Fraunhofer ILT

Research for a Sustainable Future

Annual Report 2022

Contact

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Foreword

Dear Readers,

At Fraunhofer ILT, 2022 was a year in which we as #OneTeam modernized our organizational structures and realigned them to market needs. Last year, we started reorienting our vision and mission and, thus, restructured the institute to better position ourselves on the market and to focus on our technological expertise. As a result, Fraunhofer ILT is stragetically positioned for the future.

Sustainable and climate-friendly technologies have increasingly come to the fore in production, and it is precisely here that lasers can create real added value: thanks to their high precision, efficiency and resource conservation when compared to conventional processes. For this reason, we are focused on developing the automated control of laser application processes with artificial intelligence (AI) in a German-Canadian collaboration. New process control software makes the process considerably more robust. The topic of AI was also in focus at our 13th International Laser Technology Congress – AKL'22. Three of many new topics at AKL'22 – deep learning, cloud computing and virtual commissioning in combination with laser technology – reflect the changing use of laser technology. From numerous application examples, the approximately 520 participants were able to gather ideas for their own continuing developments and obtain detailed information about the latest trends in laser technology. The response was outstanding.

At the LASER World of PHOTONICS 2022 trade fair, Fraunhofer ILT presented new laser systems that are being used to study the earth's atmosphere. In the Franco-German climate mission MERLIN (Methane Remote Sensing LIDAR Mission), a small satellite will measure the greenhouse gas methane in the earth's atmosphere for at least three years using a laser developed and qualified for space missions at Fraunhofer ILT. With photonic know-how, we are also contributing to the new field of quantum technology. Under the leadership of Fraunhofer ILT, the Fraunhofer-Gesellschaft and the Dutch research center QuTech signed a MoU to collaborate on long-term projects in the field of quantum networks. Before that, Fraunhofer ILT and QuTech had already achieved notable success for making a stable quantum internet a reality: a quantum frequency converter with a world record for low noise.

We also advanced numerous innovations in conventional production technology again in 2022. For example, the first laser-manufactured microplastic filter was tested in a sewage treatment plant. To accomplish this, millions of holes with a diameter of only 10 µm were drilled within a very short time using the multibeam laser process developed at Fraunhofer ILT. And scientists in our newly opened Hydrogen Lab are optimizing fuel cells for hydrogen technology. These and other examples from our annual report will give you insight into the numerous developments at our institute.

If we have piqued your interest, please feel free to contact our experts directly. We look forward to hearing from you.

Cordially,

Constantin Häfner

Prof. Dr. rer. nat. Constantin Häfner

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Declaration of Principles

We constantly expand our expertise and know-how, initiate trends of the future and, thus, decisively contribute to the continuing development of science and technology.

Mission

We conduct applied contract research, this means we turn original ideas into innovative and disruptive solutions, enable our partners to develop competitive solutions to complex technological challenges and thus increase the competitiveness of our customers. We train excellent and competent experts and thus contribute to the competitiveness of Germany as a location for industry and science.

Customers

We focus on what our customers need. We place great emphasis on discretion, fairness and partnership in our customer relations. According to the requirements and expectations of our customers, we develop solutions and implement them. We want our customers both to be pleased and pleased to return to us.

Opportunities

By concentrating on our core competencies, we expand our knowledge in our networks strategically. We strengthen our network consisting of industrial and institutional partners with complementary services and establish strategic partnerships. We increasingly operate on international markets.

Fascination Laser

We are fascinated by the unique properties of laser light and the diversity of applications resulting from them. We are excited by the possibility of setting international standards through leading technological achievements and first-time industrial implementation.

Staff

Our success is based on the interaction of the individual and the team. Each one of us works independently, creatively and oriented toward a specific goal. All the while, we proceed reliably, with attention to detail and are aware of the need to conserve resources. We place our individual strengths in the team and treat our colleagues with respect and fairness. We work together, across disciplines.

Strengths

Our broad spectrum of resources enables us to offer one-stop solutions. We deliver innovative and cost-effective solutions and offer you R&D, consulting and integration. We solve our customers' tasks in multi-disciplinary teams using diverse and innovative facilities.

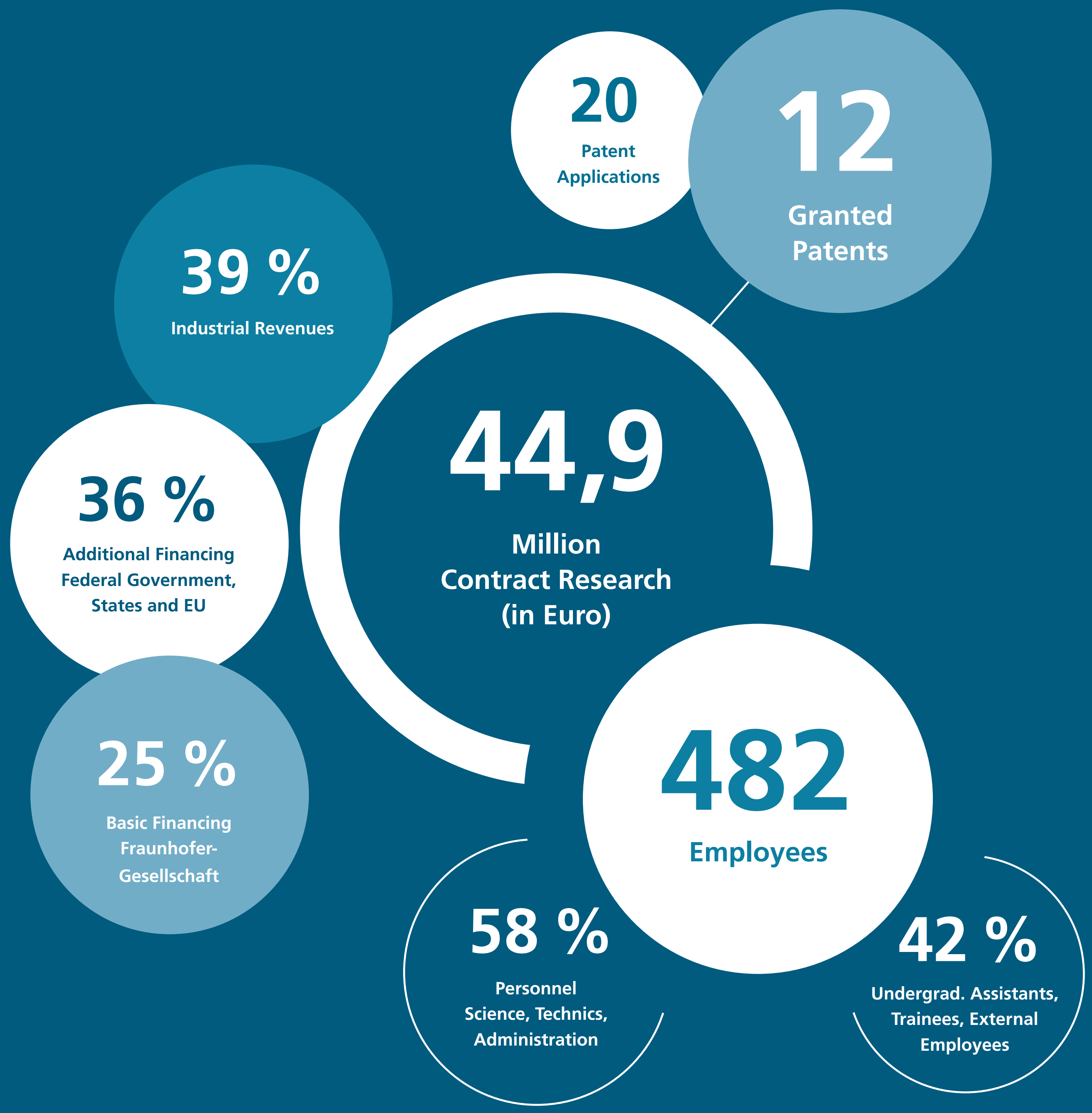
Management Style

Cooperative, demanding and supportive. Our management style is based on knowing the value of our employees as individuals, of their know-how and commitment. We have our employees formulate targets and make decisions. We place great value in effective communication, goal-oriented and efficient work as well as in making clear decisions.

Position

Our expertise extends from developing beam sources, processing and measuring technologies, via applying them all the way to integrating a plant within the customer's production line. We work in a dynamic equilibrium between applied basic research and development. We actively formulate and design research policy goals.

Facts and Figures 2022



Profile of the Institute

Fraunhofer ILT – stands for combined know-how in the field of laser technology for more than 35 years

DQS certified by DIN EN ISO 9001:2015 Reg. No. 069572 QM15

Partner for innovations

Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With more than 480 employees and more than 19,500 m² of net floor area, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

Under one roof, the Fraunhofer Institute for Laser Technology ILT offers research and development, system design and quality assurance, consultation and education. To process the research and development contracts, we have numerous industrial laser systems from various manufacturers as well as an extensive infrastructure. In the nearby Research Campus Digital Photonic Production DPP, companies cooperating with Fraunhofer ILT work in their own separate laboratories and offices. This special form of technology transfer is based on a long-term cooperation agreement with the institute in the field of research and development. The added value lies in the use of the technical infrastructure and the exchange of information with the experts on site.

In addition to established laser manufacturers and innovative laser users, start-ups from the fields of special plant engineering, laser manufacturing technology, laser measurement technology and quantum technology can find a suitable environment here for implementing their ideas in industry.

Fraunhofer ILT is part of the Fraunhofer-Gesellschaft, which is one of the leading research institutes in Germany with 76 institutes, around 30,800 employees and an annual research budget of 3.0 billion euros.

We open up perspectives

The services offered by Fraunhofer ILT cover a wide range of topics in laser technology. Customers from research and industry can benefit from our extensive expertise and valuable know-how in the fields of lasers, optical systems, quantum technology, laser measurement technology, additive manufacturing, surface technology, joining, cutting, digitalization, EUV and plasma technology, and medical technology.

Our scientists develop optical components, laser systems and laser beam sources adapted to specific applications and with tailored output powers as well as with spatial, temporal and spectral properties. The spectrum ranges from free-form optics, tunable lasers, diode and solid-state lasers to fiber and ultrashort pulse lasers (UKP lasers).

Services of Fraunhofer ILT

- Development of laser beam sources
- Components and systems for beam guiding and forming
- Packaging of optical high power components
- Modeling and simulation of optical components as well as laser processes
- Process development for laser materials processing, laser measurement technology, medical technology and biophotonics
- Process monitoring and control
- Solutions for digital production
- Model and test series
- Development, set-up and testing of pilot plants
- Development of X-ray, EUV and plasma systems
- Photonic components and systems for quantum technology

Cooperations

The Fraunhofer Institute for Laser Technology ILT has partnerships with domestic and foreign companies and research centers in the field of laser technology so that it can offer its customers solutions from a single source. Fraunhofer ILT also maintains close contacts to universities, associations, chambers of commerce and trade, testing institutes and research ministries.

Alumni network

Fraunhofer ILT and the associated chairs and subject areas of RWTH Aachen University significantly contribute to the qualified training and advanced training of young scientists in the field of laser technology. Thanks to their practical experience and in-depth insight into innovative developments, these employees are equipped with the best prerequisites to take up work in science and industry. They are, therefore, junior staff in demand.

Since 2000, Fraunhofer ILT has been operating the alumni network Aix-Laser-People, which has over 500 alumni, to promote contact both with ILT employees and with each other. More than 80 percent of the alumni work in the manufacturing industry, many of them in laser-related industries, while 20 percent continue to work in science. Over 40 companies have been founded by former employees in the last 30 years. By transferring innovative minds to industry and science, Fraunhofer ILT provides a direct benefit to society. In addition to the alumni network Aix-Laser-People, the association Arbeitskreis Lasertechnik AKL e.V., founded in 1990 by ILT executives, bundles the thematic interests of those who continue to work in the field of laser technology.

With more than 480 employees and more than 19,500 m² of net floor area, the Fraunhofer ILT is among the most significant research institutes in the field of laser technology worldwide.

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Board of Trustees – Well Advised!

The Board of Trustees advises the Fraunhofer-Gesellschaft as well as the Institute's management and supports the links between interest groups and the research activities at the institute. In 2022 Dr. Joseph Pankert took the chair of Fraunhofer ILT's Board of Trustees from Carl F. Baasel.

Members 2022

Dr. Joseph Pankert	TRUMPF Photonic Components GmbH (Chairman)
Dr. Reinhold E. Achatz	Consultant
Carl F. Baasel	Baasel Verwaltung GmbH
Dipl.-Ing. Frank C. Herzog	HZG Group
Prof. Ursula Keller	ETH Zürich
Dipl.-Ing. Volker Krause	Laserline GmbH
Dipl.-Ing. Michael Lebrecht	Mercedes-Benz AG
Prof. Gerd Marowsky	Advanced Microfluidic Systems GmbH
Manfred Nettekoven	Chancellor of RWTH Aachen University
Dr. Silke Pflueger	Consultant
Dr. Stefan Ruppik	Coherent
Dr. Torsten Scheller	JENOPTIK Automatisierungstechnik GmbH
Dr. Ulrich Steegmüller	ams-OSRAM International GmbH
Prof. Christiane Vaeßen	Zweckverband Region Aachen
Dr. Hagen Zimer	TRUMPF Laser GmbH

The 37th Board of Trustees meeting was held on November 10 and 11, 2022 at Fraunhofer ILT in Aachen.

Organization Chart

Board of Directors Fraunhofer ILT
Prof. Constantin Haefner (Director)
Prof. Peter Loosen (Dep. Director)
Dr. Vasvija Alagic-Keller (Comm. Director)

- **Marketing and Communications**
  Dipl.-Phys. Axel Bauer
- **Corporate Development**
- **Administration and Infrastructure**
  Dr. Vasvija Alagic-Keller
  - **Information Technology / Administration / Construction and Workshops**

- **Business Development Research Markets**
  Prof. Arnold Gillner
  - **Energy Industry**
  - **Aerospace**
  - **Mobility**
  - **Microelectronics**
  - **Medical Technology / Health**
  - **Strategic Mission Initiative (SMI) Quantum Technology**
    Dr. Bernd Jungbluth
- **Data Science and Measurement Technology**
  Prof. Carlo Holly
  - **Process Control and System Technology**
    Dipl.-Ing. Peter Abels
  - **Material Analysis**
    Dr. Cord Fricke-Begemann
  - **Computational Methods**
    Prof. Carlo Holly (acting)
- **Surface Technology and Ablation**
  Dr. Christian Vedder
  - **Micro and Nano Structuring**
    Dipl.-Phys. Martin Reininghaus
  - **Thin Film Processing**
    Samuel Moritz Fink M.Sc.
  - **Polishing**
    Dr. Edgar Willenborg
- **Laser Medical Technology and Biophotonics**
  Dr. Achim Lenenbach
  - **Laser Medical Technology and Bioanalytics**
    Dr. Georg Meineke
  - **Biofabrication**
    Dr. Nadine Nottrodt
- **Joining and Cutting**
  Dr. Alexander Olowinsky
  - **Joining of Metals**
    Dr. André Häusler
  - **Joining of Plastics and Transp. Materials**
    Maximilian Brosda M.Eng.
  - **Cutting**
    Dr. Frank Schneider
- **Laser Material Deposition**
  Dr. Thomas Schopphoven
  - **Additive Manufacturing and Repair LMD**
    Min-Uh Ko M.Sc.
  - **Coating LMD and Heat Treatment**
    Viktor Glushych M.Sc.
- **Laser Powder Bed Fusion**
  Tim Lantzsch M.Sc.
  - **LPBF Process and Systems Engeneering**
    Niklas Prätzsch M.Sc.
  - **LPBF Application Development**
    Dipl.-Ing. Simon Vervoort
  - **AM Polymers**
    Prof. Sebastian Bremen
- **Lasers and Optical Systems**
  Dipl.-Ing. Hans-Dieter Hoffmann
  - **Optics Design and Diode Lasers**
    Dr. Martin Traub
  - **Solid State Lasers**
    Dipl.-Phys. Marco Höfer
  - **Fiber Lasers**
    Patrick Baer M.Sc.
  - **EUV Technology**
    Dr. Klaus Bergmann
  - **Packaging**
    Dr. Heinrich Faidel
  - **Ultrafast Lasers**
    Dr. Peter Rußbüldt
  - **NLO and Tunable Lasers**
    Dr. Bernd Jungbluth

Status: August 2023

Fraunhofer ILT in Figures

Personnel 2022

Personnel 2022	number
Permanent staff	**279**
Scientists and engineers	175
Technical staff	52
Administrative staff	52
Other employees	**203**
Undergraduate assistants	188
External employees	13
Trainees	2
Total number of employees at Fraunhofer ILT	**482**

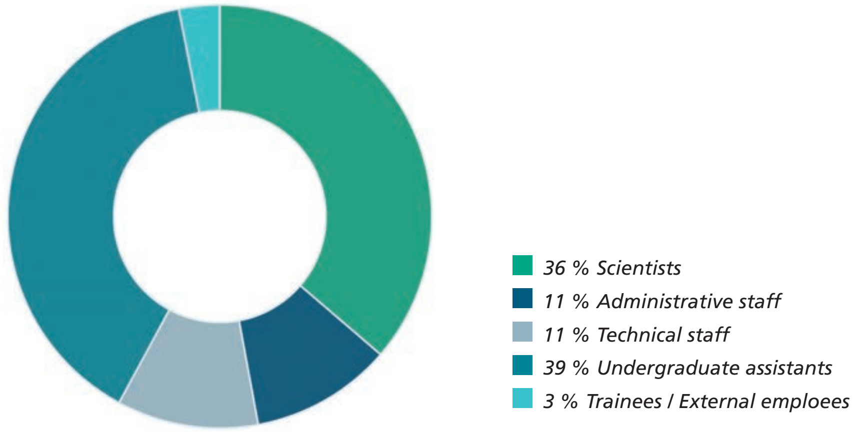
Expenses 2022

Expenses 2022	Mill €
Staff costs	24,3
Material costs	17,1
Expenses operating budget	**41,4**
Investments	**3,5**

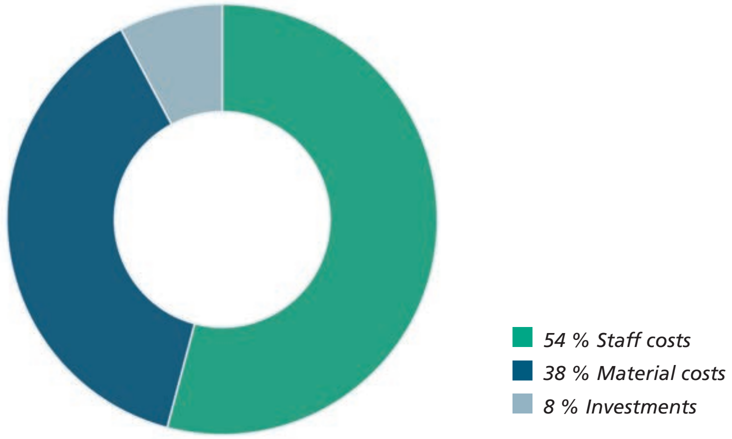
Revenues 2022

Revenues 2022	Mill €
Industrial revenues	17,5
Additional financing from Federal Government, States and the EU	16,0
Basic financing from the Fraunhofer-Gesellschaft	11,4
Revenues general budget	**44,9**
Fraunhofer Industry ρ_{Ind}	**42,3 %**

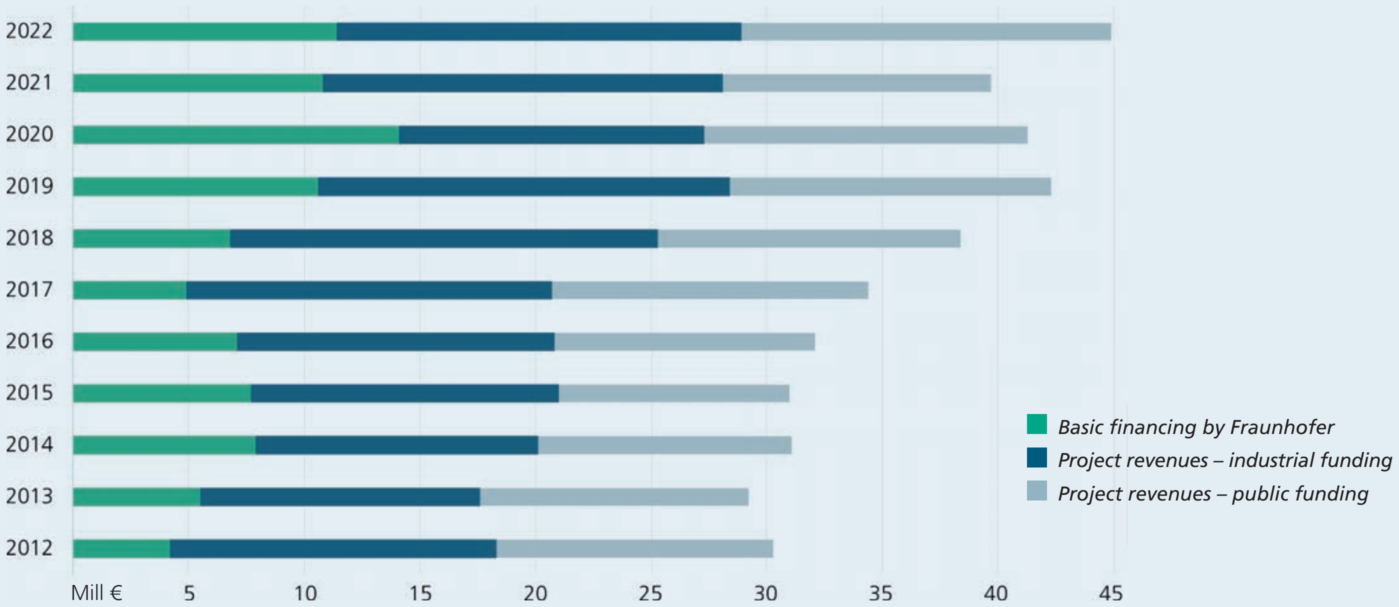
Personnel 2022



Expenses 2022



Revenues over the last 10 years



Awards and Prizes

In 2022, employees of Fraunhofer ILT were again honored, for example Prof. Arnold Gillner with the Fraunhofer Thaler. The award is presented to individuals who have rendered outstanding services to the Fraunhofer-Gesellschaft.

