

Optical stamping with USP lasers

Generating microstructures in record time for the tool and glass industries

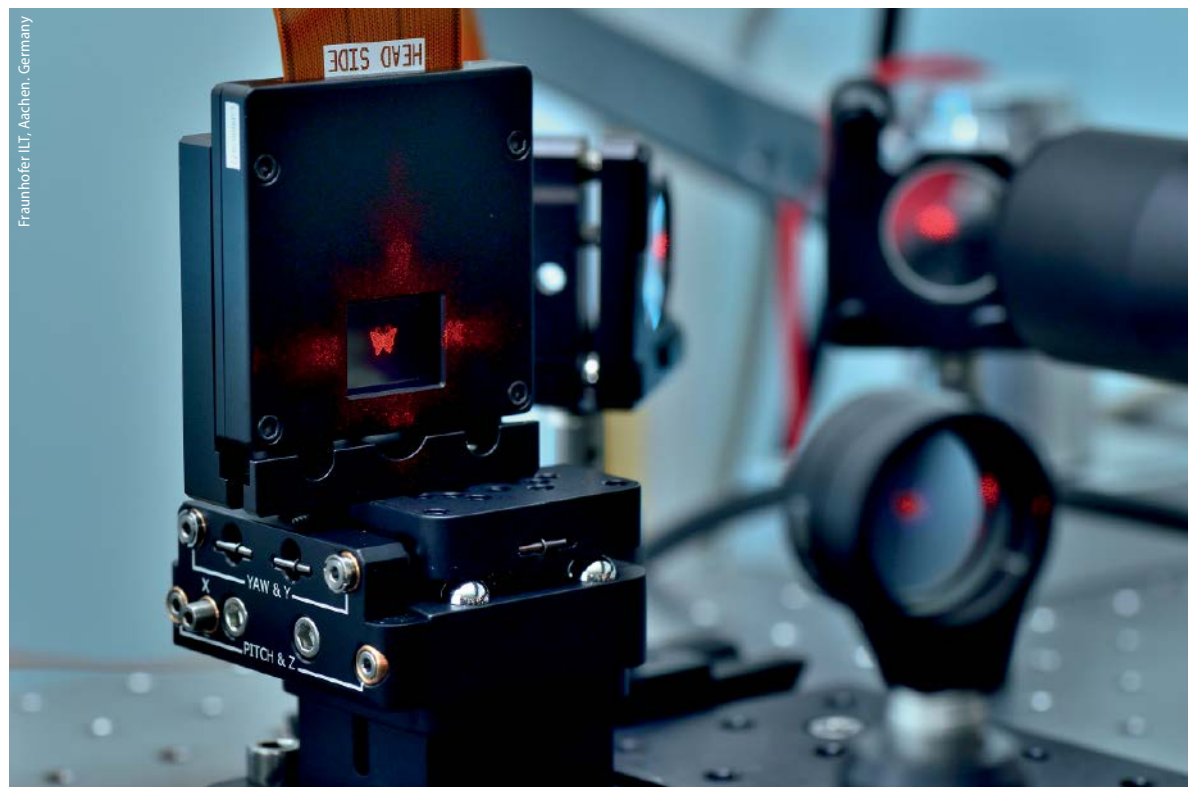


Fig. 1 With the optical stamping process, the beam of an ultrashort pulse laser can be precisely shaped into the desired pattern – such as the butterfly in this image. This allows microstructures to be created precisely, reproducibly, and in a fraction of the time that was previously required.

The optical stamping process enables precise and reproducible generation of microstructures with a single laser pulse – eliminating the need for surface scanning, a time-consuming step. Researchers in Aachen are using a spatial light modulator (SLM) to shape the beam of an ultrashort pulse laser precisely into the desired pattern and apply it directly to the workpiece surface. This significantly speeds up processing and opens up new possibilities for, among others, the steel and metalworking industries or the glass industry. Initial tests show that process times can be reduced by at least 80 percent.

Modern surface treatment processes enable users to precisely adjust material properties. For example, the coefficient of friction can be varied over a wide range; surfaces can be functionalized to be hydrophobic or hydrophilic and even antibacterial.

However, producing such microstructure is often problematic. In ultrashort-pulse laser (USP laser) ablation, a single small laser spot is guided over the entire surface, making the process very time-consuming for large areas. Wet chemical etching not only produces waste that is harmful to health and the environment, but the process is also inflexible because it requires

masks. Electrical discharge machining (EDM) also has its disadvantages: It consumes a great deal of energy, produces toxic sludge, and only delivers random, stochastic microstructures. Unlike the laser process, the surface properties cannot be specifically tailored to subsequent process steps.

