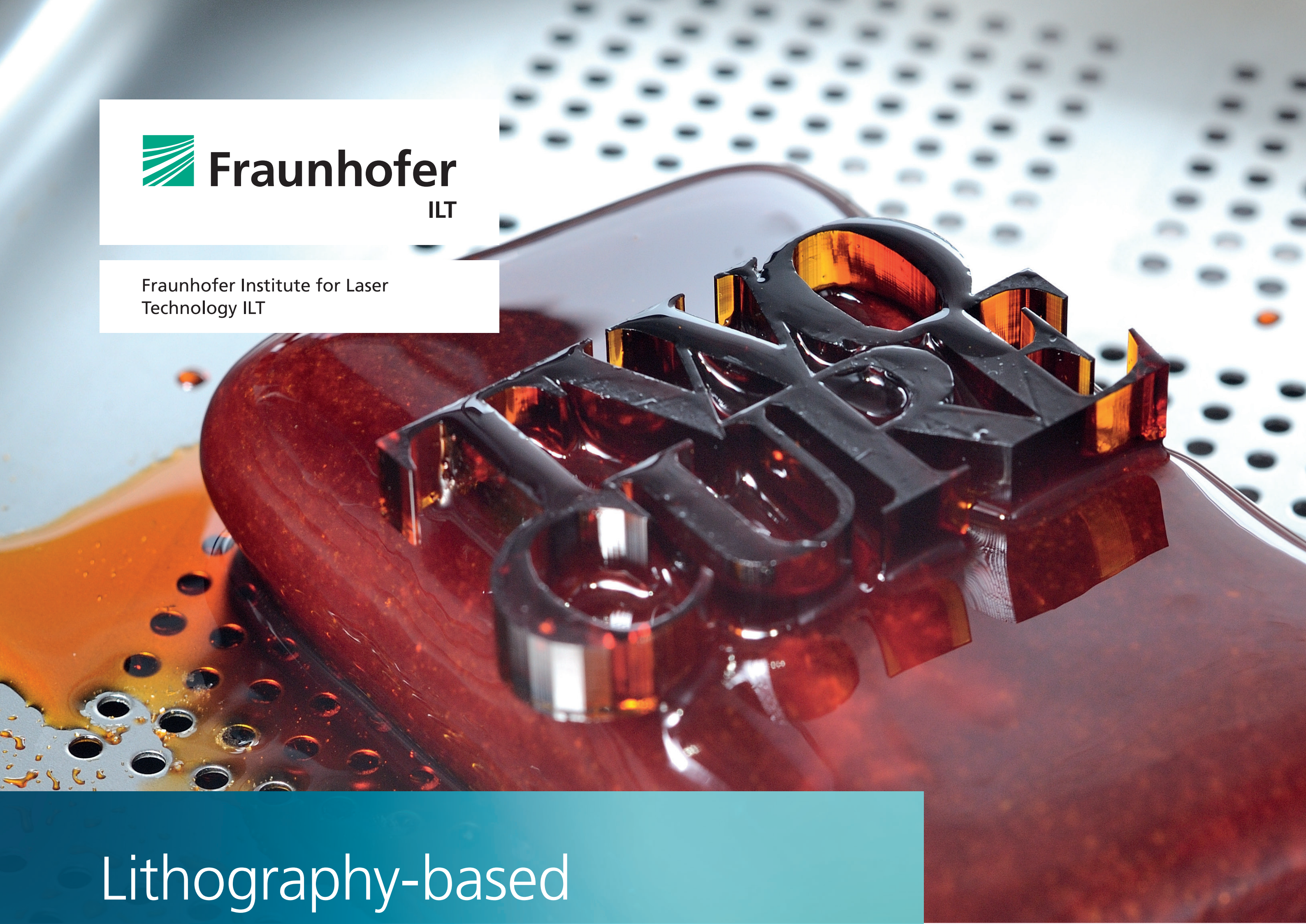


Fraunhofer ILT

Fraunhofer Institute for Laser Technology ILT

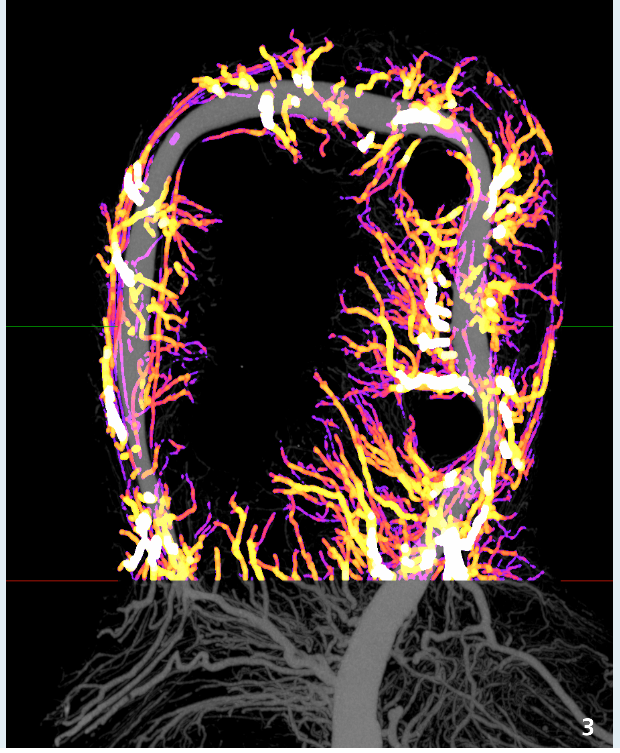
Lithography-based Additive Manufacturing

Lithography-based additive manufacturing processes have already established themselves for the manufacture of various products thanks to their high flexibility, precision and cost-effectiveness, e. g. for inner-ear hearing aids in medical technology or for jewelry production. Faster printing processes and improved materials allow series production of novel products in these and other areas. At the Fraunhofer Institute for Laser Technology ILT, materials and processes are being researched and developed for this purpose – to deliver customer-specific solutions and open up new areas of application.

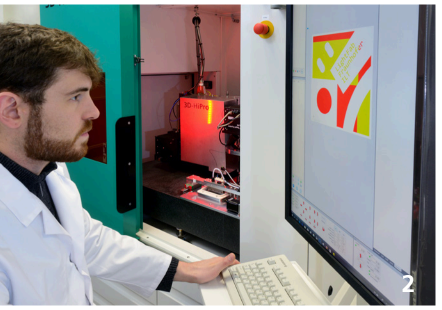
Lithography-based Additive Manufacturing

Lithography-based additive manufacturing processes include all 3D printing processes in which liquid photo resins are polymerized and, thus, cured using UV or visible light. Starting with stereolithography (SL) developed in the 1980s, a large number of different process variants have been developed to date and established in many applications for lithography-based manufacturing.

With TwoCure® technology individual plastic parts can be additively manufactured, without the need for support structures.



Lithography-based Additive Manufacturing



1. Printed structure made of TwoCure® photo resin, © Nick Hüdepohl.
2. Plant with DLP-MPP process combination.

The right process for every application

Irradiation can be carried out, for example, with laser radiation via a scanner system or with LED radiation, whereby the light is modulated in two-dimensions with the aid of digital light processing (DLP) or via LCD masks. With such processes, structural resolutions of between 20 µm and 100 µm can be achieved at maximum process speeds in the range of a few cubic centimeters per hour. Both stereolithography and DLP processes can also achieve structure resolutions of down to 1 µm by using high magnification optics, but then at a correspondingly reduced process speed. Even higher resolutions of < 1 µm can be achieved with multiphoton polymerization (MPP, also known as direct laser writing), although the build-up rate is lower here and is typically in the order of 1 mm³/h. In most processes, two-dimensional layers are generated, thus fabricating the component successively. For components with curved surfaces, this layer-by-layer construction forms surfaces with steps in the range of the lateral resolution or layer thickness. Quasi-continuous process control or volumetric methods eliminate the artifacts of layer-by-layer buildup, which has a positive effect on surface quality.