Dr. Patrick Hoyer (left, Research Planning Fraunhofer-Gesellschaft) awards Prof. Arnold Gillner (right) the Fraunhofer Thaler.

Fraunhofer Thaler Award for Prof. Arnold Gillner

Prof. Arnold Gillner, Head of Business Development at Fraunhofer ILT, has made a decisive contribution to the success of Fraunhofer ILT during his more than 35 years of service. Not only has he made broad scientific achievements in laser materials processing, but he has also shown steady commitment and outstanding dedication to the Fraunhofer-Gesellschaft.

As early as 1987, the graduate physicist was awarded the Joseph von Fraunhofer Prize for his developments in laser materials processing. In 2012 he received the Innovation Award Laser Technology from the Arbeitskreis Lasertechnik e.V. for developing a short-pulse laser along with new applications, and in 2020 he was given the Science Award of the Stifterverband für Verbundforschung. On November 10, 2022, Dr. Patrick Hoyer presented the Fraunhofer Thaler to Prof. Arnold Gillner on behalf of the Executive Board of the Fraunhofer-Gesellschaft during the Fraunhofer ILT Board of Trustees meeting in Aachen.

EUV Tech Award of the SPIE for Sven Glabisch

Sven Glabisch was honored with the EUV Tech Award for Emerging Talent in the Industry following the conference SPIE Photomask Technology + EUV Lithography in Monterey, California from September 25 to 29, 2022. A committee of renowned scientists selected his contribution – on characterizing line roughness of nanoscale periodic lattice structures with EUV spectrometry – as one of the most impressive contributions of the student participants.

Christina Giesen selected for the Fraunhofer TALENTA program

Christina Giesen, a member of the Laser Medical Technology and Bioanalytics group at ILT, successfully applied for the TALENTA funding program. The TALENTA funding is a career and development program of Fraunhofer, which helps female scientists and female managers develop personally and strategically by offering partial funding, tailored qualification seminars and networking.

1 Laboratory tour at Girls' Day, © Fraunhofer IPT.
2 Exchanging experience at Student University of Mechanical Engineering, © Chair of Laser Technology LLT at RWTH Aachen University.

Training the Next Generation

Girls' Day – Girls' Future Day on April 28, 2022

On April 28, 2022 – for the first time since the pandemic – the three Fraunhofer Institutes in Aachen opened their doors again to interested girls from the 5th to the 7th grade. The schoolgirls spent a whole day gaining practical insight and hands-on experience in male-dominated occupations. In addition to seeing a brief presentation of the institutes and touring the laser labs and production halls, the girls were also able to conduct their own experiments and, for example, create their own hologram or extract DNA from tobacco plants. In a relaxed final group session, the schoolgirls then had the opportunity to ask the ILT employees their questions.

Student University of Mechanical Engineering from July 25 to 29, 2022

In 2022, the Student University of Mechanical Engineering, along with participation of the Cluster of Excellence Internet of Production IoP, took place again at RWTH Aachen University. Twenty-one high-school students from all over Germany spent a week at RWTH Aachen University to get an impression of studying mechanical engineering and its many opportunities – even after successful completion. By visiting various institutes, the participants gained insight into the fields of production, process, plastics, textile and automotive engineering as well as optics and laser technology. In addition to lectures and tours of the institutes, the students were also able to conduct their own experiments. On July 29, 2022, they then got an inside view into the world of photonics at Fraunhofer ILT and were able to learn how laser radiation works and how optical technologies influence our everyday lives.

Participants of Girls' Day 2022.

Training the Next Generation

Well-qualified young scientists are the prerequisite for ensuring that research expertise and innovative capability in Germany remain strong in the long term.

1 "Doors Open with the Mouse" at Fraunhofer ILT.
2 Participants of the Fraunhofer ILT Student Day.

Networking at Open LASER LAB, © Research Campus DPP Aachen.

Open LASER LAB on May 9, 2022

On May 9, 2022, more than one hundred students from Aachen and the surrounding area accepted the invitation of the Research Campus DPP, the LLT, TOS and NLD chairs and Fraunhofer ILT to take a look behind the scenes of laser technology and its many possible applications at more than fifty stations.

At this event, the Open LASER LAB, the students personally exchanged ideas with the scientists of the chairs and institutes. This way, they were able to ask numerous questions in a relaxed atmosphere, gain new impressions for their own careers, and get to know various fields of technology, applied research, and the proximity to industrial partners on site. They took guided tours through a total of three buildings to learn about quantum technology, additive manufacturing, medical technology, laser-beam development, surface technology, laser joining, laser cutting, EUV technology, optical systems, digitalization and laser measurement technology. Afterwards, the students finally could discuss potential job opportunities in the networking part of the Open LASER LAB at the Research Campus DPP in more detail.

Fraunhofer ILT Student Day on July 19, 2022

As part of an Eastern European exchange organized by the Mechanical Engineering department of RWTH Aachen University, Fraunhofer ILT invited students to an institute tour with short presentations.

"Doors Open with the Mouse" on October 3, 2022

In keeping with this year's motto "Exciting Connections", the employees of the Joining and Cutting department welcomed around 60 inquisitive children for the first time on Mouse Door-Opener Day and immersed them in the world of laser technology. How can you work with light? What do you actually do with a laser? How does the name get onto the metal door sign? These and many other exciting questions were answered for the children, who were able to watch, marvel, understand and get involved in the live demonstrations. In addition to assembling a lovingly designed "wooden mouse box", they were then able to fill their box at further stations and build a stainless steel mouse step by step. From cutting the individual parts on the cutting laser, to marking the mouse contours, to micro-welding the individual parts, the young scientists showed a great deal of dexterity. As a reward, they received limited "mouse giveaways" made with the laser at the end.

Open Workshop Day at Ecurie Aix on October 20, 2022

Together with Fraunhofer IPT, Fraunhofer ILT participated in the open workshop day at Ecurie Aix as a recruiting measure and informed interested students about career opportunities at Fraunhofer.

bonding company contact fair on November 8, 2022

For the seventh time in a row, Fraunhofer ILT presented itself in Aachen at the largest student-organized company contact fair, the bonding. Alongside 300 other exhibitors, Fraunhofer ILT provided students and graduates from the fields of engineering, economics and natural sciences, in particular, with comprehensive information about entry-level and career opportunities in personal discussions.

"5 to 12" – RWTH Science Night on November 11, 2022

Every year, the RWTH Science Night "5 to 12" presents science in an unusual form at an unusual time. Science is made understandable and tangible for all generations in an entertaining way with a wide range of exciting lectures, film screenings and cabaret as well as musical performances. The Chair for Technology of Optical Systems TOS at RWTH Aachen University demonstrated the versatility of light as a tool on November 11, 2022 in the C.A.R.L. Lecture Hall Center in Aachen. Together with MHL²-Laser&Lights, TOS presented the laser harp, which was created as part of a project with the motto "Making Music with Light – Experiencing Music-Synchronous Laser Shows".

Working at Fraunhofer ILT

www.ilt.fraunhofer.de/en/jobs-and-carrer.html

Business Units

Fraunhofer ILT develops innovative solutions tailored to applications in many different industries. For the business units Energy Industry, Microelectronics, Medical Technology/Health, Mobility as well as Aerospace, Fraunhofer ILT bundles its expertise to form a comprehensive systemic approach.

Business Units

- Energy Industry
- Aerospace
- Mobility
- Microelectronics
- Medical Technology / Health

Laser technology can provide solutions for various industries: whether as a tool in automotive manufacturing, as a measuring instrument in the environmental sector, for diagnosis or therapy in medical technology or as a communication medium in space technology. By combining different competencies, Fraunhofer ILT can generate innovative solutions for new products and manufacturing queries. The institute's business units Mobility and Energy Industry are presented here as examples.

Convincing production technology for the mobility of tomorrow

In Mobility, Fraunhofer ILT offers solutions specifically for lightweight construction and electromobility, both of which apply to the automotive industry as well as to aviation and rail-bound vehicles. For this purpose, Fraunhofer ILT has been working for years with partners from the mobility industry and provides innovative solutions for manufacturing and component development.

For lightweight construction applications, the institute develops and qualifies manufacturing processes for ultra-high-strength steels and composites such as dual-phase and TWIP steels as well as for fiber composite and hybrid materials. These processes include high-speed cutting and welding for metals as well as manufacturing solutions for CFRP materials, which are used primarily in aviation. Thanks to new developments for plastic-metal bonding and for additive manufacturing, Fraunhofer ILT can help the industry exploit the full material potential of innovative lightweight solutions for various applications. In particular, high-power ultrashort pulse lasers (UKP lasers) offer new possibilities for advancing surface processing and component functionalization.

Together with partners, Fraunhofer ILT is developing powerful LiDAR systems that fulfill the basic requirements for autonomous driving vehicles. Compact high-power diode lasers and miniaturized optics as well as new integration solutions are the best prerequisites for powerful sensory solutions for automotive technology.

For the e-mobility market, Fraunhofer ILT is developing systemic solutions for battery modules and battery packs, solutions that allow energy storage devices to be integrated into different vehicles in a manner that saves both space and energy. The institute is mainly focusing its developments on construction, process development and design of modules and manufacturing systems.

Innovative laser solutions for energy generation and storage

Sustainable energy generation and efficient energy storage are currently several of the most important issues in politics and society. Indeed, the energy sector is currently facing several major challenges: sustainably generating and converting energy as well as storing it temporarily.

In this context, Fraunhofer ILT develops innovative solutions in the field of energy generation and storage with its expertise in cutting, joining, structuring and additive manufacturing. In this context, not only does the institute address individual manufacturing issues, but it also looks at the entire value chain up to product qualification.

For the power generation sector, Fraunhofer ILT is developing high-performance processes in the field of turbomachinery engineering with technologies to manufacture and repair turbine components using additive processes. The focus here is on new high-temperature materials that can also be used for hydrogen-powered power plants in the future.
For the direct generation of electrical energy from photovoltaics, Fraunhofer ILT develops high-performance processes for increasing the absorption of solar cells by means of rapid surface structuring and for packaging solar cells into solar modules.

Hydrogen plays a central role in the energy transition. Here, the institute develops fuel cells and manufacturing technologies for fuel cells and electrolyzers, covering the entire laser-based value chain from forming technology to fabrication and packaging to testing of the finished fuel cells. Novel coating and assembly technologies will make an important contribution to a new generation of fuel cells.

Finally, in the Energy business unit, Fraunhofer ILT develops solutions for long-term energy storage. The institute focuses on Li-ion batteries, redox flow batteries and solid-state batteries, covering the entire value chain from cell production to battery pack manufacturing. In addition, it is developing innovative laser-based manufacturing steps such as high-rate structuring of battery electrodes and fast, reliable joining techniques for module production, as well as new systems engineering solutions for recycling batteries.

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Reseach Results 2022

Fraunhofer ILT is one of the world's most important contract research and development institutes in laser development and laser applications. Customers from research and industry benefit from its extensive expertise and valuable know-how in the fields of lasers, optical systems, quantum technology, laser measurement technology, additive manufacturing, surface technology, joining and cutting, digitalization, EUV and plasma technology, and medical technology. Our core competencies include developing new laser beam sources and components, laser measurement and testing technology, and laser manufacturing technology. In the following you will find excerpts of our current research projects:

- Data Science and Measurement Technology Department
  - Process Control and System Technology Group
  - Material Analysis Group
  - Computational Methods Group
- Surface Technology and Ablation Department
  - Micro and Nano Structuring Group
  - Thin Film Processing Group
  - Polishing Group
- Laser Medical Technology and Biophotonics Department
  - Laser Medical Technology and Bioanalytics Group
  - Biofabrication Group
- Joining and Cutting Department
  - Joining of Metals Group
  - Joining of Plastics and Transparent Materials Group
  - Cutting Group
- Laser Material Deposition Department
  - Additive Manufacturing and Repair LMD Group
  - Coating LMD and Heat Treatment Group
- Laser Powder Bed Fusion Department
  - LPBF Process and Systems Engineering Group
  - LPBF Application Development Group
  - AM Polymers Group
- Lasers and Optical Systems Department
  - Optics Design and Diode Lasers Group
  - Solid State Lasers Group
  - Fiber Lasers Group
  - EUV Technology Group
  - Packaging Group
  - Ultrafast Lasers Group
  - NLO and Tunable Lasers Group

Data Driven Innovation – Connecting the Real and Digital Worlds

The interdisciplinary team at ILT researches and develops models, software and systems that link the real and digital worlds to unlock intelligent cyber-photonic systems in production and digital business models. New methods and algorithms based on artificial intelligence play a central role for process monitoring, self-learning systems and in measurement technology.

The Data Science and Measurement Technology department takes an integrated approach to increasing productivity, efficiency and quality for laser-based manufacturing and metrology. We research and develop digital solutions in combination with customized laser beam sources, optical systems, sensors and systems engineering to make innovative production and measurement technology possible. For this purpose, we utilize methods from artificial intelligence to analyze sensor and image data as well as to adapt processes for self-learning laser systems. In the field of material analytics, we develop systems that classify materials for recycling and the circular economy. For our customers, we enable disruptive innovations and digitalization in photonics with our expertise in data science, modeling and metrology.

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Data Science and Measurement Technology Department

- Process Control and System Technology
- Material Analysis
- Computational Methods

AIRISE – AI in manufacturing

Economic production with AI

The economic success of a product is significantly influenced by many factors along the production chain, including time needed, the number of rejects and the use of resources. While machines and raw materials are mostly constrained by boundary conditions, there is great potential in using data to reduce waste and shorten production time. However, identifying relevant data and processing it selectively pose significant challenges, which can be met by applications using artificial intelligence (AI) algorithms. Despite the availability of such algorithms, it is still challenging to identify, select and apply data sources in the industrial environment in terms of technology and regulation.

Individual support with the application

The AIRISE network provides companies with individual support for applying AI in manufacturing. The spectrum of services the network offers ranges from identifying suitable data sources to implementing sensor systems and data interfaces all the way to using AI-based analysis results to optimize production. The network's activities focus on defining the objective and verifying success across the value chain.

AI expertise across all industries

AIRISE enables companies to strengthen their AI competence in the field of manufacturing. The network not only develops and technically implements AI, but also analyzes and agrees on measures for its application. AIRISE is based on current assessment procedures, which also set the legal framework for the use of AI in the production environment.

AI methods and technologies can be used in all manufacturing processes where input variables and manufacturing results can be technically determined. The network's range of services finds its place in all industries and enables companies to impart new knowledge in the field of artificial intelligence for manufacturing to their employees.

Companies can obtain technical and financial support via public calls for proposals on airise.eu. AIRISE is supported by the EU with funds from the Horizon Europe research program under Grant Agreement 101092312.

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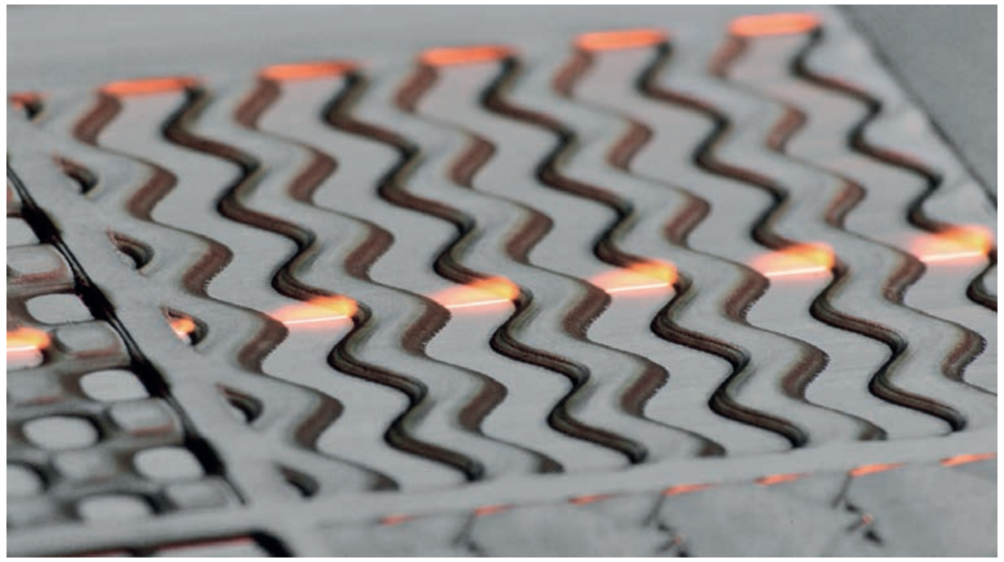

Ultra-short pulse laser ablation to produce AI-optimized surface properties.