“The optical stamping process allows this problem to be circumvented,” explains Sönke Vogel from the Micro and Nano Structuring group at the Fraunhofer Institute for Laser Technology ILT. Vogel and his team use a spatial light modulator to precisely shape the beam of a USP laser into the desired pattern (**Fig. 1**) and apply it to the work-piece surface in

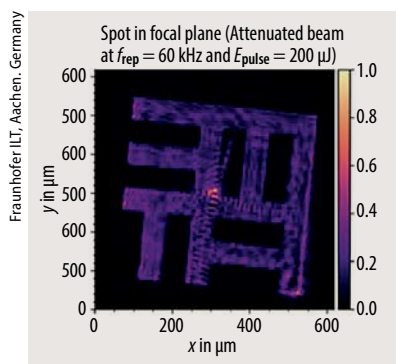


Fig. 2 Unlike permanently installed beam shaping optics, optical stamping allows the pattern to be flexibly adjusted using software.

a single step. “This creates microstructures that are precise, reproducible, and made in a fraction of the time previously required, with significantly less wear and tear compared to mechanical processes and without the need to retool the optics.”

In optical stamping, the laser beam is not guided across the surface using scanner mirrors, but is shaped into the desired structural pattern in a single step and transferred directly to the workpiece. The core component is an SLM with liquid crystal on silicon (LCoS) technology. This reflective liquid crystal display changes the local refractive index with pixel precision, thereby modulating the phase front of the incident laser light, transforming an initially round beam into a complex, freely selectable intensity profile.

Paul Buske from the Computational Optics group at RWTH Aachen University’s Chair of Technology of Optical Systems TOS develops phase masks for the SLM using optical neural networks. Each phase mask corresponds to an optically realized plane, and wave optics methods are used to calculate the connections between these planes. This allows phase masks for almost any desired beam profile to be created quickly and precisely. “Thanks to established AI training methods, optical neural networks enable un-

precedented flexibility in beam shaping,” he explains.

Unlike permanently installed beam shaping optics, this approach makes it possible to flexibly adjust the pattern via software without mechanical changes (**Fig. 2**). “Pattern sizes and geometries can be varied, expanded, or completely replaced,” Vogel continues. USP lasers with pulse durations in the ps and fs range remove material with high precision while minimizing thermal effects. Thanks to this, the industry can generate deterministic microstructures with precisely reproducible geometry, reduce processing times significantly, and adapt structures to the specific requirements of individual components or subsequent processes (**Fig. 3**).

Targeted microstructures for steel sheets

In flat steel production, for example, the surfaces of embossing rolls have so far mostly been microstructured stochastically using EDM. Although the structures embossed in this way improve properties such as the bendability or adhesion of coatings, they are not tailored to specific subsequent processes. In addition, the surfaces of the embossing rolls wear out quickly and have to be regularly reworked at great expense.

In the EU project METAMORPHA, the researchers are pursuing a different approach together with partners. The project aims to develop innovative surfaces and thus sustainably improve the quality of European flat steel products. The partners were able to demonstrate an 81 percent reduction in process time. According to Benjamin Lauer and Kai Horwat, project managers at thyssenkrupp Steel Europe, “innovative surfaces are an important lever for ensuring the quality and competitiveness of European flat steel products. The collaboration in the project shows how laser processes can be transferred directly into industrial practice.”

While EDM structures require the worn roller surface to be mechanically ground down and then completely restructured, deterministic laser structures can be specifically re-lasered (**Fig. 4**). This can extend the roller’s service life by a factor of ten – a significant advantage in terms of material usage, energy consumption, and production costs.

Fast structuring for signal transmission

Another technology demonstration involves low-E glass (“low emissivity”), an ultrathin metal layer on glass that reflects heat radiation

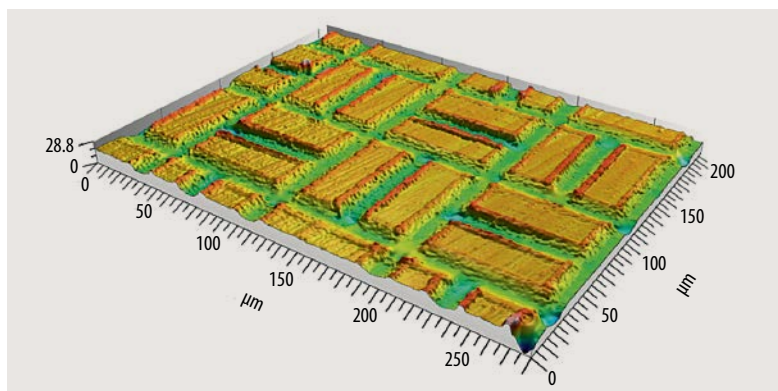


Fig. 3 3D surface profile of an optically stamped microstructure: The deterministic basic pattern is created with stationary laser pulses and shows clearly defined reliefs with reproducible geometry.

