PRESS RELEASE

Kilowatt boost for ultrafast laser material processing

A new ultrashort pulse (USP) laser beam source from TRUMPF, designed for industrial use, will significantly expand the range of applications of USP laser processes. The Fraunhofer Institute for Laser Technology ILT in Aachen will be systematically exploring the potential of this beam source with an average output of 1 kW in the coming months. Among other things, experiments are planned to optimize processes in battery and fuel cell production, toolmaking and semiconductor technology, as well as to test various beam guidance strategies. Many of these pilot applications have their origins in the Fraunhofer internal Cluster of Excellence Advanced Photon Sources (CAPS), to which 21 institutes of the Fraunhofer-Gesellschaft belong.

"In the Fraunhofer CAPS cluster, we want to clarify how high-power beam sources can expand the range of applications for USP laser processes," explains Dr. Dennis Haasler, leader of the group Micro- and Nano Structuring at Fraunhofer ILT. His team will systematically examine this question over the next few months with appropriate experiments. The focus will be on a new USP laser beam source from TRUMPF with an average output power of 1 kW.

As part of a bilateral cooperation, the company is providing Fraunhofer ILT with the new TruMicro 9000, a system designed for industrial applications. Since it provides power into the kilowatt range, this beam source offers many times the average power of the currently most powerful USP lasers for industry. Its pulse energy of 10 mJ also significantly exceeds the previously available level. Indeed, the system has the potential to trigger a productivity boost in USP material processing that many users are waiting for: it has a pulse duration of less than 900 fs, numerous burst options and a very high beam quality of $M^2 < 1.3$ – combined with high flexibility at different operating points and the operating standards familiar from TRUMPF industrial lasers. "For the first time, we have a kilowatt beam source that performs like established industrial USP lasers in the 200 W class," explains Haasler. He and his team will now evaluate how the high-energy laser pulses can be used for industrial manufacturing and finishing processes.

High performance based on a combination of proven technology components

"By combining tried-and-tested technology components in the amplifier chain, we have succeeded in significantly increasing both the maximum individual pulse energy and the resulting average power," reports Steffen Rübling, product manager for the

USP lasers in the TruMicro family at TRUMPF. According to Rübling, the new beam source achieves the typical USP laser beam quality despite its impressive output because the development team was able to draw on a wealth of experience: TRUMPF offers USP lasers of various power classes, each of which is based on different amplifier technologies, including fiber, disk and slab amplifiers. In addition to this technological diversity within their portfolio, the team also benefited from the knowledge gained from component development for continuous wave (cw) and short pulse lasers. For example, the main amplifier of the new TruMicro 9000 – a so-called multi-pass cell – was originally used to amplify nanosecond pulses in the power range of 3 kW. The transfer of such tried-and-tested technology modules to the USP beam source has ensured that it meets industrial requirements straight away. With this stable beam source, Fraunhofer ILT can now explore its application potential.

It depends on the right process strategies

The ILT team will focus on process control strategies and system designs that can be used to optimally utilize the high average power for processing the respective workpieces. Several test setups are available in the Fraunhofer ILT laboratory for this purpose, which the team can use to direct the high power and energy input of the beam source onto the component surfaces for effective and gentle processing. A key advantage of USP laser processes comes into play here: Although their femtosecond or picosecond pulses concentrate a great deal of energy, the thermal load on the material remains minimal thanks to their short duration.

As the new system has a power level of 1 kW and high pulse energy, beam splitting and beam guiding strategies that promise greatly increased productivity through the parallelization of the machining processes are necessary. To prove this, Haasler's team will be relying on the four system technology approaches shown schematically in Figure 4: The simplest approach is the burst mode that can be implemented with conventional galvo scanners. Here, the high energy of the femtosecond pulses is distributed over up to eight individual pulses. The researchers will also be using special system technology and optical strategies for beam shaping and ultrafast beam deflection or for the parallelization of machining processes. "We need the different approaches in order to find out which strategy we can use to achieve the highest productivity for the respective industrial application," explains Haasler. For example, a different system technology is required for the selective ablation of polymer layers from compound bipolar plates than for the point-by-point removal of active material layers on battery electrodes for their contacting or for the micro structuring of metal surfaces.