1 Test field with carrot plants, © Odd.Bot.
2 Weeding robots, © Odd.Bot.

LABRADOR – Intelligent and environmentally conscious weeding

Cultivating organic products in agriculture is a laborious undertaking for farmers because they are prohibited from fighting undesirable vegetation with chemicals. While conventional agriculture still uses herbicides to prevent or limit the growth of weeds, organic farmers usually have to remove weeds mechanically and by hand, which is time-consuming and costly. Furthermore, weed removal machines can only be used in the areas between cultivated rows. For weed growth within the rows, manual weed removal has traditionally been most common here, but several variants are currently under development: Processes using laser radiation or electric shocks, for example, are currently being investigated as alternatives.

Fighting weeds with light

Light is a necessary resource for plants, but in too high doses it can destroy them. Together with the companies Odd.Bot (NL), Delphy (NL) and Amtron (DE), Fraunhofer ILT launched the LABRADOR project in November 2022 to research an innovative and sustainable process for reducing weeds with light. The consortium aims to develop an environmentally friendly robot that effectively destroys weeds in agricultural fields without harming crops and soil.

The weed control robot will use an image-based system and artificial intelligence to recognize plants and distinguish between crops and weeds. A light-based process will be used to destroy the weeds locally and selectively by irradiating the plant with a high intensity light. For this, the research is focusing on the use of high-power LEDs as a light source. At the end of the project, the industrial partners should be able to market field robot for agricultural use.

The R&D project underlying this report is being carried out internationally under the EU's Eurostars program and nationally on behalf of the German Federal Ministry of Education and Research BMBF under the grant number 01QE2240C.

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Sorting high quality minerals with LIBS

Refractory bricks are high-grade minerals used in industry for all high-temperature processes. In steel, cement or glass production, they are in direct contact with the hot and partly molten product, protecting the furnaces and other aggregates. In these processes, the refractory material is partially consumed and must be replaced after a certain service life. A considerable amount of residual material remains and can be reused for new applications, provided that the material can be separated into pure fractions. Since visual inspection can only be used to identify this refractory material to a very limited extent, automatic sensor-based sorting could significantly increase the amount of material available for reuse.

Efficient sorting with laser-based sensor technology

The laser-induced breakdown spectroscopy (LIBS) method can be used to determine the composition of individual pieces of material on a conveyor belt. In its patented 3D scanning LIBS technology, Fraunhofer ILT combines location-accurate analysis with intelligent automatic positioning of the measurement points. In addition, it evaluates the measurement data obtained using machine learning. The individual components of the material can first be analyzed and then its material assigned to a material class with LIBS.

Recycling instead of mining

In industry, refractory materials are used in many varieties, the mixing of which would lead not only to a loss of quality, but ultimately to a loss of refractory properties. Many types cannot be distinguished with the naked eye; black magnesia-carbon bricks, in particular, are difficult to identify. Thanks to the LIBS process, individual mineral constituents can be both identified and their distribution in the inhomogeneous material captured, a capability that allows the product to be accurately assigned to its material class.

Together, Fraunhofer ILT and its European project partners are developing the entire process chain to implement automatic sorting and high-quality material recycling of used refractory materials in industry, the use of which will contribute to the conservation of natural resources.

The work was carried out within the framework of the EU project ReSoURCE under the grant number 101058310.

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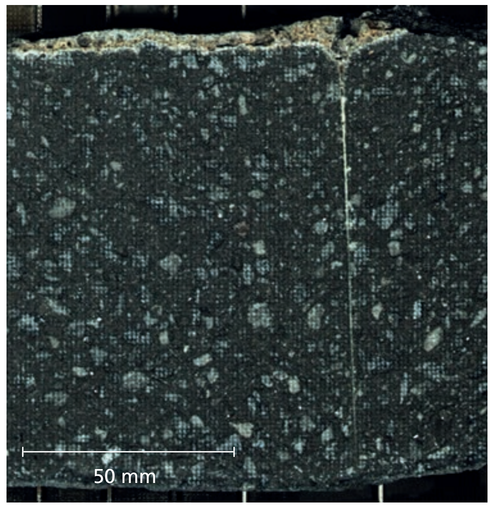
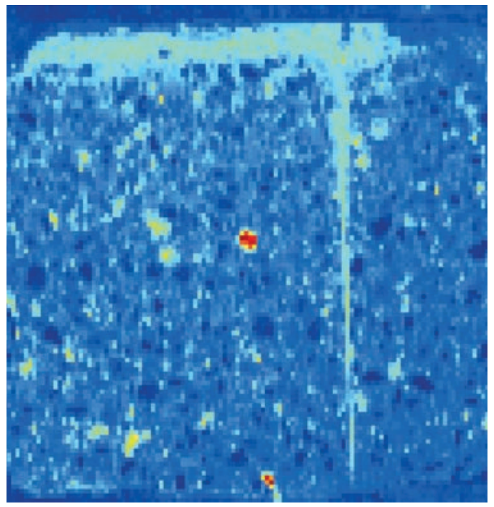
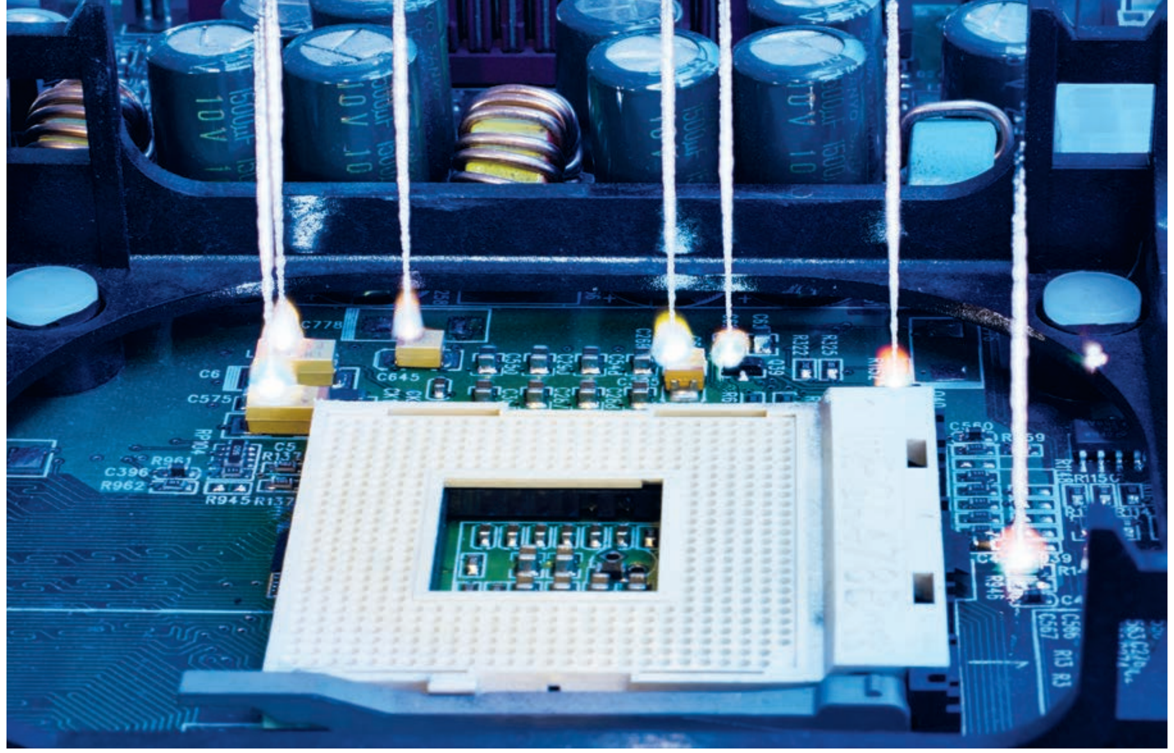




1 Cut surface of a used refractory brick.
2 LIBS measurement: distribution of low (blue), medium (green) and high (red) aluminum contents.



LIBS analysis of electronic components on a circuit board.

Identification of valuable technology metals in electronic waste

Modern electronic products contain a variety of metallic elements to ensure they function at a high standard. In addition to the base metals found in these products, technology metals are also used, such as tantalum, tungsten and rare earth elements. Germany and Europe are highly dependent upon imports of these materials. To ensure sustainable development, companies have to reduce their use in primary production, which is why recycling from old equipment will become essential in the future. In today's recycling processes, however, the technology metals are largely lost. One reason for this is that the metals are only concentrated in a few electronic components and usually account for only a small proportion of the total mass.

Conserve natural resources

In order to recycle technology metals more efficiently, Fraunhofer ILT has developed a process in which the composition of individual electronic components can be determined spectroscopically in their installed state. Components containing valuable substances are then quickly removed and sorted without contact. The metals can be efficiently recovered from these new sorting fractions using existing technological processes.

Sustainable recycling with LIBS

The process of scanning laser-induced breakdown spectroscopy (LIBS) can be used to efficiently determine the composition of electronic circuit boards and identify worthwhile components to then be removed selectively. By using LIBS on a large number of cell phone models, the institute has generated an extensive database that serves as the basis for a take-back system for used cell phones with a suitable material stream for selective dismantling. In the future, high-quality technology metals can be extracted from these materials for use in new products. Also, complex components can be analyzed with the help of LIBS for targeted further processing.

The R&D project underlying this report was carried out with funding from the European Regional Development Fund (ERDF) under the grant number ERDF 0802005.

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Modeling laser-based drying of battery electrodes

When lithium-ion battery electrodes are manufactured, a liquid mixture of ceramic, binder and solvent has to dry, a process that plays an important role as it can save energy and significantly impact the performance of the cell. Indeed, the temperature, speed, and time of drying influence the distribution of the binder, with uneven distribution leading to reduced adhesion between the electrode and current collector, increased electrical resistance, and reduced cell capacity. Experimental diagnostics and numerical simulation can be used to analyze the influence of drying parameters on binder dispersion.

Definition of a suitable simulation model

In the project »Laser-based Drying of Battery Components« Fraunhofer ILT, Instruction and Research Department NLD of RWTH Aachen University and industrial partners are exchanging their know-how on process simulation and experimental tests to define a suitable reduced model by phenomenological model reduction approach. The model predicts the distribution of the binder and thus the adhesion force of the anode.

Modeling and optimization of the drying process

Two main phases of the drying process have been identified. In phase 1 the liquid mixture shrinks, whereby a homogeneous distribution of the binder should be targeted. Phase 2 includes pore emptying, final drying, but also cracking, which should be avoided. The analysis shows that the thermal relaxation time is short compared to the drying time, and the temperature is almost constant while the solvent evaporates. At a low drying rate, the binder concentration increases gradually and remains almost homogeneously distributed, but the required drying time is undesirably long. At a high drying rate, the short drying time leads to a large concentration gradient and the binder accumulating near the surface of the film. Much better results are obtained with multiple drying steps, e.g. two layers with increased adhesion and reduced drying time.

The developed physical modeling can be used to improve the laser-based drying process of electrode slurries and ceramic coatings.

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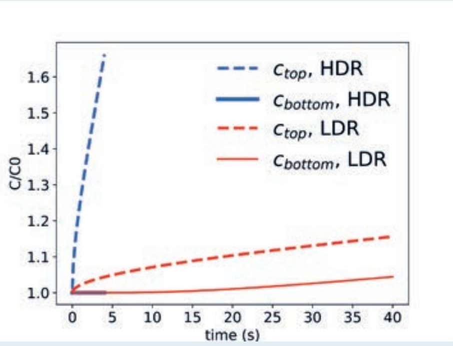
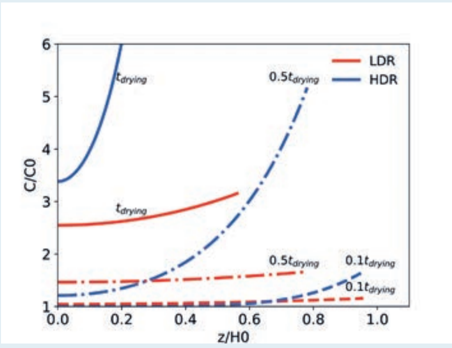
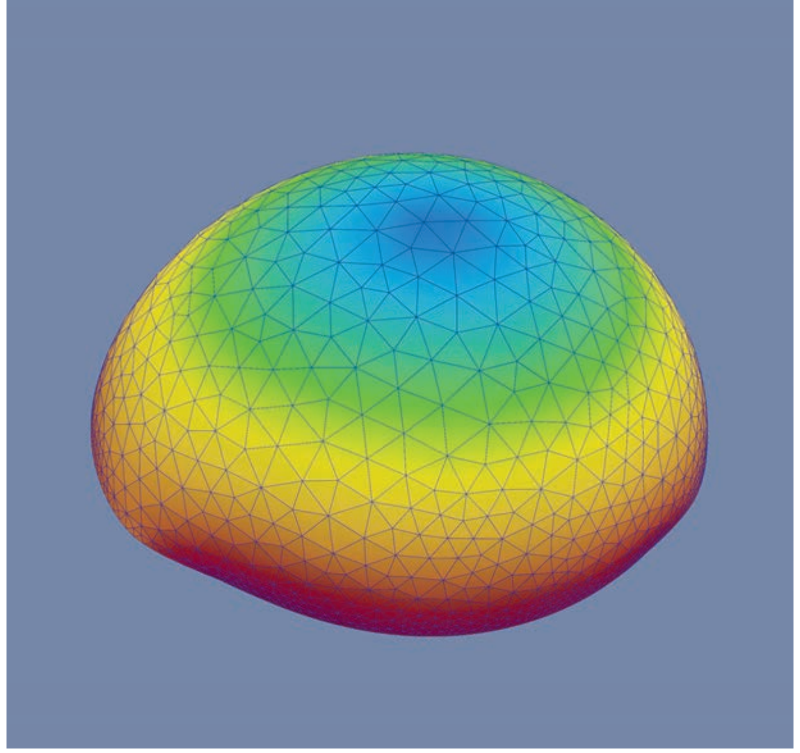
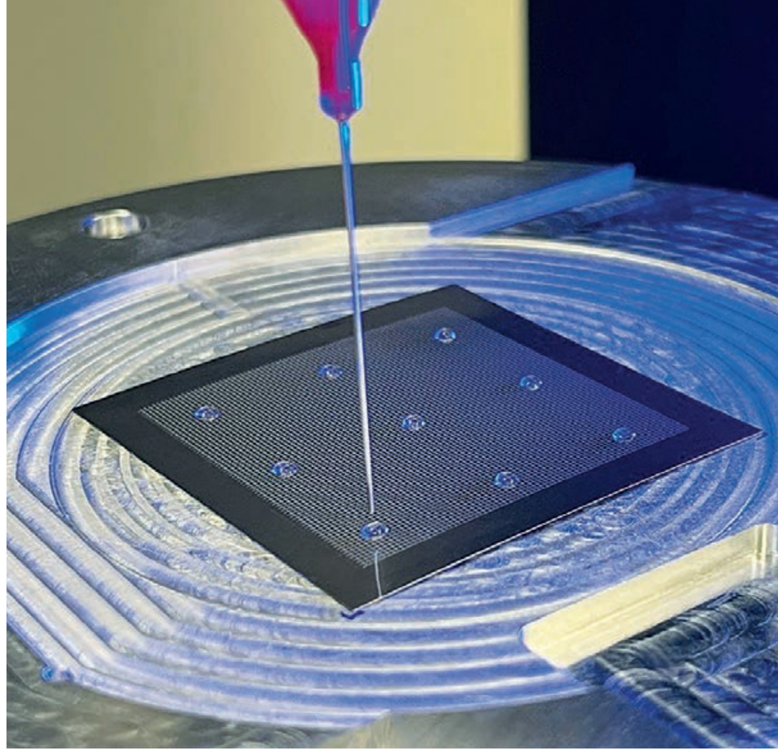




1 Temporal variation of binder concentration at film surface.
2 Spatial variation of binder concentration at low and high drying rate.





1 Temporal variation of binder concentration at the boundaries.
2 Spatial variation of binder concentration at low and high drying rates.

Optimization of laser structured surfaces by simulation

Surface properties play a central role in nature and in many technical applications. The requirements for technical surfaces are diverse and depend on the respective application. The properties of such surfaces can be specifically changed by structuring with laser radiation; for example, hydrophilic and hydrophobic properties can be adjusted by introducing structures in the micro- and nanometer range. The challenge in doing this lies in the material-specific design of the micro- and nanostructures in order to generate desired wetting properties.

Model for simulation of contact angle and drop shape

A droplet can assume several equilibrium states on a rough substrate, each of which represents local energy minima. The particular shape that a droplet assumes depends on the texture design, the surface chemistry, and the depth of penetration of the liquid into the textures. To predict the contact angle and droplet shape on textured surfaces under heterogeneous wetting conditions, Fraunhofer ILT has developed a macroscopic model based on thermodynamic equilibrium principles.

Wide range of applications

The equilibrium contact angles of liquid droplets on rough surfaces can be predicted as functions of laser-structured surfaces and their chemical properties. On surfaces with locally varying properties, the respective droplet shape and motion can be simulated using differential geometric methods. Fields of application are processes in which surfaces must exhibit specific wetting properties. In the medical field, these include the repulsion of endogenous fluids such as blood on surgical equipment or the wetting and, thus, the growth of cells on surgically transplanted artificial joints. Another new field of application can be found in the targeted integration of wetting-promoting or -repelling properties on bipolar plates for fuel cells.

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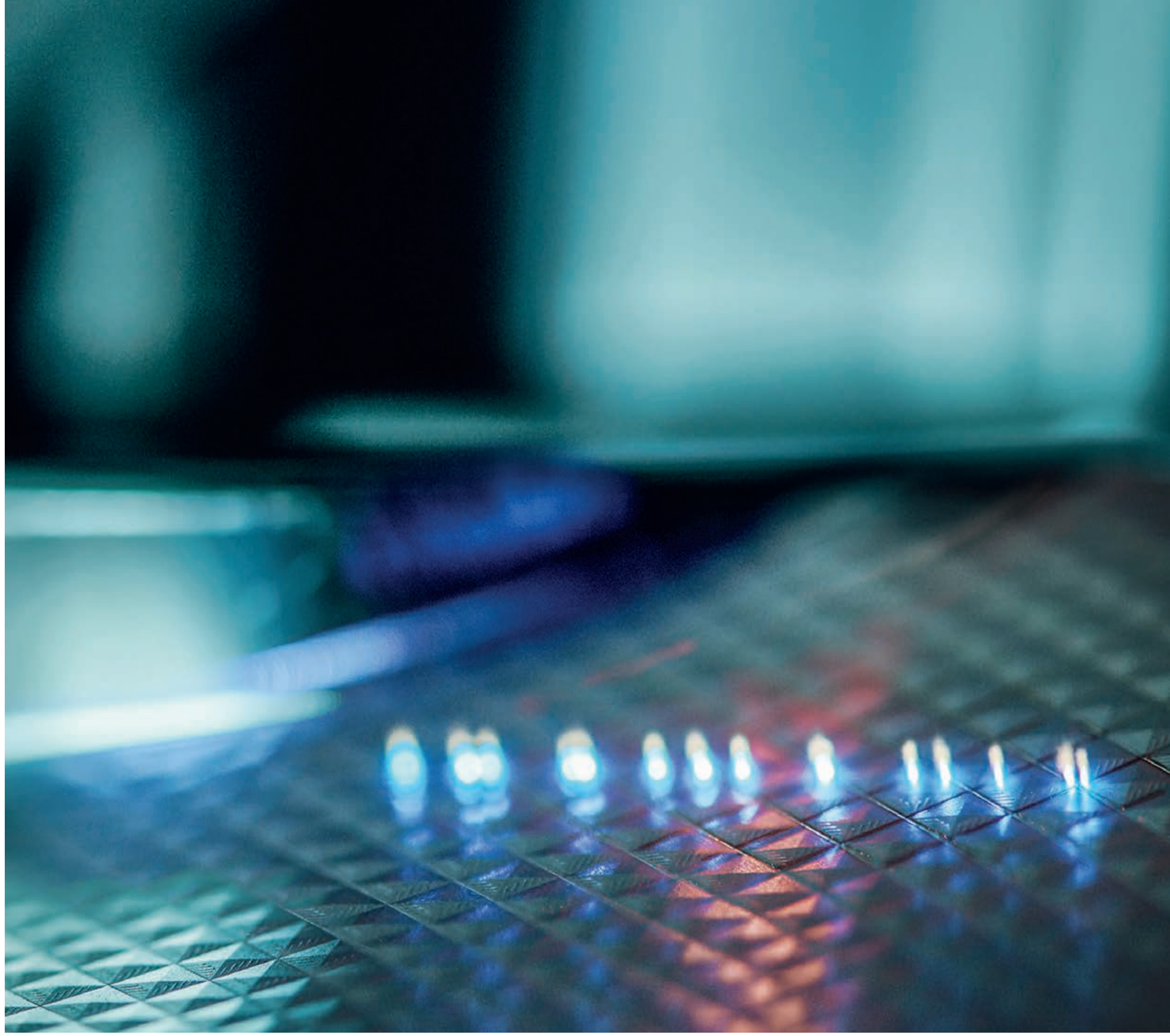
Functional Surfaces and Coatings through Laser Material Processing

The Fraunhofer ILT team of Surface Technology and Ablation develops innovative processes for laser material processing as well as the corresponding system technology to create application-specific solutions for demanding tasks from a wide range of industries. The main areas here are laser-based micro- and nanostructuring, thin-film processing and polishing.