In addition, significant time savings can in principle be achieved compared with processes in which work is carried out layer by layer. When considering if lithography-based additive manufacturing process is cost-effective, research must weigh up the required product properties, the photo resins that can be used and the advantages and disadvantages of the individual processes against each other.

Wide range of material properties

The inherent versatility of lithography-based processes not only applies to the processes but also to the materials used. The underlying photo resin consists of a reactive monomer or oligomer base, an absorbing component that limits the penetration depth of the radiation, and so-called photo initiators that decompose through light absorption and thereby start polymerization. In most cases, this combination leads to the formation of thermosetting or elastomeric plastics. By varying the functional groups and the backbone of the reactive components used and by adding fillers, research can achieve a wide variety of product properties. Moreover, a wide range of materials is available, from hard-brittle materials with moduli of elasticity in the gigapascal range and elongations at break of ~1 percent, to soft-elastic materials with Shore A hardness > 50 and elongations at break > 150 percent, to abrasion-resistant or flame-retardant materials. Biocompatible materials approved for the manufacture of Class IIa medical devices can also be used with lithography processes. Optical properties of the components range from highly transparent to colored-transparent to opaque-matte-colored when using filled photo resins.

Indirect manufacturing expands material portfolio

When the photo resins are filled with solid particles, components can be indirectly created from materials that are not photo reactive. Ceramic or glass-filled photo resins can, for example, be printed and subsequently sintered in such a way that the polymer matrix can be liquified or burned out to produce ceramic or glass components. Burn-out molds can also be produced using wax-containing material, which can be embedded in a thermostable matrix material. After printed parts have been burned out in the furnace, metal components can then be cast.

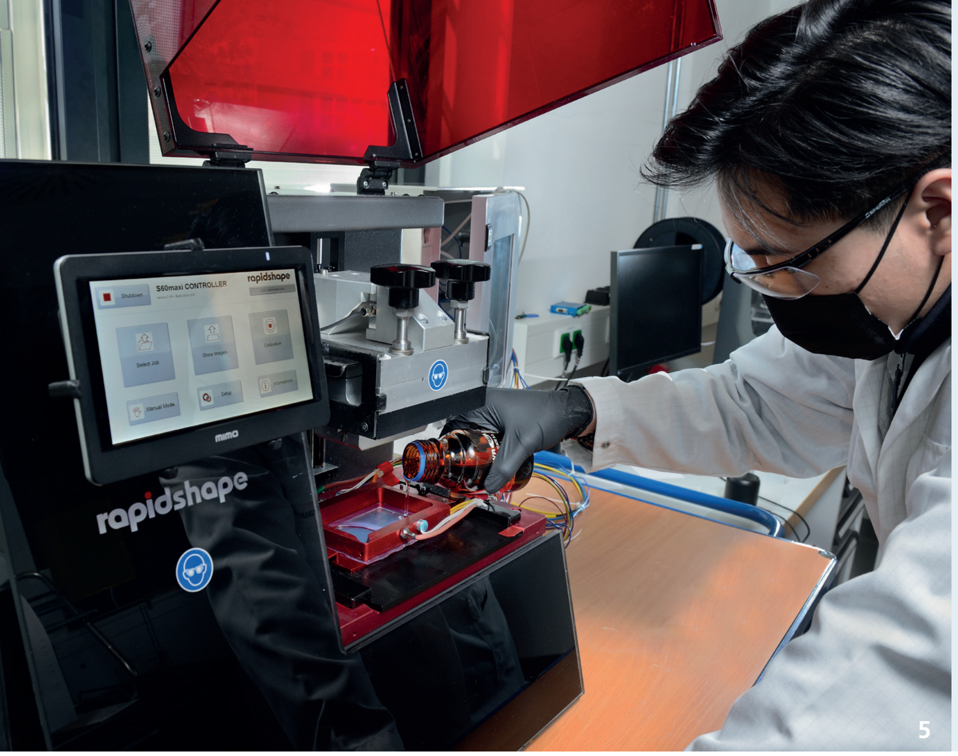
Utilization of all strengths through process combinations