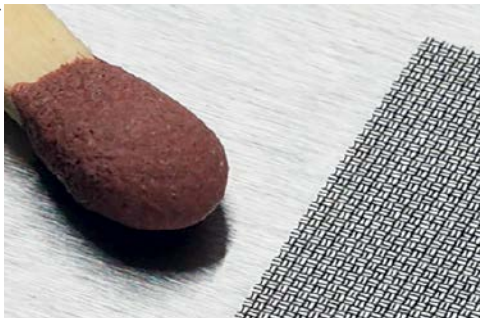


Fig. 4 Component manufactured using the optical stamping process

and thus protects buildings or vehicle interiors from heating up. However, this coating also blocks mobile phone waves. To enable reception, the metal layer must be partially removed – a time-consuming process with a scanning single-beam USP laser.

Optical stamping allows precise openings to be made in the coating in a single pulse without subjecting the glass to thermal stress. The USP laser removes the layer with pinpoint accuracy while leaving the substrate undamaged. In tests at Fraunhofer ILT, the beam was shaped into a circular pattern with a diameter of 450 μm using an SLM and applied at a feed rate of 9 m/s, a pulse energy of 200 μJ , and a repetition rate of 20 kHz (“single-pulse ablation on the fly”). The result: clear, sharply defined structures that allow radio waves to pass through without significantly impairing the thermal insulation. Compared to conventional scanning at 3 m/s, 600 kHz, and 4 μJ per pulse, the processing speed and area rate were dramatically increased by a factor of 30.

Prospects for further applications

The potential of optical stamping extends far beyond the steel and metalworking industries or the glass industry. “In principle, any application that requires periodic microstructures can be developed”, emphasizes Vogel. One

example is hydrophobic surfaces, where defined micro-reliefs specifically increase the contact angle of water. Such structures can, for example, help fuel cells efficiently remove condensate water, thereby improving performance. Another area of application is the direct marking of components with data matrix codes. Here, optically stamped codes can be generated on a millimeter scale in a single process step – an advantage especially for industries with high traceability requirements such as medical technology or the pharmaceutical industry. New possibilities are also opening up in the processing of technical ceramics and the functionalization of plastic surfaces.

“What makes optical stamping so special is the combination of speed, precision, and flexibility,” says Vogel. “We can adjust the structural pattern using software in a fraction of a second without having to mechanically reconfigure the optics. This opens up new possibilities not only for existing applications such as rollers or low-E glass, but also for completely new markets.”

Contact

Sönke Vogel, Micro and Nano Structuring Group, Phone +49 (0)241 8906-180, soenke.vogel@ilt.fraunhofer.de

Dr.-Ing. Dennis Haasler, Group Leader Micro and Nano Structuring, Phone +49 (0)241 8906-8321, dennis.haasler@ilt.fraunhofer.de



17. Blechexpo

Internationale Fachmesse für Blechbearbeitung

10. Schweisstec

21.-24. Okt. 2025

Stuttgart

be part of the best

Blech-, Rohr- und Profilmbearbeitung
Stanztechnologie
Trenn-, Füge- und Verbindungstechnologien
Pressen- und Umformtechnologie
Stahl-, Metallservice und Oberflächentechnik

Das Messeduo zeigt die moderne, zukunftsorientierte Blechbearbeitung, bildet komplette Prozessabläufe ab und präsentiert mit den Ausstellern in **9 Messehallen**, aufgeteilt in **5 Themen**, eindrucksvoll die Leistungsfähigkeit der Branche. Es genießt allerhöchstes Interesse und wird von einem hochkarätigen Programm eingerahmt, inklusive der Verleihung des Innovationspreises „best Award 2025“.



AUSSTELLER-FORUM

best CONGRESS **22. Oktober 2025**
 ab 16:00 Uhr



Sichern Sie jetzt Ihr kostenfreies Ticket:

Registrierungsseite:
www.schall-registrierung.de

Ticket-Code: TAQE4-V494A

blechexpo-messe.de
schweisstec-messe.de

Veranstalter: P. E. SCHALL GmbH & Co. KG T +49(0)7025 9206-0
 blechexpo@schall-messen.de schweisstec@schall-messen.de