The latest laser beam concepts developed here make it possible to produce tailor-made component surfaces. For example, powerful ultrashort pulse laser systems are combined with multi-beam optics to increase productivity while maintaining the highest surface quality. In addition to surface polishing and the selective ablation of layers, the department is also developing laser-assisted component coating processes that enable new material combinations and energy savings in production. The team focuses on developing inline-capable and automatable processes as well as on scaling, multi-axis processing and laser-based process chains. Its areas of application range from energy technology, electromobility, aerospace technology, medical technology and tool and mold making to microelectronics, optics and quantum technology.



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Laser structuring of bipolar plates

The bipolar plate represents the heart of the fuel cell and enables the continuous supply and separation of the reaction gases, integrates cooling channels to remove the heat of reaction and establishes the electrical contact to the anode and cathode. Bipolar plates are usually made of metals or composites. Currently, the low corrosion resistance of metallic bipolar plates and the manufacturing-related resistances of composite bipolar plates pose an obstacle to large-scale industrial applications. To face such challenges, laser structuring of bipolar plates could become a key technology to fully exploit the potential of fuel cells. Indeed, the surface structure introduced by laser processing allows corrosive reaction products to be removed selectively, the flow properties to be increased locally and electrical surface resistances to be reduced considerably.

New processes for large-area and continuous machining

Fraunhofer ILT uses a 5-axis processing system with an integrated femtosecond beam source to structure bipolar plates. On metallic bipolar plates, the structures produced can be characterized by means of contact angle analysis, which allows the scientists to draw conclusions about the surface energies and to specifically adjust the wetting properties. For bipolar plates made of composite materials, the institute is investigating the surface resistance using contact resistance measurement after the coating has been removed. In combination with highly repetitive beam sources and fast scanning systems, a large-area, continuous machining process can be implemented in production.

Bipolar plates for PEM fuel cells

When metallic bipolar plates are structured, the wetting properties of the surfaces can be specifically adjusted and the contact to the gas diffusion layer increased. When composite bipolar plates are structured, the resistance can be reduced by a factor of five in direct comparison to grinding; area rates of 4,300 cm²/min are reached during laser processing. The coating removal and manufacturing processes developed are of great importance, particularly for products that need properties promoting or repelling wetting by liquids. The focus of the work carried out by Fraunhofer ILT is on the structuring of metallic and composite bipolar plates for low-temperature PEM fuel cells.

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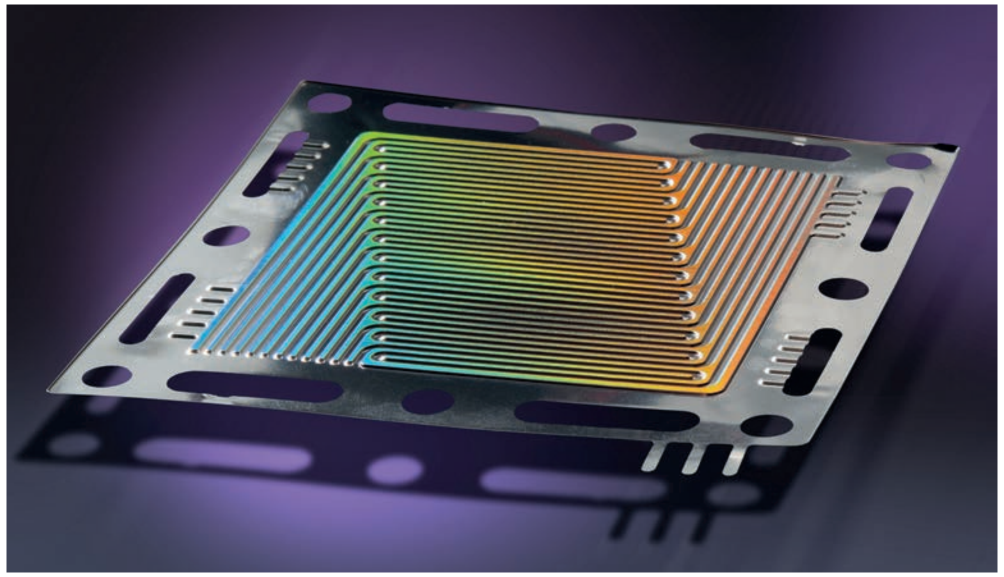
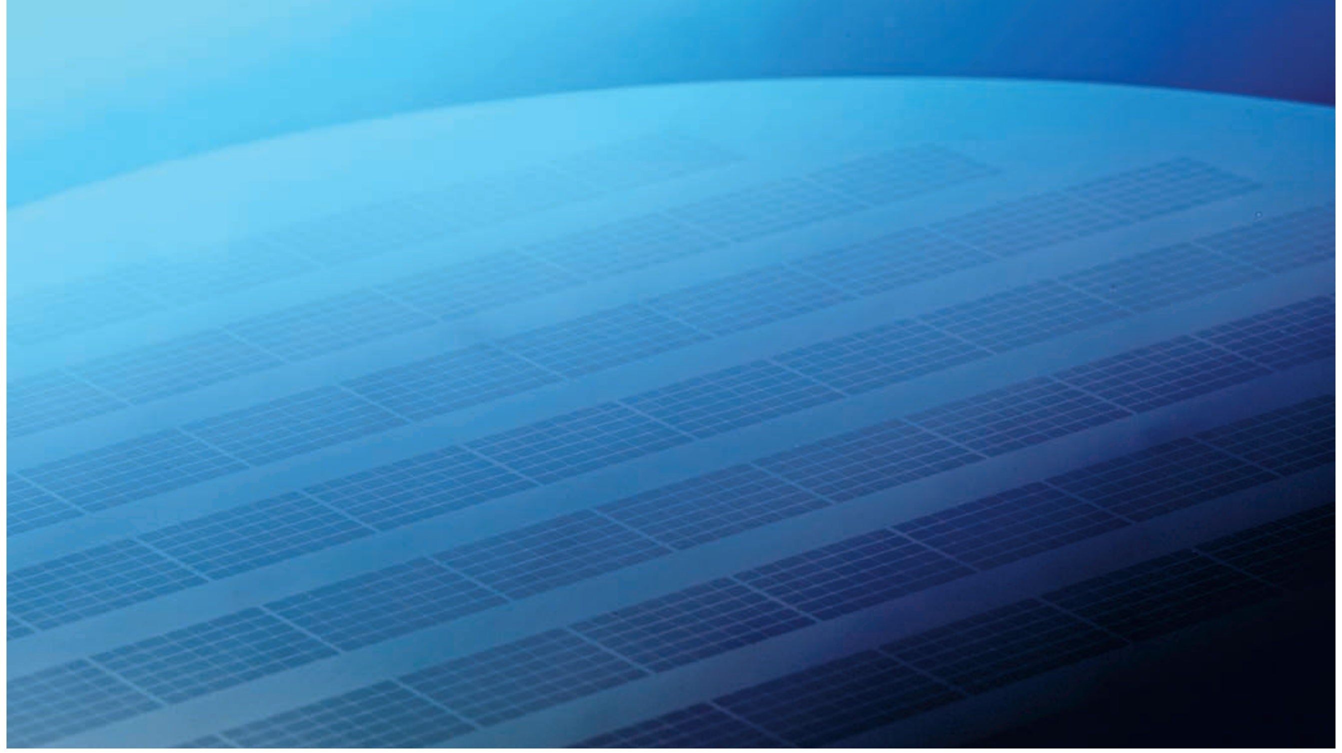


Selectively structured metallic bipolar plate.



Precise laser ablation for microelectronics components.

Precision laser processing for microelectronics

Lasers for microelectronics

To meet the demands caused by its rapid growth, the microelectronics market requires new, flexible, ecological and cost-effective solutions for material processing and structuring. As the industry aims to produce in a green, environmentally friendly manner – to reduce or avoid chemical usage and lower the energy required to manufacture a chip – innovative, digital, laser-based manufacturing technologies are finding wider acceptance. Especially in PCB manufacturing, wafer dicing and packaging, as well as in the production of flexible photonic integrated circuits (PIC), laser-based manufacturing brings immediate benefits if the precision and quality of the processes meet the stringent requirements of this future industry.

UV and DUV radiation as enablers

The high precision, flexibility and quality required of the components can only be achieved when the laser as well as the corresponding system technology are carefully selected. Excimer and solid-state UV as well as DUV lasers are used to achieve increased resolution and tailor-made surface properties of the generated structures. The short wavelengths enable high spatial resolution and efficient interaction with matter. Both mean the treatment is more located and efficient compared to visible or IR radiation, while the underlying layers and surrounding structures are impacted less severely.

Damage-free processing due to customized laser system technology

With the high-power UV lasers available in the »UV Center of Excellence« recently established with the company Coherent, Fraunhofer ILT was able to demonstrate that different sub-µm structures can be fabricated with direct laser ablation. In addition, the flexibility of the laser-based approach enables the partners to process flat wafers and complex 3D surfaces where conventional mask-based lithography techniques reach their limits. The unique picosecond laser system with 266 nm wavelength makes it possible to generate structures with an edge roughness < 500 nm and paves the way for novel forward-looking laser delamination/transfer processes for fabricating microelectronic components.

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Laser-based drying of lithium-ion battery electrodes

The energy transition has increased the demand for energy storage systems, thus making modern and energy-efficient manufacturing processes for energy storage systems necessary. By contrast, conventional drying is an energy-intensive process step in the production of lithium-ion batteries (LIBs). It is normally carried out in long continuous furnaces, which currently still use 92 percent fossil gas and take up a lot of space. Not only can laser radiation be used for drying and reduce the energy and space requirements, but the laser beam sources can be operated with renewable energies, which reduces dependence on fossil fuels.

Laser-based roll-to-roll process

Fraunhofer ILT is developing a laser-based drying process for water-based battery electrode layers. In a roll-to-roll system, copper foils are coated with anode slurries through slot nozzles and dried using laser radiation. Peak temperatures above 160 °C must be avoided to prevent damage to the approx. 80 to 100 µm thin anode. Area-irradiating diode lasers are used to enable a large throughput in the roll-to-roll process.

Efficient drying with laser radiation saves energy and space

When laser radiation is used to efficiently dry LIB anodes, energy requirements can be lowered by up to 50 percent. The required drying distance can be reduced by at least 60 percent according to the results obtained so far. The components contained in the anode are not damaged by the laser radiation and suitable process monitoring. The anodes produced in this way have the same properties as anodes dried by conventional process. The institute is currently using a specially developed extraction concept, adapted process control and appropriate process understanding to further increase the belt speeds to industrially relevant orders of magnitude and to combine them with downstream laser structuring processes.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research (BMBF) under the grant numbers 03XP0316C (project LASERSCALE) and 03XP0414F (project IDEEL).

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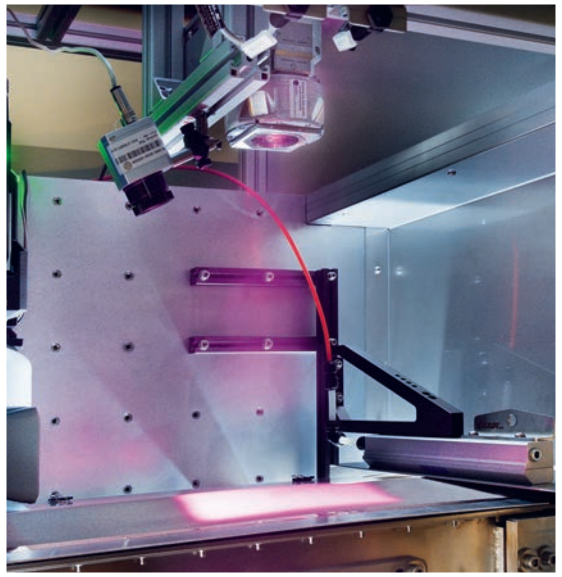
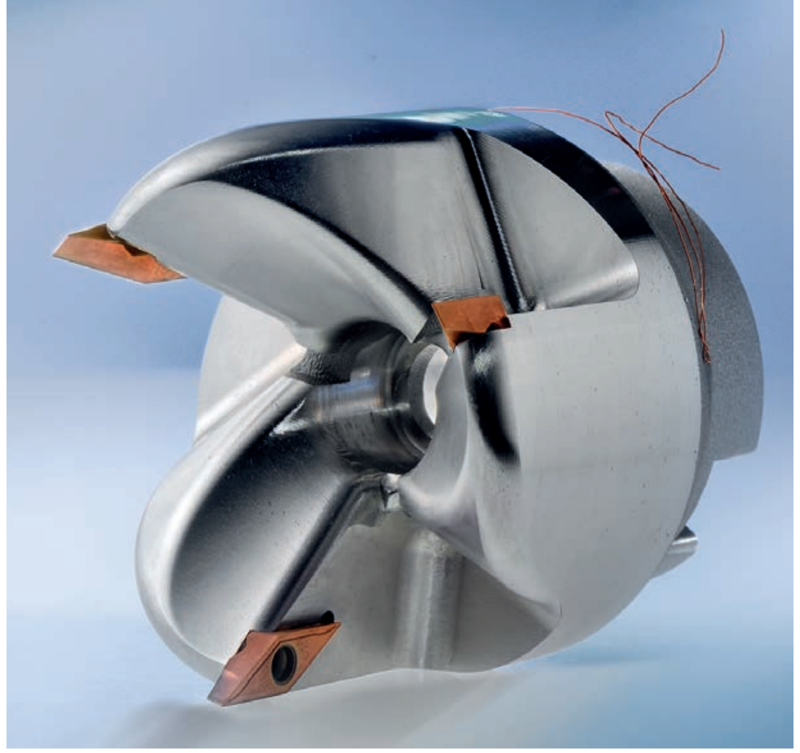


1 Roll-to-roll system for the production of battery electrodes in the Battery Lab of Fraunhofer ILT.
2 Laser drying module with adapted processing optics.



1 Component produced by the LPBF process with integrated sensor technology.
2 Printed strain gauges in incomplete AM component.

Laser-based integration of printed sensor technology in AM components

In the context of megatrends such as Industry 4.0 or the Internet of Things, companies increasingly have to analyze the condition of machines and components in all phases of their service life. To accomplish this, however, a comprehensive sensor infrastructure is required, one that can be realized by using additive manufacturing processes. Currently, sensors are only manually applied to the component surfaces in most applications. However, the optimal sensor position is often directly in the stress zone inside the component. If the functional printing of sensors is combined with 3D structure printing processes such as the laser powder bed fusion (LPBF) process, printed sensors can be integrated directly into the components in the course of inline production.

Multi-stage process for smart components

Fraunhofer ILT has developed a multi-stage process on the basis of a cutter head for a milling tool. Structural printing using LPBF is interrupted to integrate printed strain gauges using a digital functional printing process (e.g. aerosol jet printing) and laser-based thermal post-treatment (Fig. 2). Finally, the structural printing process is continued and the construction of the smart component is completed (Fig. 1).

Potential through high degree of individualization

By combining structural and functional printing with laser-based post-treatment processes, the institute has shown that it can additively manufacture a component with integrated sensor technology. This innovation enables the sensor to be optimally positioned for condition analyses such as load measurements in inaccessible places or near-contour measurements of the component temperature as well as protection of the sensor technology from mechanical and environmental influences. The sensor geometry can also be adapted to individual components. In addition to temperature or strain measurement sensors, further functional elements such as integrated heaters or similar can be implemented in the future. Since this combination process can be customized to such a high degree, a wide range of potential applications are possible, such as in toolmaking and mechanical engineering, in the automotive sector, and in energy or aerospace technology.
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Innovative laser process for edge finishing of high-strength steel sheets

When cutting sheet metal, manufacturers often find it impossible to prevent burrs and surface defects, such as microcracks, from forming. These surface defects significantly impair the mechanical properties of sheet metal components, e.g. as they can initiate fatigue cracks under dynamic loading. Furthermore, burrs increase the risk of injury to people and impair the functionality of components or machines.

Improvement of edge crack sensitivity and cyclic loading capacity

Laser edge finishing of sheet metal is an innovative new finishing process for deburring, specific edge shape adjustment and smoothing of sheet metal materials. It is based on using continuous laser radiation to remelt the edge of a component. When the metal is in the liquid state, the roughness of the edge can flow out due to surface tension and is smoothed. Burrs and microcracks can also be melted in this way. Through the appropriate choice of process parameters, a defined rounding of the edge up to edge reinforcement can also be set. At the same time, since the material solidifies so quickly, the edge area is thereby heat treated and the microstructure selectively changed.

Significant advantages with laser finished edges

Fraunhofer ILT has demonstrated feed rates of up to 9 m/min with a 5 kW diode laser. Hole expansion tests and Diabolo tests show that the edge crack sensitivity of high-strength steels is significantly reduced and the forming capacity is increased by more than 240 percent compared to the conventionally produced cut edge. Fatigue tests also show that the number of cycles of a laser-finished cut edge can be increased by 220 percent compared with a non-finished cut edge. Laser edge finishing has been demonstrated on an industrial scale using both large components and series parts.

The R&D project Laser Edge underlying this report was carried out on behalf of the German Federal Ministry of Economics and Climate Protection (BMWK) under the grant number IGF-20931 N.

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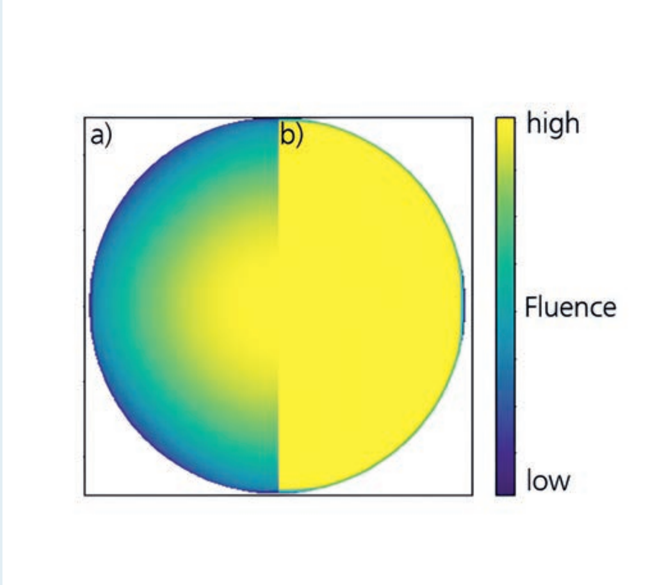
1 Laser edge finishing process.
2 Laser edge finished specimen for hole expansion test.