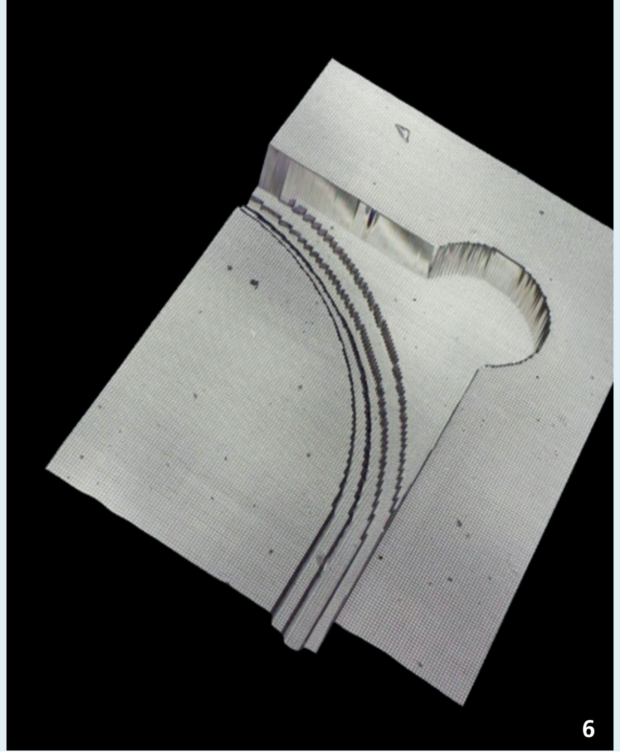
Different process types can be advantageously combined to use complementary process specifications. For example, Fraunhofer ILT has designed a process version with an MPP processing head and a DLP processing head, allowing component areas with small structural elements to be cured at high resolution (MPP) and other areas to be cured more quickly (DLP) to ensure economical production. Alternatively, a low-resolution DLP processing head can be combined with a high-resolution one for optional large-area or high-resolution exposure.

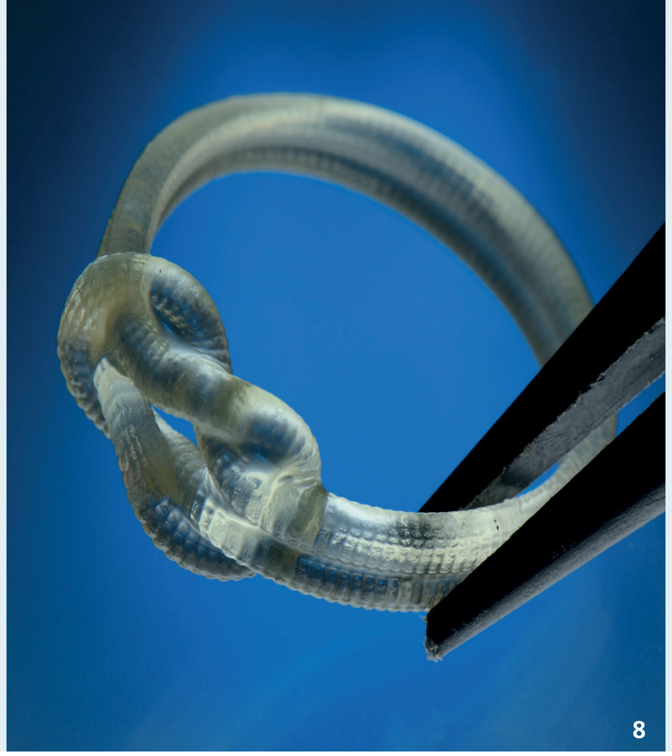
Integration in process chains – The TwoCure® process

