tomography and photosensitisers, Luis Arnaut (CLL)
  - Multimodal photoacoustic imaging of tumor angiogenesis, Jithin Jose (FUJIFILM Visualsonics)
- 9 March 2022, Ultra-high charge electron beam generation using TW-class femtosecond laser system, Diana Gorlova (M.V. Lomonosov Moscow State University)

The next events will address energy-related topics, such as batteries and fusion energy. Check the Laserlab-Europe webpage for registration, future topics and details.

Laserlab Europe

How to apply for access

Interested researchers are invited to contact the Laserlab-Europe website at www.laserlab-europe.eu/transnational-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 Laserlab-Europe 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 Laserlab-Europe. 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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