1 Homogenized energy input by path planning tool: a) without and b) with optimized path planning.
2 Laser polishing machine for free-form glass optics.

Laser polishing of aspheres and free-form optics made of glass

Machine technology and CAM-NC data chain

In recent years, process development for laser polishing of glass has made such considerable progress that the technology is increasingly relevant for imaging optics as well. Current challenges are the development of a suitable machine technology and the CAM-NC data chain for programming these machines even for non-planar surfaces.

Since laser radiation strikes the edges of optics at a non-perpendicular angle during laser polishing at high process velocities of more than 5 cm²/s, there is distortion of the interaction surface and changes in absorption behavior. In addition, local deviations in the radius of curvature (aspheres, freeform) lead to altered heat conduction conditions. All of this contributes to an uneven polishing result already at angular deviations < 10°.

The effects described can be compensated for by geometry-dependent, local adaptation of the process parameters. For this purpose, Fraunhofer ILT has developed software for CAM-NC path planning.

New software for CAM-NC path planning

The resulting CAM-NC data chain can calculate the path planning for a free-form lens with a diameter of 100 mm within a few minutes. Based on the lens geometry, process parameters such as laser power and scanning speed are locally adapted to the optical geometry, and a similarly adapted machine technology implements this path planning. The calculated adaptation achieves uniform polishing with roughness Sa < 1 nm even for incidence angles of up to 45° to the optical axis.

This project was funded by the Fraunhofer Future Foundation as part of the Future Place funding line.

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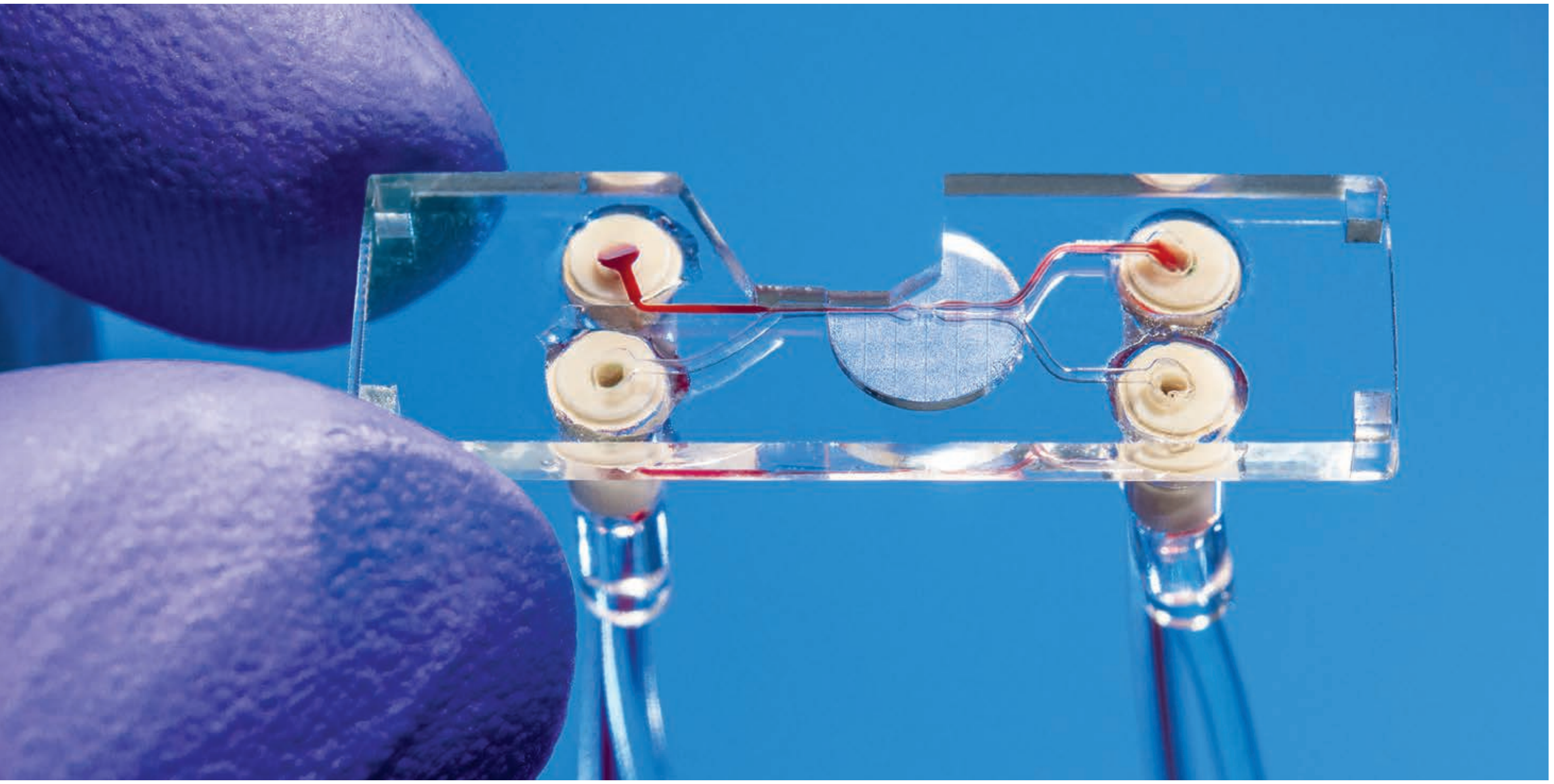
Laser Technology for Precision Medicine and a Healthy Environment



Fraunhofer ILT's interdisciplinary team uses biological, clinical and laser expertise to develop laser-based solutions for medical applications and biomedical research. Our research portfolio covers high-precision laser surgical systems, devices for in vitro diagnostics and environmental analysis, as well as innovative stereolithographic methods and bioprinting processes.

In the field of laser surgery, our team focuses on processes and systems for cutting hard tissue in minimally invasive procedures in neurosurgery. In addition, we develop diagnostic processes based on microfluidic sorting and detection systems for the differentiation and separation of pathogens as well as diagnostic particles for infection diagnostics. We offer customers in biomedical research innovative laser processes for the targeted transfer of single cells onto diagnostic chips. We also have patented stereolithographic processes that allow the automated production of individualized medical devices.

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Laser Medical Technology and Biophotonics Department

- Laser Medical Technology and Bioanalytics
- Biofabrication

Rapid sepsis diagnostics by cell separation in a microfluidic sorting system

Every year, 49 million people worldwide contract sepsis, 11 million of whom die during the course of the disease. In Germany, sepsis is the third most common cause of death after cardiovascular disease and cancer, with 85,000 deaths per year. It is caused by an infection of the bloodstream with primarily bacterial pathogens. While broad-spectrum antibiotics for sensitive pathogens kill effectively, they are ineffective against pathogens that have become resistant to antibiotics. In this case, a resistance profile of the pathogen must first be determined, and then highly specific narrow-spectrum antibiotics must be administered. Such resistance determination requires separation and cultivation of the pathogen. This takes more than 24 hours, so unfortunately effective therapy often comes too late for those affected.

Saving time thanks to a new sorting system

Scientists at Fraunhofer ILT have, therefore, developed a microfluidic sorting system to significantly speed up the isolation of pathogens from a patient's sample. The system makes use of the cross-flow called Dean flow, which occurs in spiral-shaped curved microchannels. With appropriate parameter selection, this flow causes bacteria to separate out from blood cells in a patient sample based on their size. This high-throughput separation process was investigated and conducted on a fused silica chip.

Rapid resistance test for efficient and rapid isolation of pathogens

The process for separating the larger erythrocytes and leukocytes from the 1 µm to 3 µm sized bacterial cells was demonstrated using the Dean flow sorting chip in fused silica. The efficient and rapid isolation of the pathogens forms the basis for a rapid resistance test in the microsystem. This technology, developed at Fraunhofer ILT, allows the separation of typically several 100 to several 1000 bacteria from a 10 ml blood sample within 2 hours.

Fields of application in medicine

In addition to the addressed rapid resistance tests, the technology can be applied in microbiological assays based on cell cultures as well as in biomedical research. The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research under the funding program "Innovative medical technology solutions for the prevention and care of nosocomial infections" under the grant number 13GW0431C.

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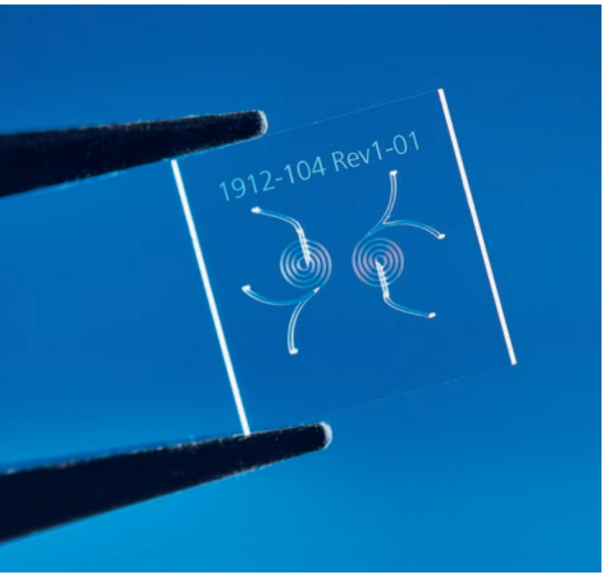
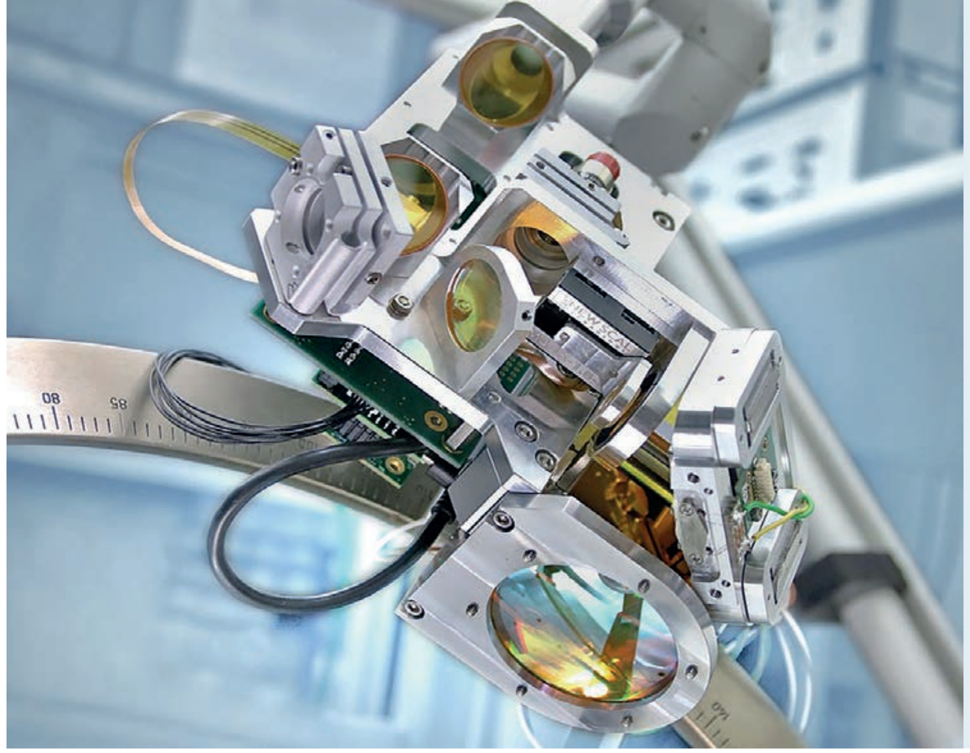
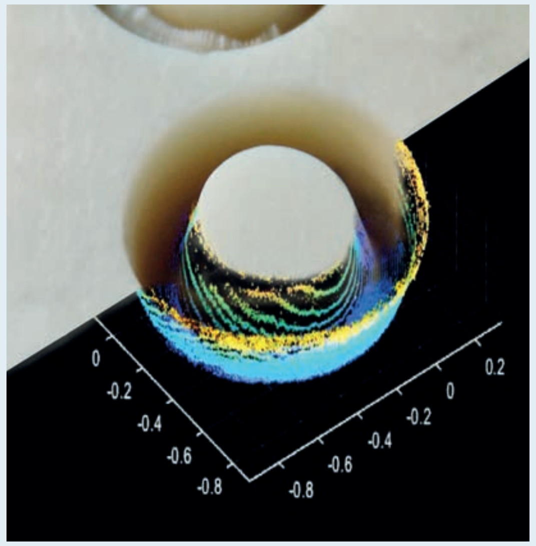


1 Fused silica chip with two Dean flow sorting structures.
2 Separated blood cell flow at a branch in the sorting chip.





1 Laser applicator with integrated mini-scanner, telescope, OCT sensor and beam position monitoring.
2 Circular laser cut on a bovine bone with superimposed point cloud from the measurement data of the OCT scan.

Laser craniotome for awake surgery for deep brain stimulation

Towards gentle craniotomy in awake patients

The shaking paralysis (tremor) that occurs in patients with Parkinson's disease can be suppressed by deep brain stimulation (THS) with a brain pacemaker. To accomplish this, a surgeon must position an electrode with submillimeter precision in the target volume of the brain while functionally testing it on the awake patient. The combination of THS and awake surgery significantly increases the success rate in the treatment of patients with severe movement disorders. However, opening the skull (craniotomy) causes massive stress in awake patients who are only locally anesthetized. Scientists at Fraunhofer ILT are, therefore, developing a laser surgical system for craniotomy to minimize patient trauma and increase acceptance of the effective procedure.

Innovative laser surgery system combines cutting laser beam, mini-scanner and OCT measurement

The laser cutting process uses an applicator to distribute pulses of a CO_2 laser beam along the cutting line by means of a mini-scanner, such that the 2-mm-wide laser cut can be made efficiently in bone to a depth of 6 mm without causing thermal tissue damage. In addition to the cutting laser, an OCT measurement beam is guided along to measure the cutting depth and residual bone thickness during ablation. This real-time monitoring is intended to prevent injury to the underlying hard meninges (dura) and brain.

The laser ablation process investigated here was implemented in a demonstrator for the use case of deep brain stimulation. All subsystems such as mini-scanner, OCT sensor, beam monitoring and the cutting laser system can be monitored and controlled via control software. In an automated process sequence, the proof of concept has been provided on a sheep skull with the deep brain stimulation demonstrator. A round bone flap of 10 mm diameter and 3 mm thickness was cut out and the cutting depth was determined with an integrated OCT measurement. The laser craniotome is designed for cutting hard tissue on the skull and its functional scope can be extended to other applications such as brain tumor surgery. The project is funded by the Fraunhofer-Gesellschaft within the research program ATTRACT under the project name STELLA.

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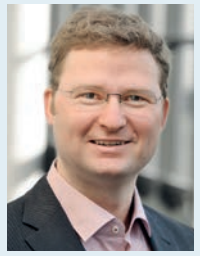

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LIFT microscope for contact-free cell culture preparation

In personalized medicine, highly specific drugs are tested on autologous cell cultures of a patient for side effects as well as for their effect on customized therapies. For this purpose, so-called induced pluripotent stem cells (iPSC) are taken from the patient and can be differentiated into different tissue types for drug testing. To make such in vitro testing procedures with the patient's own cells economical and to transfer them to routine diagnostics, a laboratory has to grow, analyze and sort iPSC cultures automatically.

Combining cell recognition and LIFT in one system

In an inverted microscope with cell culture chamber, the project partners have combined high-speed microscopy software with an algorithm for automatic cell recognition (Fraunhofer IPT) and a module for laser-induced forward transfer (LIFT) developed at Fraunhofer ILT. With this system, it can sort cells gently, automatically and without contacting them. The LIFT process uses a MIR beam source with a wavelength of 2.94 µm, which has already been proven for the transfer of single cells and cell clusters from an aqueous environment. By combining cell detection and the LIFT process in one system, the partners can culture cells and selectively remove selected pluripotent stem cells from culture using laser-induced forward transfer without manual steps. A carrier substrate with cell culture medium accommodates the removed cells; there, the selected iPSC cells can be further cultured in a new culture for in vitro testing.

Versatile applications in everyday laboratory work

Thanks to its modular design, the transfer system serves a wide range of applications in everyday laboratory work. Existing cell analysis systems and microscopes can be expanded and individual work steps automated. Thanks to this reduction of manual work steps, laboratories will be able to produce in vitro test systems faster, more reliably and cheaply and, thus, conduct routine diagnostics in personalized medicine.

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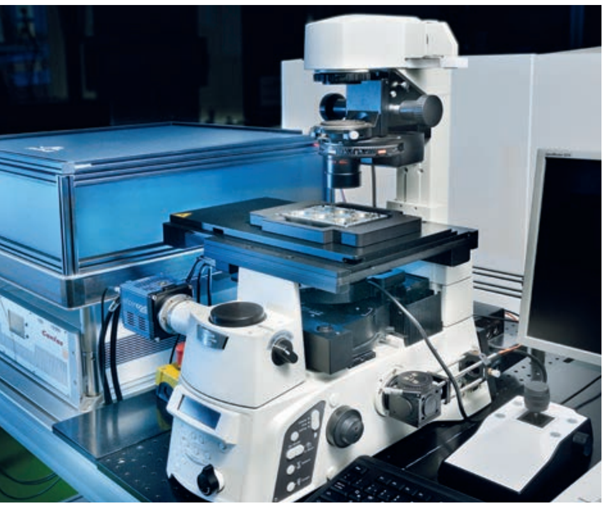
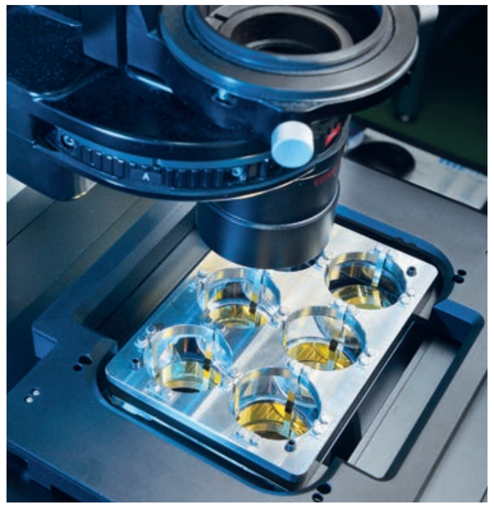
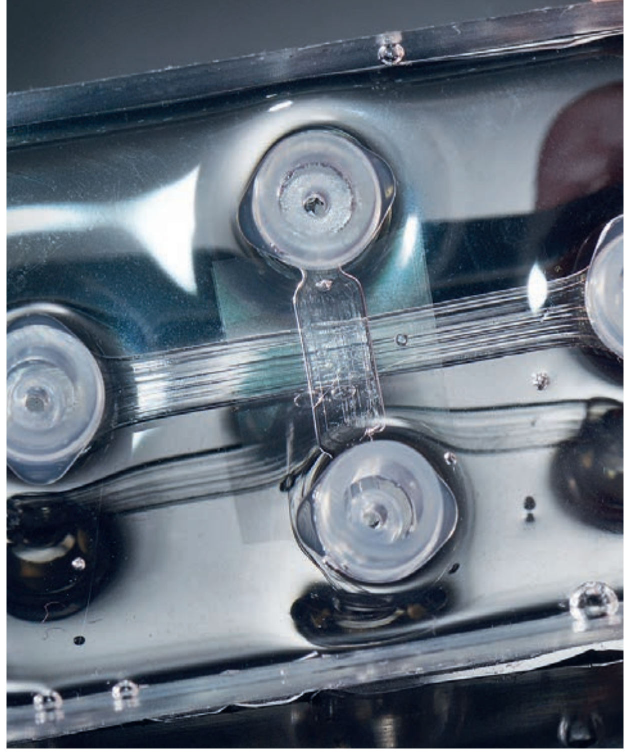




1 Microscope with integrated high-speed image recognition and laser-assisted cell separation.
2 Substrate holder for collecting and cultivating transferred cells in the multiwell cell culture vessel.