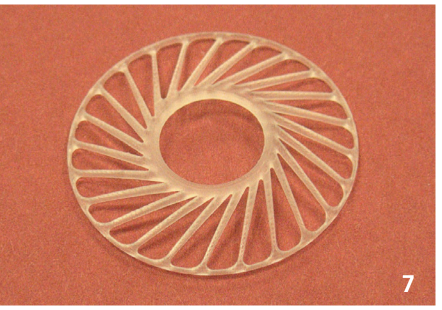
The patented TwoCure® process of Fraunhofer ILT has decisive advantages over other process variants. By using a material with two curing mechanisms – thermally reversible and photochemically irreversible – there is no need for the use of support structures anymore, because layers to be cured are mechanically held in place by underlying thermally solidified layers. Support structures are component elements to be cured, which are necessary in many processes to support overhanging structures. These have to be digitally created, printed and then usually removed manually. This requires time and material effort and will impair the surface quality of the printed components.

3. µCT image of angiogenesis in the field of cultivation patient-specific and transplantable tissue flaps.
4. 3D printed manufactured plastic chambers with different closure mechanisms and geometries.









5. DLP system with temperature-controlled process chamber for processing high-viscosity photo resins.
6. Microfluidic channel structure fabricated with a pixel size of 10 µm.
7. Additively manufactured, high-resolution cross-strut wheel (Ø external: 22 mm).

The TwoCure® process also eliminates the need to position components in contact with the build platform during printing. This provides the basis for a process design that allows for continuous production. The thermally solidified block is mechanically moved and heated outside the process area, releasing the manufactured components from the photo resin matrix. This continuous printing approach can be integrated into existing process chains, also because manual post-processing steps such as the removal of support structures are no longer required.

Higher photon energy for process control

For some applications, it makes sense to use smaller wavelengths and thus larger photon energies. This may be the case when highly transparent systems are desired. The absorption cross-section of absorbing molecules is usually much higher for light in the UV-C range than for longer wavelengths. This way, absorbers no longer need to be used and the photo initiator concentration can be reduced. In the field of thiol-ene click chemistry, the additivation of initiators can be dispensed with completely since the thiol monomers contained can be initiated directly. When such initiators are no longer needed, the production of biocompatible components can be expanded since initiators often cause cytotoxic behavior. In addition, the step-growth mechanism of thiol-ene photoreactions offers further advantages for material properties. However, UV-C-based lithography systems are not commercially available. For this reason, a UV-C-SL system was developed at Fraunhofer ILT. The beam source is a frequency quadrupled Nd:YAG laser with a wavelength of 266 nm and a power of 70 mW at a resolution of 50 µm. It has an installation space of 50*50*50 cm³.

Hot process control

A limiting factor in material selection is viscosity. Highly viscous materials cannot be used because enormous forces are generated here during layer generation, which can lead to component defects or cracks in the bottom of the vat. Monomers and oligomers for the production of mechanically and thermally highly stable polymers are often highly viscous. In order to process these materials, reactive diluents are usually added, which, however, can adversely affect the mechanical properties. One way to reduce the viscosity is to heat the photo resins in the process. At Fraunhofer ILT, equipment has been converted so that work can be carried out at elevated temperatures of up to 80°C, which has made it possible for the institute to develop highly viscous materials that can subsequently be used in hot or volumetric processes.