Ultrafast beam guiding or splitting into up to 900 individual beams

At Fraunhofer ILT, the team will combine the new kilowatt beam source with a polygon scanner from Moewe, which enables scanning speeds of up to 1 km/s on a processing area of 700 x 900 mm². A multi-beam system is also available for the tests, which enables them to test various processing strategies with a single beam or beam splitting into 100 or even up to 900 parallelized partial beams on a processing area of 400 x 400 mm². The fourth option available to the team is beam shaping with spatial light modulators (SLM). This promising approach is currently still under development. As the beam can be transformed into optical stamps of almost any design, it could ensure even greater processing efficiency in the future. "This is especially true in combination with high-power USP lasers," says Haasler.

Fraunhofer ILT will now systematically clarify how the power and pulse energy of the new USP beam source can be turned into an advantage for production with the respective beam guidance and process strategies. The pilot applications come from practical experience. Input is provided by the CAPS cluster, which includes 21 Fraunhofer Institutes. Within the cluster, they can access the specific laser expertise of Fraunhofer ILT and the two Fraunhofer Institutes for Applied Optics and Precision Engineering IOF in Jena and for Material and Beam Technology IWS in Dresden for their own project ideas and applications for their industrial partners. Other USP applications that the team will be evaluating have their origins in various collaborative research projects in which Fraunhofer ILT is working with industrial partners to find new process solutions for the production of batteries, fuel cells or electrolyzers. In addition, there are many applications in toolmaking, medical and environmental technology, semiconductor production and printed electronics in which USP material processing promises quality advantages. However, a widespread industrial use has so far failed due to insufficient productivity levels. This could now change thanks to the performance boost of these USP beam sources.

Broad demand for reliable, highly productive USP processes

With the new USP beam source from TRUMPF, the Fraunhofer team will now clarify in detail how the kilowatt power can be used in material processing, and how the high power level affects the process quality, the workpieces and the optics used. "Ten millijoules of pulse energy require high-quality, precisely designed optical components, explains Haasler. Practical issues such as the heat input into the component or the possible development of contamination as a result of the increased material ablation also need to be clarified. It is also questionable to what extent the combination of high ablation and repetition rates can lead to unwanted shielding of the laser beam at certain points or whether there is a risk of interaction between the ablated material and the surrounding partial beams during multi-beam processing. Other questions concern the service life and contamination of the optical elements in the process chamber and radiation protection. Last but not least, there is the question of whether 1 kW is enough or whether even more powerful lasers are needed to fully exploit the industrial potential of USP processes. According to TRUMPF Product Manager Rübling, the modular architecture of the TruMicro 9000 makes this possible: "In addition to further increasing the average power, we are also able to convert the wavelength or extend or reduce the pulse duration," he explains.

In preparation for the tests with the current system, Fraunhofer ILT has theoretically approached various applications in micro- and nano structuring and calculated the required laser power based on the required material ablation volumes and rates. The spectrum of these applications includes the targeted structuring of graphite layers on the electrodes of lithium-ion batteries to increase their power density and fast-charging capability, the selective ablation or selective roughening of bipolar plates for fuel cells and electrolyzers, the laser structuring of printing rollers and specific applications in printed electronics. Other promising fields of application include ultra-fast nano-polishing, micro-drilling in water filters and cutting wafers into individual chips. According to Haasler, high-performance USP processes also hold great potential for a specific surface functionalization, for example with regard to anti-reflective properties or self-cleaning effects or friction minimization and flow optimization. The aerospace industry also has a need for such functionalization, one that the new system can fulfil since USP processes are suitable for producing highly emissive aluminum surfaces for heat dissipation from satellites.