1 OoC of PDMS with intersecting channels separated by a membrane.
2 Cell cultivation in four OoCs with automated perfusion.

3D bioprinting of organ-on-chip systems

Organ-on-chip (OoC) systems have found their way into biomedical and pharmacological research in recent years. OoCs are microfluidic chip systems that supply 3D cell cultures with nutrients and better reflect in-vivo conditions of living organisms than two-dimensional in-vitro cell cultures. Testing new drugs on such 3D cell cultures greatly accelerates their development and helps make animal experiments less necessary. In the future, OoCs could even serve as a precursor for the cultivation of artificial organs.

Building cell models for artificial organs

Fraunhofer ILT scientists are researching the production of organ-on-chip systems by extrusion printing according to the sacrificial bioprinting process. This process uses different polymer materials as well as cell-laden hydrogels, so-called bio-inks. Typical cells for colonization are endothelial cells for vascularization of tissues. The continuous perfusion of the OoC system makes it possible to cultivate and investigate the cells over longer periods of time. In this context, thanks to the transparent properties of the microfluidic chips, cells can be examined with an optical microscope. Thus, organotypic cell models with functional properties can be constructed and examined in the laboratory.

Co-cultivation models for assay development

OoCs fabricated by extrusion-printing methods were seeded with different cell types and cultured under continuous perfusion in the laboratory. For endothelial cells, flow conditions were determined in which growth occurred directionally along the direction of flow, a mandatory requirement to build artificial blood vessels and vascularized organoid structures. In addition, the project partners have developed both a co-cultivation model with endothelial and epithelial cells in separate cell spaces and a migration assay for monocyte stimulation. Both are fundamental to linking multiple organ systems and involving the immune system in the assembly of OoCs. Potential applications are in drug discovery, biomedical research, and the development of patient-specific assays. The work carried out in the project SiCellNet was funded by the Fraunhofer "KMU-akut" program.

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Joining and Cutting – Not just a Question of Adjustment

The Fraunhofer ILT laser experts in the Joining and Cutting Department investigate a wide field of laser material processing. The applications they examine use a large variety of materials, from metal and plastic to wood and glass, and address a wide range of workpiece dimensions, from thick sheets to thin foils.

The department focuses on laser-based connection technology – in particular, for electrical contacts in energy storage and power electronics – including laser welding and soldering as well as processes such as plastic welding and glass frit bonding. For laser cutting, it develops processes and process-specific components such as optics, cutting nozzles and control systems. In addition to high-performance processes such as high-speed cutting and thick sheet cutting, the experts look at integrating applications that combine cutting, welding and additive powder processes. The application areas here range from battery technology and fuel cell manufacturing to packaging and textile technology. We offer users customized solutions from feasibility studies to complete individual laser processing machines.

Joining and Cutting Department

- Joining of Metals
- Joining of Plastics and Transparent Materials
- Cutting

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Laser-beam welding of electrode stacks for lithium-ion battery cells

The electrical contacting of electrode stacks is an important step in the manufacture of lithium-ion battery cells. To increase productivity, Fraunhofer ILT is developing an overall process directly linked to electrode production in order to automatically manufacture the electrode-separator composite of a lithium-ion battery cell. As a result, the project presented below is expected to help reduce the overall costs in the production of electric vehicles and thus strengthen the value chain of electromobility.

High speed contacting of electrode foils

In the HoLIB project, Fraunhofer ILT is developing a laser-beam welding process to contact electrode foils for Li-ion battery cells at a very high speed. Depending on the process regime (heat conduction welding or deep penetration welding), the institute is investigating the parameters power, feed rate, beam shape and irradiation strategy with different wavelengths. It is focusing on fiber lasers (1070 nm), »green« disk lasers (515 nm) and »blue« diode lasers (450 nm). Important criteria here are the geometric dimensions of the weld seam, such as the width and height of the top bead, and the microstructure.

Productivity increase in cell production

Thanks to the laser-beam welding process developed and the associated pressing device, the electrode foil stack can be contacted with the arrester tabs in a single process step. The weld geometry is dimensioned according to the required current carrying capacity with the aid of local power modulation and can be flexibly transferred to other cell formats. Both copper and aluminum are used as materials. Since the absorption is adapted by the beam shape and wavelength as well as the associated energy input, the cell stacks can be joined without damaging the individual foil layers. The institute is using different irradiation concepts, depending on the material and composite thickness. The ProZell 2 cluster aims to increase productivity in the production of battery cells. In addition, laser-beam welding of thin electrode foils can also be transferred to other industrial areas.

The HoLiB project (grant number 03XP0236A) is being funded by the German Federal Ministry of Education and Research (BMBF) in the ProZell competence cluster for battery cell production.

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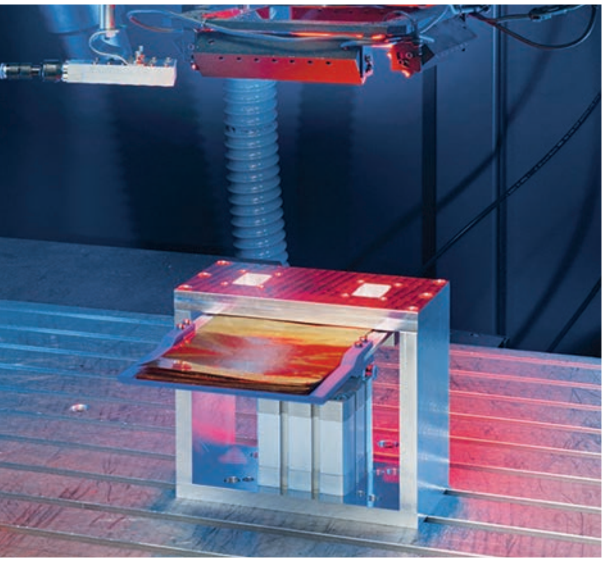
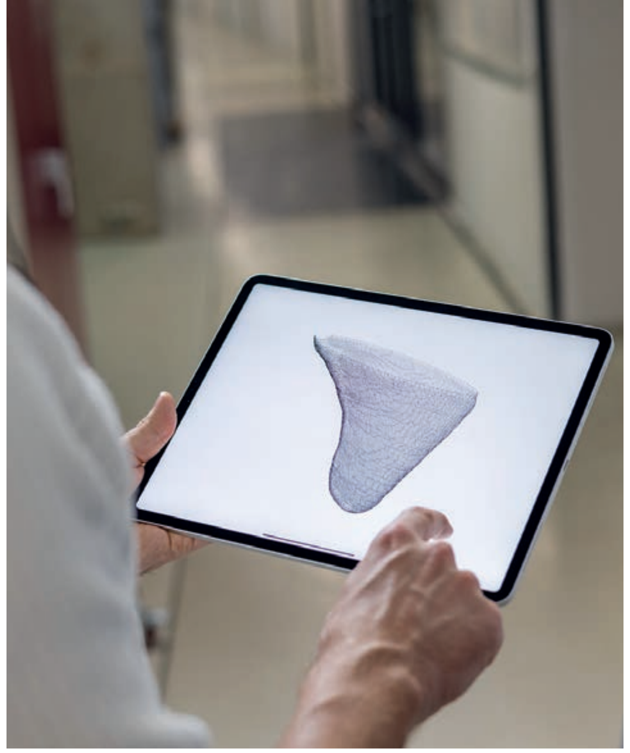


1 Laser-beam microwelding of electrode stacks with a wavelength of 1070 nm.
2 Cross-section of the contacting of the copper foils to the arrester tab.



1 Analysis of steam capillaries from synchrotron data, © TRUMPF.
2 Laser-beam welding with green laser, © TRUMPF.

In-situ analysis of laser processes using synchrotron radiation at DESY

Laser-based processes can play a significant role in fabricating sensitive components for fuel cell and battery technology since their energy input can be flexibly and precisely adjusted. By using synchrotron radiation, research can investigate these laser beam processes in-situ with high temporal and spatial resolution to gain precise insight into the fundamental phenomena of the molten and vapor phases.

Implementation and application

At the Deutsches Elektronen-Synchrotron DESY (German Electron Synchrotron) in Hamburg, a mobile and modular setup can be used for investigating laser-based manufacturing processes. With this platform, laser beam sources of different types and wavelengths (fiber, disk, ring mode or ultrashort pulse lasers) and optical systems (scanner-based and fixed optics) can be modularly interchanged to conduct laser beam welding, cutting and drilling experiments. Fraunhofer ILT is using synchronized process control with optical and acoustic sensors to develop more detailed algorithms for process evaluation.

Basic transfer to industry

The setup developed here is used as a tool to study the following physical dynamic process properties:

- Spatial distribution of energy deposition on the material surface
- Influence of the laser wavelength on the material-laser interaction
- Geometry of steam capillary and melt pool
- Melt pool dynamics and flow profiles

In the course of very complex basic research, Fraunhofer ILT is serving as a pioneer to help industrial partners gain access to DESY on a service basis. In this context, the existing experimental setup, including existing beam sources and optics, can be used within the framework of a bilateral collaboration to generate new or extend basic findings for industrial applications.

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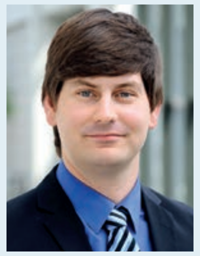

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Trilateral Fraunhofer-DFG transfer project "High Speed Weld"

Laser transmission welding (LDS) has established itself as method for producing strong joints in partially transparent plastics. One limitation of LDS, however, is the necessary interaction time between laser radiation and matter. Usually, irradiation times of up to one second are required to produce welded joints. As part of the "High Speed Weld" project, a high-speed laser welding process (H-LDS) is being developed that will allow a significant reduction in processing times. Based on this, Fraunhofer ILT and the project partners are developing optical systems and the necessary plant technology for the industrialization of H-LDS.

High speed joining process for packaging

To implement this technology, the institute is initially extending an existing simulation model to generate fundamental findings on the heating, cooling and welding behavior during the high-speed process. For this purpose, the material properties of the plastics used being determined under high heating and cooling rates. Based on the simulation results, an optical system is being designed and used to verify the simulation results in order to determine the process limits.

Results and fields of application

In initial tests, the typical processing time can be reduced by a factor of about 100 down to 0.01 s while the joining surface is irradiated simultaneously. Microscopic examination of the seam cross-section shows no damage. A tensile shear test shows that the base material fails in an otherwise intact welded joint.

In addition to Fraunhofer ILT, the project partners involved are the Institute for Plastics Processing (IKV) in Industry and Trade at RWTH Aachen University, Laserline GmbH and Leister Technologies Deutschland GmbH.

The project "High Speed Weld – Development of a high-speed laser welding process for joining plastics" is funded under the Fraunhofer-DFG Transfer Program.

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1 Top: Laser-welded PA6.6-GF20 specimen. Bottom: Fracture pattern after tensile shear loading with failure of the base material outside the weld area.
2 Microscopic analysis of the joining plane without any visible damage or heat-affected zone.

1 Multi-chamber hybrid reflector.
2 Hybrid lens holders.

Class A surfaces with laser-based hybrid material composites

Motivation

To fulfill certain needs in production – lightweight construction and increased functionality, to name just two trends – the industry will need to combine different dissimilar materials in photometrical applications. The requirements of LED technology can be met by combining the good thermal conductivity of die-cast components with the high surface quality of injection molded components. In the NRW Form-LIGHT project, a plastic-metal hybrid composite with a Class A surface was developed.

NRW project Form-LIGHT

Within the project, Fraunhofer ILT examined how an undercut structure could be inserted into the light metals aluminum and magnesium. A part of its investigation was to compare different focal lengths as well as to vary the laser power, the scanning speed, the number of passes and the structure arrangement. Using cross-sections, the institute considered and evaluated the effects of varying these parameters, and it selected the parameter settings based on this evaluation for the subsequent process. In it, plastic is injected into the structures by means of back injection to generate a positive locking fit.

Advantages for the automotive industry

The project demonstrated that the combination of plastic and light metal can reduce the limitations of each material and harness the advantages of both for automotive applications such as headlamp systems.

This project was funded by the European Regional Development Fund (ERDF) under grant number EFRE-0801472.

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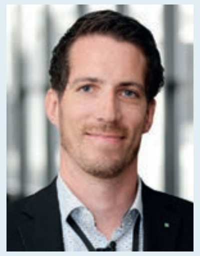

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Laser cutting and welding with artificial intelligence

Laser cutting requires high process stability and reliable process monitoring in continuous processes, such as in laser blanking, and in chained processes, such as in the production of bipolar plates or battery electrodes from the roll. Artificial Intelligence (AI) can be used to interpret process signals during cutting and welding, which means that quality assurance as well as process monitoring and control becomes more robust and can meet the high demands of real-time evaluation of dynamic processes.

The joint project DIPOOL

The joint project DIPOOL, scientifically coordinated by Fraunhofer ILT, aims to combine the unique temporal and spatial programmability and controllability of laser tools with suitable machine learning (ML) and AI methods. To obtain meaningful data quality, the institute applies minimally invasive laser modulation (MILM) patterns on the machining process. The process continuously responds to these with characteristic signals dependent upon its state. When such response signals are available and they are fused with further sensor data of the machine, a highly efficient training of ML algorithms is possible as well as reliable conclusions and decisions of the AI system.

Use in laser blanking

Fraunhofer ILT identified suitable modulation patterns and resulting response signals for the DIPOOL laser blanking demonstrator system. It integrated the AI into the system control on a real-time capable process computer with FPGA, on which data acquisition, pre-processing and inference are clocked at 1 to 2 milliseconds and thus run sufficiently fast for the high-speed cutting process. The DIPOOL project partners are currently also investigating how suitable the method is for welding car body components.

The joint project DIPOOL is funded by the German Federal Ministry of Education and Research (BMBF) within the funding measure ProLern (grant number 02P20A000) and is supervised by the Project Management Agency Karlsruhe (PTKA).

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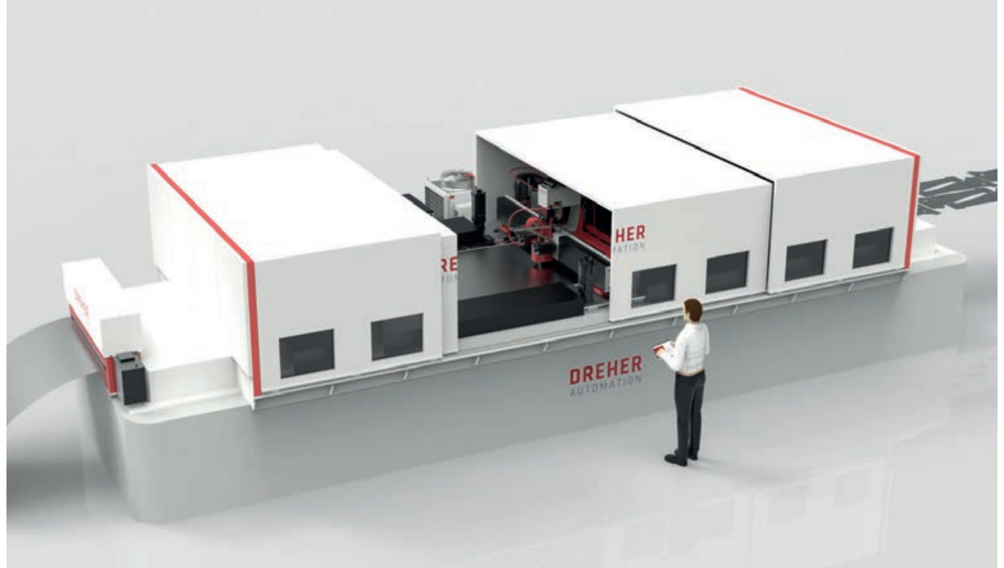

DIPOOL laser blanking demonstrator system, © AutomaticSysteme Dreher GmbH.

Laser beam fusion cutting with the "cutting whistle".

Control of melt dynamics on the basis of a resonant nozzle – the "cutting whistle"

Using high-speed video analyses of the melt film on the cutting front, Fraunhofer ILT determined that high-frequency melt waves have a positive effect upon the cutting edge roughness. However, the wave frequencies can only be influenced by the process parameters to a limited extent. To amplify the high-frequency melting waves and to dampen low-frequency flow instabilities, the institute has developed an acoustically tuned cutting nozzle design, the so-called "cutting whistle." This approach aims at matching the impedance between nozzle and kerf.

The principle of the cutting whistle

The cutting whistle is based on a cavity-induced supersonic flow. The cavity formed on the nozzle exit side essentially generates two oscillation modes, whose resonant frequency can be tuned as a function of the cavity geometry. The resonances or oscillation modes are validated with a schlieren imaging system as well as with an optical microphone. Cuts are made on 6 mm thick stainless steel sheets so that their effect on the melt film dynamics and the resulting cut edge quality can be assessed; in-situ high-speed videos of the melt film are recorded and analyzed.

Optimization of laser cutting processes

The high-frequency oscillations induced by the cutting whistle not only can be detected in microphone measurements and schlieren recordings, but also have been verified for the first time by high-speed videography of the melt flow. Up to now, the melt film dynamics can be controlled specifically, especially in the upper part of the cutting front. Here, the coupling of the gas-flow oscillation is most pronounced, so that the cutting edge roughness is reduced by up to a factor of two. Future investigations are aimed at further increasing the oscillation and coupling efficiency. The use of acoustic resonances in laser beam fusion cutting is just one example of the potential that the simulative, diagnostic and practical consideration of acoustic effects offers for improving laser material processing.

The project is funded by the German Research Foundation (DFG) within the framework of the Collaborative Research Center SFB1120 Precision from Melt.