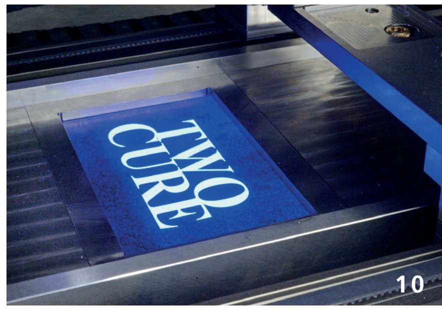
Even faster manufacturing – Volumetric 3D printing

A next step in the further development of lithography-based manufacturing processes is volumetric curing. This means that curing is no longer performed only at the surface of the reaction vessel, but at arbitrary coordinates in the build space. As a result, a layer-by-layer build would no longer be absolutely necessary and the build platform would no longer have to be moved through the usually highly viscous resin. This movement is not only time-consuming, but it also often results in an enormous force impact on the generated component due to flowing photo resin. Volumetric 3D printing is not readily available (with the exception of MPP) because the combination of irradiation wavelength and material results in Lambert-Beer absorption at the surface of the resin. This means that curing occurs primarily at the surface – regardless of where the radiation is focused.

Another option for volumetric 3D printing was demonstrated by xolo GmbH. An initiator system is used here, which is activated in two excitation stages via two different wavelengths. If light with two different wavelengths is irradiated in the reaction volume from different directions, polymerization takes place only in the overlap region. In the ZIM cooperation project »Polymeric Optic Xolography POX« founded by the German Federal Ministry of Education and Research BMBF, Fraunhofer ILT, together with xolo GmbH and the Chair of Optical Systems Technology TOS of RWTH Aachen University, is further developing corresponding printers, initiator systems, monomer and oligomer bases to enable higher resolutions and more diverse material properties.

Equipment

At Fraunhofer ILT, light is understood as a non-contact high-precision tool that can be used to process and analyze materials on a microscopic and macroscopic level. In addition to having extensive knowledge of beam sources, light properties, beam shaping and measurement methods, the institute has 3D printing laboratories with diverse process models such as DLP and LCD-based printers, MPP systems, UV-C-SL systems or also with the various special systems described above. The equipment technology is complemented by a chemical materials laboratory, which provides the appropriate analytics for rheological analyses, dynamic mechanical analyses, tensile elongation tests, refractive index measurements and absorption measurements of undiluted photo resins. Finished processed components can be measured and characterized using geometrical-optical and infrared spectroscopic methods.



8. With the TwoCure® process plastic components can be produced without supporting structures, e. g. molds for jewelry production.
9. Machine for the production of macroscopic polymer structures with resolution down to the micrometer range.
10. Cooled process chamber for resin-based 3D printing.

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Fraunhofer Institute
for Laser Technology ILT
Director
Prof. Constantin Häfner

Steinbachstraße 15
52074 Aachen, Germany
Phone +49 241 8906-0
Fax +49 241 8906-121
info@ilt.fraunhofer.de
www.ilt.fraunhofer.de

Fraunhofer-Institute for Laser Technology ILT

The Fraunhofer Institute for Laser Technology ILT is one of the most important development and contract research institutes in laser development and application worldwide. Its activities encompass a wide range of areas such as developing new laser beam sources and components, laser-based metrology, testing technology and industrial laser processes. This includes laser cutting, ablation, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, Fraunhofer ILT develops photonic components and beam sources for quantum technology.

Overall, Fraunhofer ILT is active in the fields of laser plant technology, digitalization, process monitoring and control, simulation and modeling, AI in laser technology and in the entire system technology. We offer feasibility studies, process qualification and laser integration in customized manufacturing lines. The institute focuses on research and development for industrial and societal challenges in the areas of health, safety, communication, production, mobility, energy and environment. Fraunhofer ILT is integrated into the Fraunhofer Gesellschaft.

Contact

Andreas Hoffmann M. Sc.
Telephone +49 241 8906-447
andreas.hoffmann@ilt.fraunhofer.de

Dr. Martin Wehner
Telephone +49 241 8906-202
martin.wehner@ilt.fraunhofer.de

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