USP lasers fuel the development of secondary sources

"The quality of USP processes has already been proven in many applications mentioned. The important thing now is to increase productivity to industrial levels," explains Haasler. In order for high-performance USP processes to actually be able to improve more and more products in the future, they would have to meet the cycle times of existing process chains and the cost framework.

Another possible application is the use for secondary sources for generating X-rays, which Fraunhofer ILT is exploring together with TRUMPF and other industrial partners in the current BMBF-funded research project XProLas. USP lasers serve as an upstream beam source when generating X-rays. Their high-intensity pulses are compressed to less than 50 femtoseconds and hit the so-called target – a metal such as gallium, indium or tin – sharply focused. Depending on the respective target, different plasmas are created that emit part of their energy as extremely short-wave light. The project plans to develop highly compact, excellent X-ray sources that will provide insights into ongoing battery charging and discharging processes in the future.

Important impulses toward sustainability

Based on theoretical assumptions for a wide range of applications and materials, the team will now begin practical trials. Their aim is to verify the assumed productivity benefits. Whether selectively ablating the polymer layers of compound bipolar plates or roughening the stainless steel surfaces of metallic bipolar plates, the team will systematically examine the potential of the new 1 kW beam source. Wherever surface enlargement and modifications, polishing, the exposure of contacting zones or nano and micro structuring are required, USP processes can demonstrate their specific advantages in conjunction with the corresponding beam splitting and beam guidance strategies. Their potential ranges from significantly more productive material processing to the substitution of a wide range of chemical processes.

As a result, USP technology will also make substantial contributions to sustainability: Whether it is drilling billions of tiny pores in water filters that are impermeable to bacteria using the multi-beam process, providing aircraft wings and rotor blades of wind turbines with flow-optimizing microstructures, or optimizing the performance of batteries, fuel cells and electrolyzers through nano and micro structuring and selective material ablation, the benefits for environmental and climate protection are obvious. And so the ultrashort, energy-charged pulses of light provide new impetus for the upcoming transformation towards a sustainable society.

Save the date! 8th UKP Workshop Ultrafast Laser Technology

On April 8 and 9, 2025, the 8th UKP Workshop will address the basics of USP technology as well as current developments in the field of USP beam sources and the necessary system technology. The spectrum of topics ranges from the basics of USP laser processing and the latest trends in beam shaping and laser beam sources to applications in electronics, energy storage, glass processing and microelectronics. Experts will also be presenting first results of the test series with the TruMicro 9000 at the congress.

Image 1:
Steffen Rübling, TRUMPF (left), and Dr. Dennis Haasler, Fraunhofer ILT, discuss details of operating the 1 kW USP laser from TRUMPF.
Fraunhofer ILT, Aachen, Germany / Ralf Baumgarten.

Image 2:
Steffen Rübling, TRUMPF (left), and Dr. Dennis Haasler, Fraunhofer ILT, discuss details of operating the 1 kW USP laser from TRUMPF.
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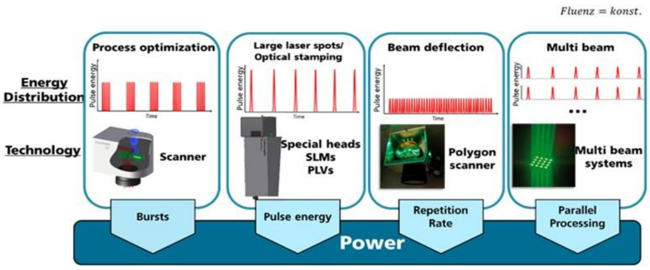
Image 3:
TRUMPF TruMicro 9000: The world's first industrial 1kW-USP laser is located in the user facility of the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS at Fraunhofer ILT in Aachen.



Picture 4:
Systems engineering approaches for implementing high average power in USP machining processes.

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