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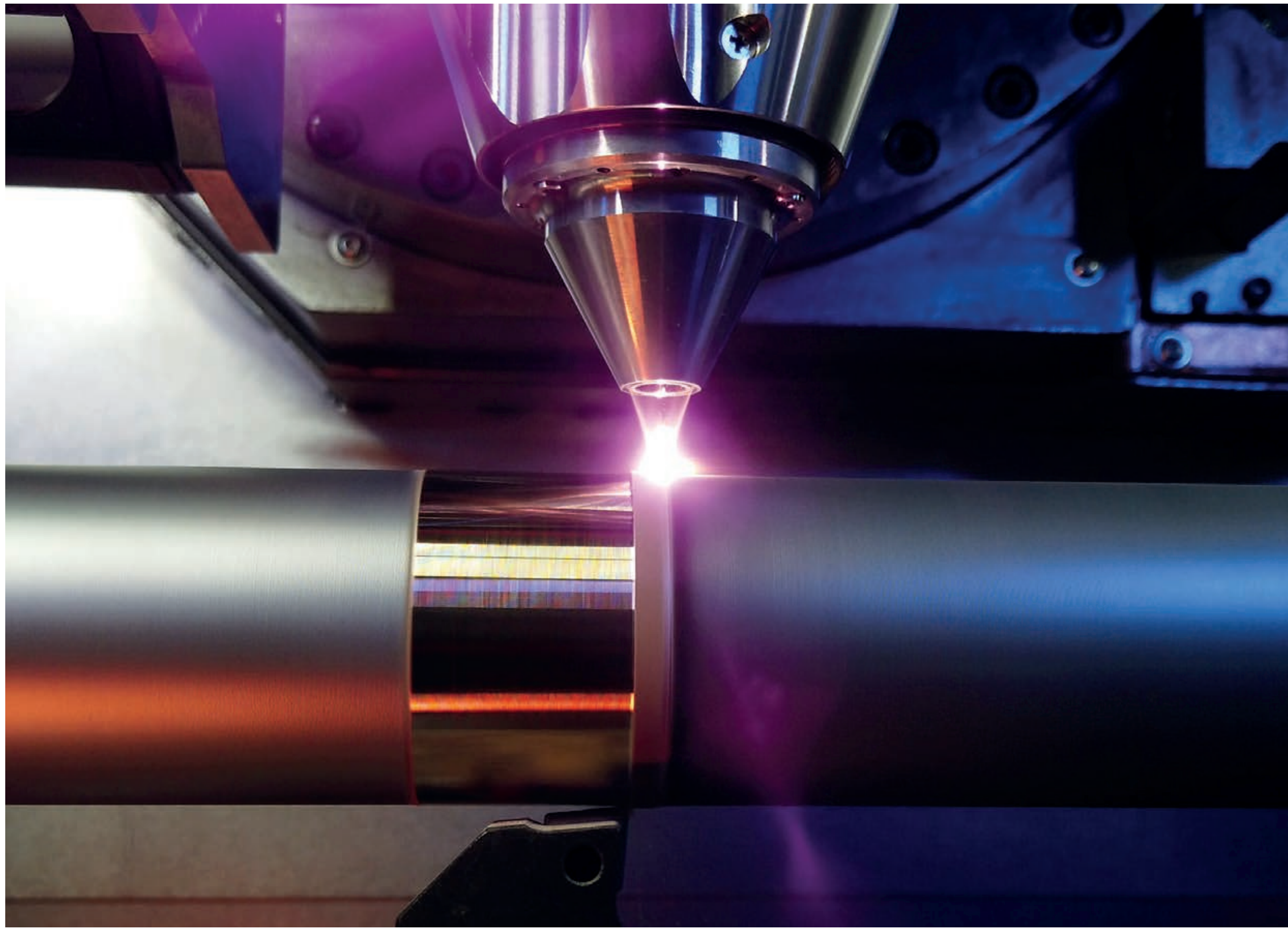
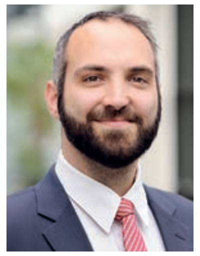
Laser Material Deposition for Sustainable Solutions in Coating, Repair and Additive Manufacturing

For over 35 years the Fraunhofer ILT's Laser Material Deposition Department has been consistently researching and developing powder- and wire-based laser material deposition (LMD) as well as the associated equipment and system technology for ever new fields of application and industries.

Various projects can be carried out efficiently thanks to our broad spectrum of available equipment technology, analysis capacities as well as extensive development know-how for diverse user industries, such as aviation, automotive or energy. Our services range from ideation and consulting to developing customized processes as well as components and process monitoring all the way to transferring the process to customer plants. The processes we develop range from highly efficient and robust coatings, reconditioning of worn components to near-contour additive manufacturing of complete components. LMD is especially attractive for small and medium sized companies since it is highly flexible: it can be easy adapted for different application fields – coating, repair and additive manufacturing – and simply integrated into existing process chains.





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- Coating LMD and Heat Treatment

COLLAR AM – Coaxial laser-arc hybrid welding

Wire-based laser material deposition (WLMD) and wire arc additive manufacturing (WAAM) are established processes in the additive manufacturing sector. Since the laser radiation can be focused so precisely, WLMD can be used to produce particularly fine structures with small surface ripples, but the deposition rate is limited. The WAAM process, on the other hand, is characterized by larger application rates, but also greater surface waviness and weld spatter, both of which lead to pore formation in the component. When the two processes are combined into a new hybrid process, the specific advantages of each can be harnessed, but this means that the required system and process technology needs to be developed anew.

Innovative system technology

For the innovative process – coaxial laser arc hybrid (COLLAR Hybrid) – Fraunhofer ILT developed a new processing head that arranges both processes in a coaxial manner. During process development, the institute determined suitable process parameters for a simultaneous process start and investigated areas with different power shares of the two processes with regard to the cladded geometrical forms and deposition rates. It then used metallographic analysis to define process windows for defect-free deposition.

COLLAR hybrid process – advantages for additive manufacturing

Thanks to the COLLAR hybrid process, components can be additively manufactured with the deposition rates of the WAAM and the precision of the WLMD. Compared to those of a pure WLMD process, the deposition rates can be increased to up to 4 kg/h, and welding speeds of up to 3 m/min can be achieved while maintaining the same qualities. All conventional welding electrodes or standard wires in the range of 0.8 to 1.6 mm can be processed with the process. COLLAR Hybrid can also be used to join 3D seam tracks. Due to its improved properties, the hybrid process can be applied in almost all areas of metal construction.

The IGF project "Direction-independent laser-GMA hybrid welding with annular focus and coaxial wire feed for joint welding and additive manufacturing – KoaxHybrid" of the German Welding Society (DVS) was funded by the German Federation of Industrial Research Associations (AiF) as part of the program for the promotion of joint industrial research (IGF) of the German Federal Ministry of Economic Affairs and Climate Action (BMWK).

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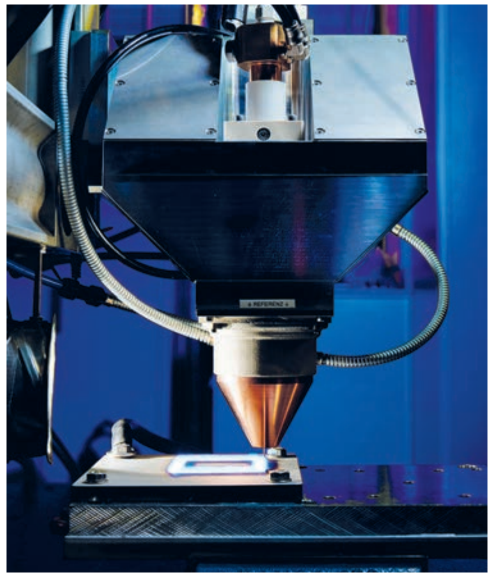
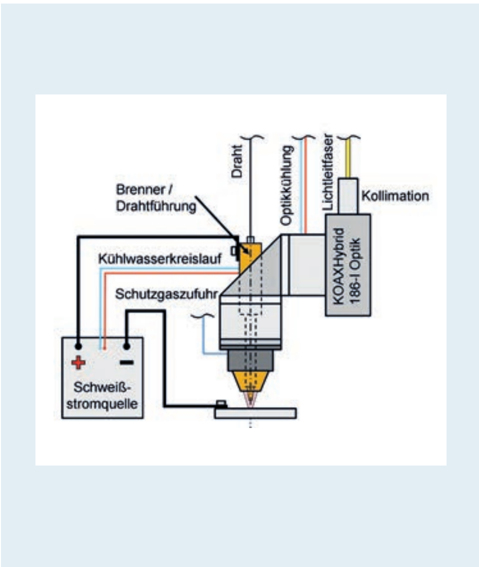
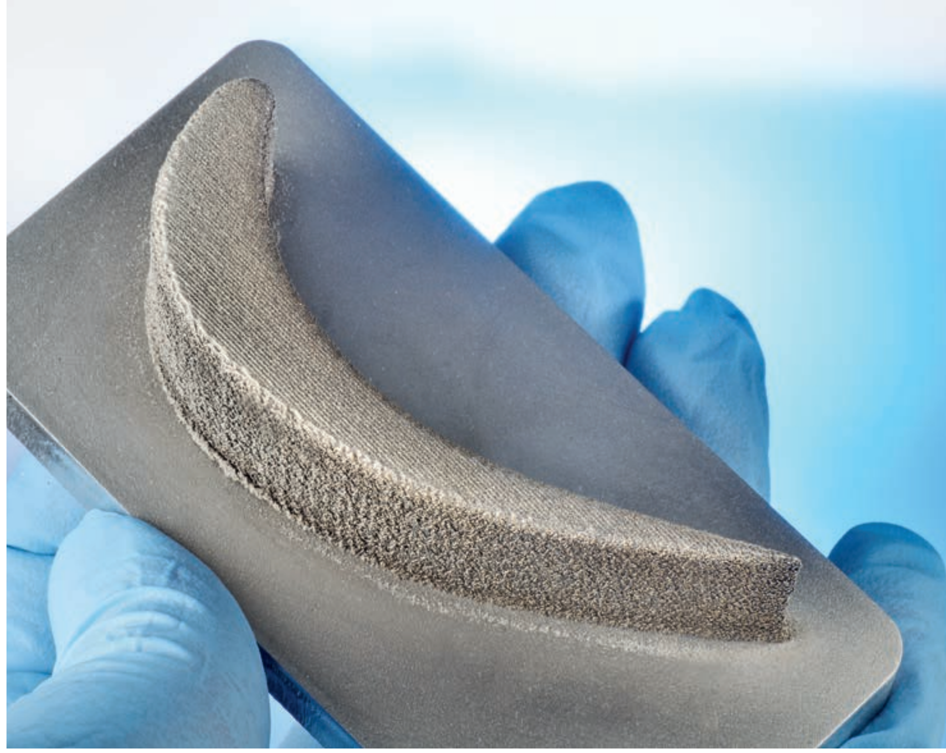




1 Electric arc and laser radiation are combined for the new COLLAR Hybrid AM process.
2 Structure of the COLLAR Hybrid AM.



1 Thin-walled component structure from IN718.
2 Blade demonstrator made of IN738.

EHLA 3D – Additive manufacturing of difficult-to-weld alloys

Greater precision and improved resolution

Using extreme high-speed laser material deposition for additive manufacturing (EHLA 3D) offers numerous advantages over conventional process guidance for laser material deposition, such as significantly greater precision and resolution of the manufactured structures and shapes while maintaining high buildup rates. When the process is specifically adapted, the heat input into the base material and filler metal as well as the cooling rates can be precisely controlled. Thanks to these advantages, alloys can be processed without defects, especially those that are considered impossible or difficult to weld with conventional processes. Among these materials are, for example, some nickel-based superalloys or aluminum- or copper-based materials.

Specially developed system technologies at the Fraunhofer ILT

Two machine tools suitable for the EHLA 3D process are available at Fraunhofer ILT: a specially developed parallel kinematic system and a modified 5-axis CNC system. This system engineering is used to experimentally identify process parameter ranges for the hot-crack-prone nickel-based alloys Inconel®718 and Inconel®738 for thin walls and shapes, to metallographically investigate the resulting microstructures, and to determine the mechanical properties.

Enormous potential for industrial applications

The innovative machines can be used to additively manufacture thin-walled structures with wall thicknesses of less than 500 µm as well as volumes without cracks and with relative densities of over 99 percent. At the same time powder deposition efficiencies of up to 97 percent can be achieved at buildup rates of around 2 kilograms per hour. In the industry consortium ICTM – International Center for Turbomachinery Manufacturing, Fraunhofer ILT manufactured a complex blade shape made of Inconel®738 without defects and close to near-net shape. The results underline the enormous potential the technology has for industrial applications, such as in turbomachinery and aerospace engineering. By combining different materials (e.g. graded layers) and exploring further material systems, this research will extend possibilities into previously unknown fields of application, such as toolmaking and repair.

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Laser cutting and heat treatment of shaped blanks made from cold-rolled strips for lightweight construction

Cold-rolled special steels are characterized by high strength, customized surfaces and narrow tolerances. Thus, they serve the special requirements of lightweight automotive construction excellently. In cooperation with the BILSTEIN GROUP (Hagen site), Fraunhofer ILT is developing a process to cut – tool-free, wear-free and flexibly – shaped blanks from cold-rolled strip using high-speed laser blanking and to soften them selectively using laser heat treatment. The processes offer significant advantages: In addition to the consistently high edge quality, the components can be formed and their crash behavior adjusted specifically. Both projects are being run within the BILSTEIN GROUP under the brand names BILCUT and BILTIC.

Targeted exploitation of laser flexibility

A major key to optimizing high-speed laser blanking in terms of productivity, quality and flexibility is to adapt all the parameters of the laser beam source and optics to the required output for the targeted product portfolio. These optimization tasks are solved by simulation calculations and experimental verification on highly dynamic processing equipment. Local heat treatment is also performed by means of laser radiation. Zoom optics allow flexible adaptation of the beam to the area to be softened.

Fast to optimum performance characteristics

The reference material is BILSTEIN grade CR600LA with a thickness of 2 mm. This can be cut at speeds of up to 52 m/min at a laser power of 6 kW. With a thickness of 1 mm, speeds of over 100 m/min are achieved. The low heat input of the cutting process minimizes edge hardening with significantly less penetration than punching. During local heat treatment, the microstructure is recrystallized in the desired component areas. By adjusting the process parameters, the industry can specifically adapt the degree of softening or the forming behavior to the required manufacturing operations and performance characteristics.

Applications in automotive lightweight construction

The applications are mainly seen in the automotive sector. One example is the demonstrator shown in the picture from the FlexHyBat project funded by the BMWK. The side member integrated in it was designed and 3D roll-formed by DataM. The associated molded board was laser-cut and partially softened by Fraunhofer ILT on behalf of the BILSTEIN GROUP.

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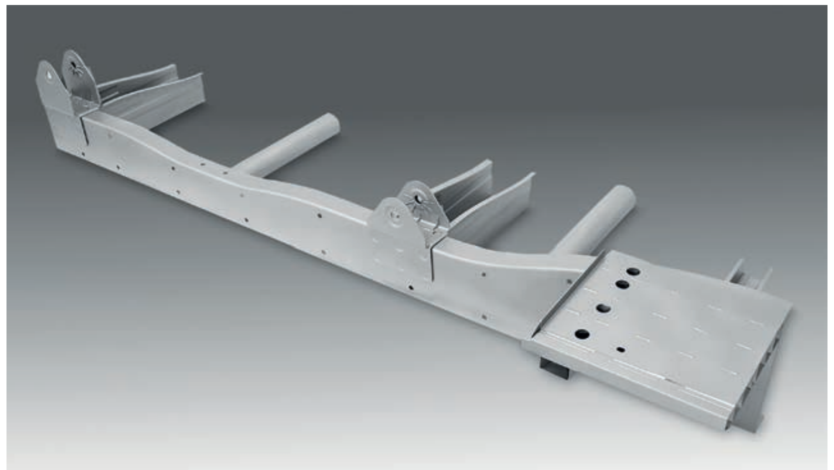
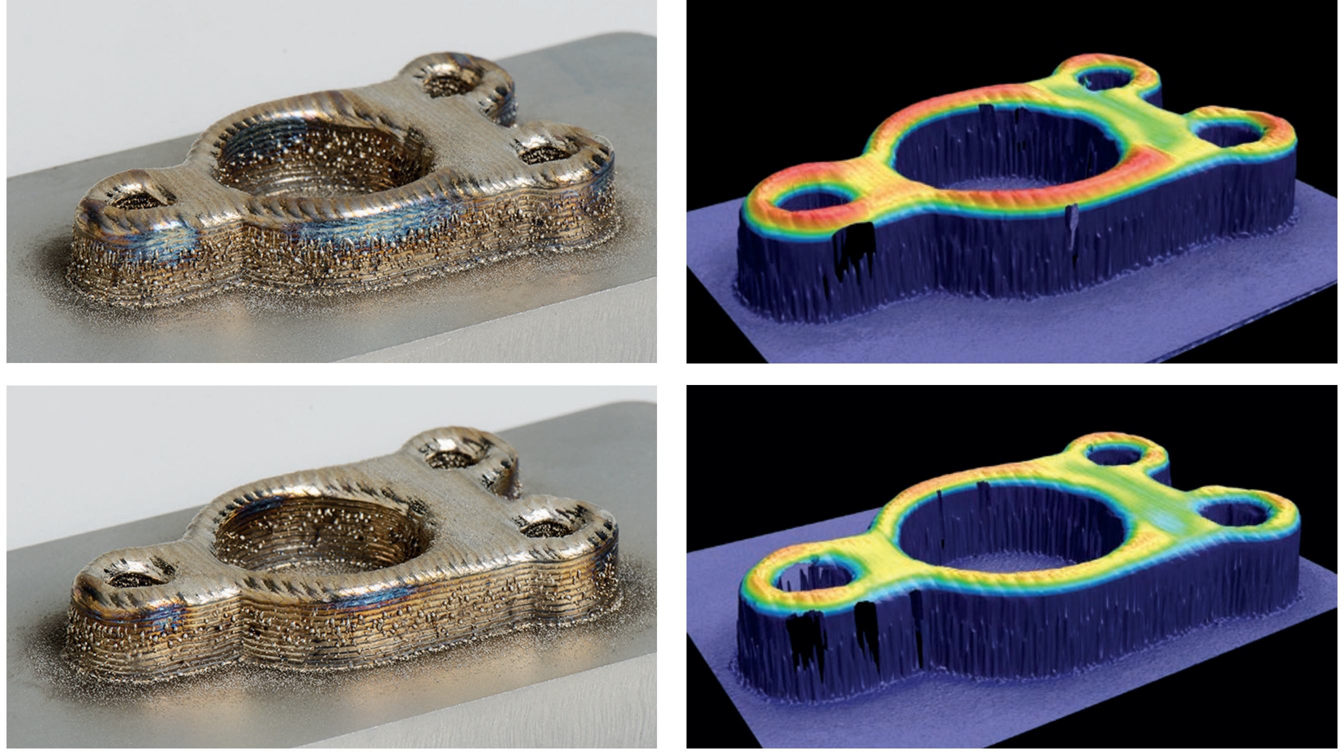


Section of a laser-cut, partially laser-debonded and 3D roll-formed longitudinal member with add-on parts, © Dörken Coatings GmbH & Co. KG.



Additive LMD setup without (top) and with (bottom) AI prediction.

AI-based process design in laser material deposition

When components are additively manufactured with powder-based laser material deposition (LMD), the heat in the volume decisively influences process stability and contour accuracy. When process parameters are kept constant, this intrinsic heating leads to thickness deviations in the deposited layers during the process since the melt pool volume changes. If all process parameters no longer interact within the optimum process window, contour deviations in the component can occur, and the process may even stop. Particularly in the case of complex geometries, time-consuming process development is required to adapt the process parameters and build-up strategies.

Step 1: Data acquisition in the process

The melt pool volume in LMD indicates how stable the process is. As a measured variable, the melt pool area can be recorded with a camera integrated into the beam path. In a first approach, the variations in the melt pool area should be reduced by adjusting the laser power in the process. For this purpose, an AI model will first be trained using data from an LMD process with constant process parameters while building a geometrical shape.

Trained AI for greater process stability

The AI model learns correlations between laser power, geometry and other component-dependent influencing factors. The trained AI model can then be used to predict the laser power required for a stable process. This eliminates the need for extensive experiments and evaluations to set suitable process parameters when, for example, the geometry of a component changes. The AI model can significantly reduce process development in LMD by predicting a stable process a priori and is continuously being improved as the amount of data increases. In the future, this model will also be extended to predict other process parameters, such as feed rate. The concept can be used for additive manufacturing, repair processes or coatings.

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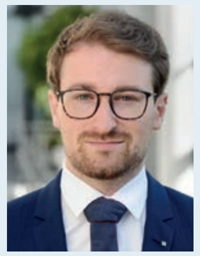

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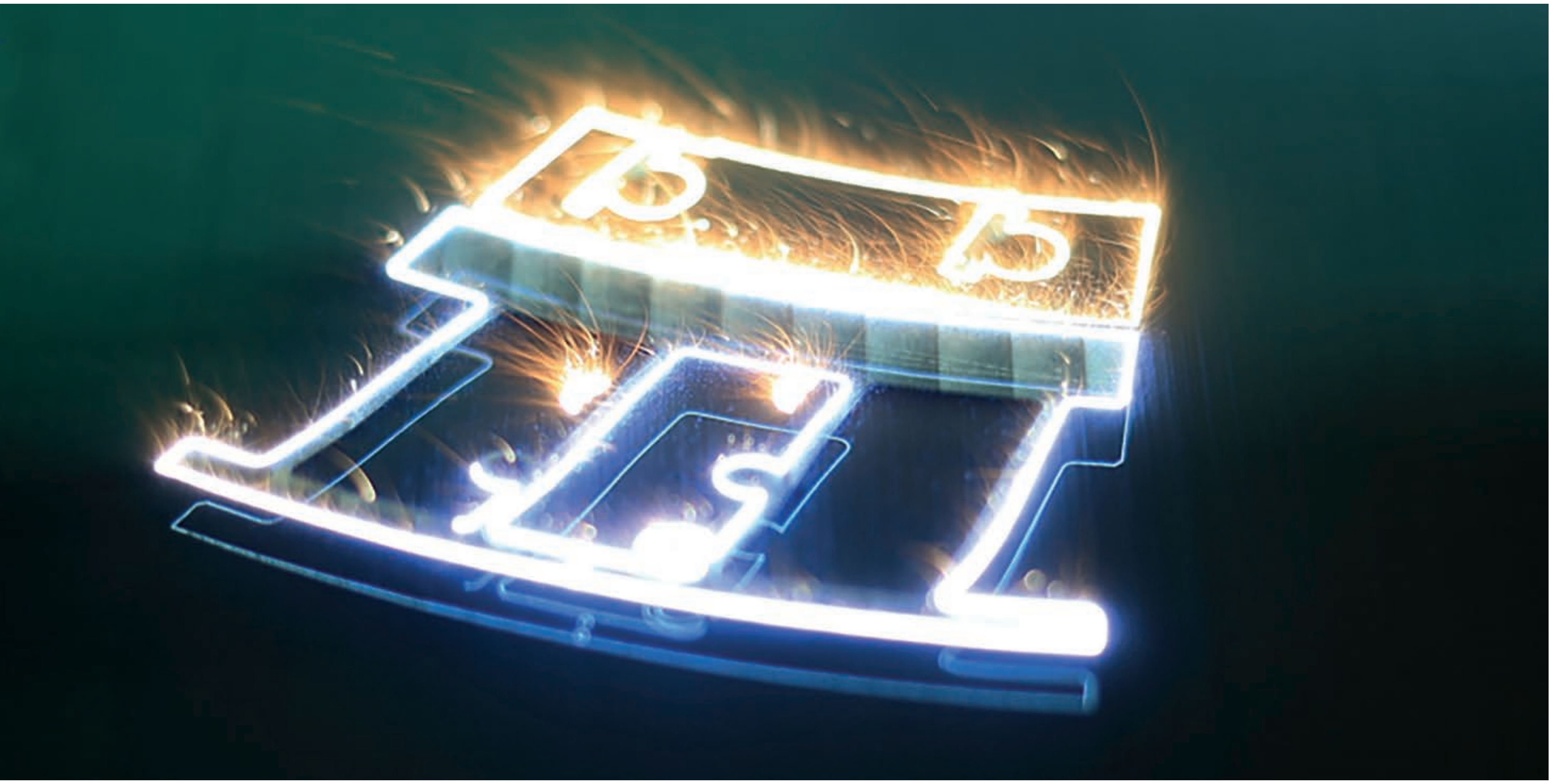
Innovative LPBF Solutions for Additive Manufacturing



The scientists in the Laser Powder Bed Fusion (LPBF) Department develop innovative solutions for industrial 3D printing. The technology they cover ranges from process control and systems engineering to the qualification of LPBF for the additive series production of functional components made of metal- and polymer-based high-performance materials.

In process and system technology, our research focuses on implementing control and monitoring solutions for component- and application-adapted LPBF process control as well as developing customer-specific machine components and overall systems for additive manufacturing. In application development, the team transfers innovative additive manufacturing technologies to industrial production and covers topics ranging from production-oriented design to function and sensor integration in components all the way to life cycle analysis for additive manufacturing chains. The department's broad technology portfolio is rounded off by laser-based manufacturing solutions for polymers, which are being researched in cooperation with the FH Aachen – University of Applied Sciences.

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- LPBF Application Development
- AM Polymers

Line integration of additive manufacturing processes

LPBF on the threshold of series production

Fraunhofer ILT has been researching the additive manufacturing process laser powder bed fusion (LPBF) since the mid-1990s. Although it was initially used as a process for prototype production, industrial users are now establishing this manufacturing process in series production. Major hurdles include high unit component costs, a low level of automation, and a lack of integration into industrial process chains – both at the digital and physical level. Fraunhofer ILT has addressed these challenges together with partners from industry and research in the projects IDAM (FKZ 13N15080) and IDEA (FKZ 13N15001) as part of the BMBF funding measure "Line integration of additive manufacturing processes".

Industrialization and digitization of additive manufacturing using LPBF

In the IDAM project focusing on automotive series production, Fraunhofer ILT investigated not only how an adaptive, geometry- and application-adapted LPBF process control could be developed, but also how support structures could be automatically removed and how recycling the metal powder used in LPBF influences the overall process. In the IDEA project, which focused on turbomachinery and aerospace, Fraunhofer ILT developed pulsed-modulated exposure of the component contour and integrated a high-resolution stereo camera into the system for detecting process instabilities.

Decisive developments for the use of LPBF in series production

Adaptive LPBF process control has made it possible to increase productivity in processing the aluminum alloy AlSi10Mg by up to 50 percent while maintaining high component quality. Using the digital tools developed, Fraunhofer ILT was able to demonstrate that the LPBF process parameters could be dynamically selected according to the component load. The developed process for wet-chemical component support enables fully automatic and tool-free support removal during LPBF.

With the aid of pulsed-modulated LPBF process control, the institute was able to increase detail resolution and contour accuracy for Inconel® 718. This innovation means that smaller part features can be manufactured, such as complex cooling systems, and reduces the amount of post-processing required. AI-based evaluation of the monitoring data can reliably detect process instabilities in LPBF such as powder bed defects and component distortion.

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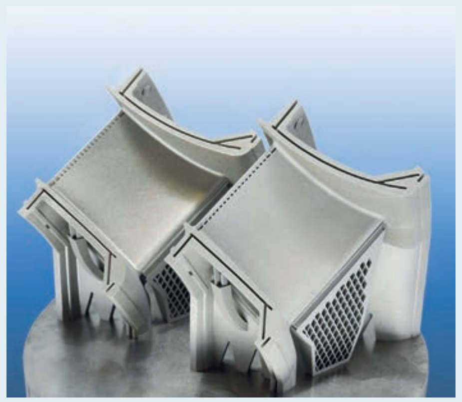
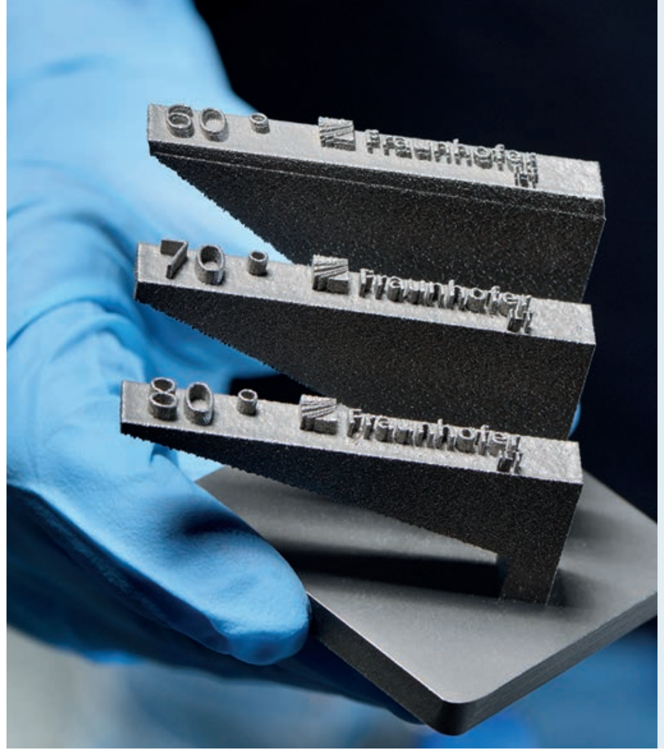
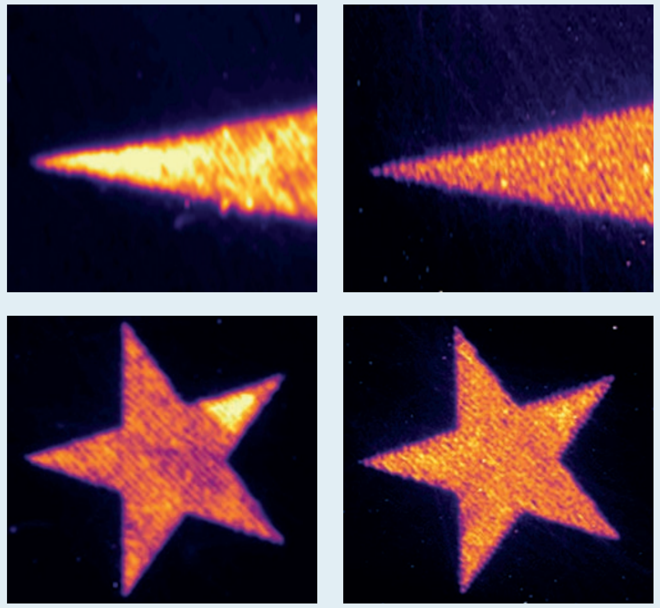


1 Pilot line for additive series production at the BMW Group, © BMW Group.
2 Turbine guide vane with continuous (left) and pulsed-modulated (right) LPBF process control.





1 Specimens manufactured with adaptive process control with up to 10° overhang structures.
2 Thermographic images of test specimens without closed-loop control (left) and with closed-loop control (right).

Adaptive process control in laser powder bed fusion

Complexity in three dimensions "for free"?

In principle, metallic additive manufacturing makes it possible to produce complex components with nearly any geometrical shape. However, component geometry and orientation as well as local fluctuations of the process boundary conditions influence the spatial and temporal temperature distribution and, thus, the processing result. For example, overhanging or filigree component areas can thermally deform or crack. As current solutions, additional support structures are manufactured and the component geometry is restricted. To overcome this, Fraunhofer ILT is currently researching how manufacturing parameters can be locally adapted to homogenize component properties.

Process modeling and closed loop control

The institute is pursuing two complementary approaches in parallel. In the first, it is extracting typical geometric features from components and modeling and experimentally investigating the effect of these features on the temperature distribution. In addition, it is deriving rules for locally adapting the process parameters from the results and implementing them by means of a specially developed plant control system. In the second, it is monitoring the thermal emissions of the melting process and using the data in a closed loop to adapt the laser power.

More geometrical freedom with the same quality

By adapting the process parameters based on these rules, the institute can already produce components support-free and with an overhang angle of up to 10°. Even tapered component areas can be manufactured with much greater geometrical accuracy. By means of a closed control loop, the radiation intensity of the melt pool can be successfully homogenized. So far, this has made it possible to improve component quality, especially in the case of complex geometries within a single layer. In the future, the institute will combine the two approaches in an adaptive process control.

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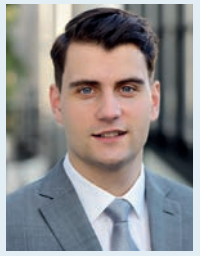

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Topology optimization of components through LPBF manufacturing

Laser powder bed fusion (LPBF) can be used to produce complex and topology-optimized components cost- and resource efficiently. Each volume increment of the component is created in the manufacturing process as the metal powder is selectively melted and solidifies. The thermal history in LPBF can differ significantly, especially for large cross-sectional changes due to different thermal conduction conditions. Process parameters and mechanical properties are generally determined using simple test geometries and are, therefore, only conditionally applicable to complex components.

In cooperation with the DLR Institute for Materials Research, Fraunhofer ILT is investigating how component geometry influences the metal structure on behalf of the German Federation of Industrial Research Associations (IGF Project No.:22135 N) and the German Federal Ministry of Economics and Climate Protection. The institutes aim to simulate the above-mentioned effects in order to predict the actual mechanical properties of topology-optimized components. Furthermore, they are investigating how the downstream heat treatment could influence the microstructure

Investigations on the material Ti6Al4V

Since titanium has low thermal conductivity, the institutes are examining the effect of the thermal history on the material Ti6Al4V. For this purpose, they are analyzing topology-optimized LPBF components and classifying them with respect to angular and cross-sectional area changes in the build direction. From the results, test shapes have been derived (Fig. 2) and manufactured using LPBF for static and dynamic tests. Subsequently, the specimens are being tested "as-built" or after hot isostatic pressing. The data obtained are documented in a component geometry catalog.

Resource-efficient production

The results show that irradiated energy is dissipated so slowly – when the exposure area suddenly increases – that an influence on the metallic microstructure can be detected. At corresponding points in the component, a mixture of α- and β-phase forms instead of the α-structure usual for Ti6Al4V. The cooling rate also has an effect on the lamella shape and size. Figure 1 shows local overheating based on tarnish colors.

The component geometry catalog developed in the project is intended to simplify the practical applicability of topology optimization and LPBF manufacturing in the aerospace, medical technology and mobility sectors. Moreover, it can accelerate innovative product development and enable companies to manufacture while using fewer resources.

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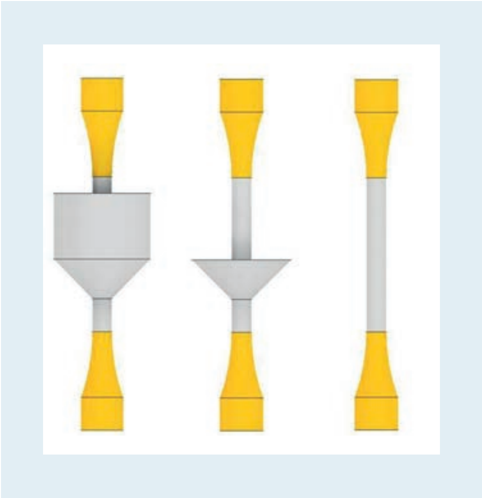

1 Demonstrator with local overheating (highlighted in red).
2 Test geometries for static tests.

1 Additive manufactured wheel bearing cap with integrated sensor system, inside.
2 ... and outside.

Laser powder bed fusion for networked mobility solutions

With condition monitoring for a mobility turnaround

To achieve national and international climate targets, countries need to cut emissions in, among others, the transport sector; rail transport will play a central role in this. Indeed, it represents the most ecologically sensible alternative for domestic and European traffic, yet must overcome several hurdles. Avoiding "delays in operations" and increasing reliability not only improve the image of public transport, but also help it compete against less sustainable individual and air transport. Since the public transport is difficult to schedule and is sensitive to failures and delays, condition monitoring and predictive maintenance of train components can contribute to the mobility turnaround.

Sensor integration in metallic components

Since it manufactures layer by layer, the laser powder bed fusion (LPBF) process makes it possible to access the inside of metallic components during production for the first time. This advantage can be used to integrate sensors directly into complex lightweight components. In the Sense-TrAIn project, Fraunhofer ILT is developing process chains to integrate strain gauges that measure the mechanical stress in the component in three spatial directions. This is demonstrated in the project using the example of a wheel bearing cover of a wheelset for trains.

Networking intelligent components

By measuring the wheel bearing cover, technicians can draw conclusions about the condition of the wheel bearing and the entire wheelset. In cooperation with partners in the SenseTrAIn project, Fraunhofer ILT is developing an integrated system suitable for retrofitting, one that records measurement data, transmits it wirelessly to a cloud and evaluates it using artificial intelligence. The system can, thus, transmit relevant condition data and warnings to DB Systemtechnik's controlling department.

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Life-cycle assessment of the LPBF process

Sustainability for LPBF in industry

Additive manufacturing processes such as laser powder bed fusion (LPBF) have reached a high level of technological maturity in recent years and are increasingly being used in series production. As far as its sustainability is concerned, the process offers advantages: functionally optimized components can be manufactured near-net-shape and resources can be saved: among others, the unmelted metal powder can be reused. These positive properties of additive manufacturing fulfill the requirements of sustainable production since they increase resource efficiency and recycling management, and reduce energy consumption. The additive process, therefore, has the advantage over subtractive processes as it produces lower emissions.

Merging of LCA to LPBF

In addition to costs and component quality, a product's ecological footprint will be an important evaluation criterion for manufacturing technologies in the future. Manufacturing companies are increasingly accepting their responsibility to reduce environmentally harmful emissions; however, implementation often fails since the emissions LPBF generates cannot be accurately measured. Life-cycle assessments (LCA) of components generate a deeper understanding of how individual process steps influence the sustainability of manufacturing and help to identify relevant parameters. Previous LCA studies have only insufficiently considered the LPBF process chain.

Life-cycle assessment using the example of a manufactured LPBF component

In this area Fraunhofer ILT is cooperating with the powder manufacturer 6K Additive (Burgettstown, PA, USA). In a joint study, industrially relevant components are being manufactured using a powder made from recycled IN718, and the partners are analyzing the process in terms of sustainability. For this purpose, they are not only collecting primary data on material and energy flows on LPBF systems before, during and after manufacturing, but also analyzing and integrating it into a software-based LCA model. This way, they can balance the ecological footprint from material production to the additive manufacturing process as a whole for the first time, and identify possible levers for further improving the ecological efficiency of the process.

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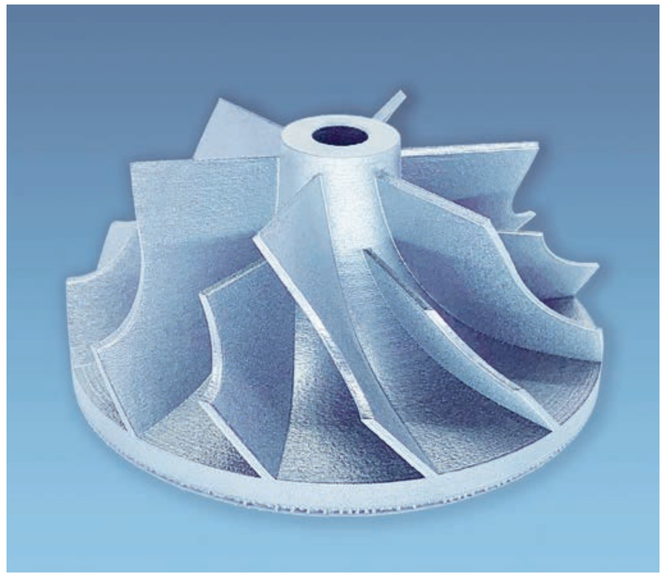
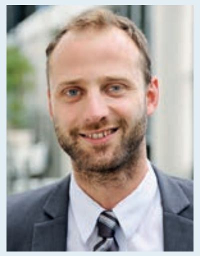


Additively manufactured impeller for an LCA study on LPBF.



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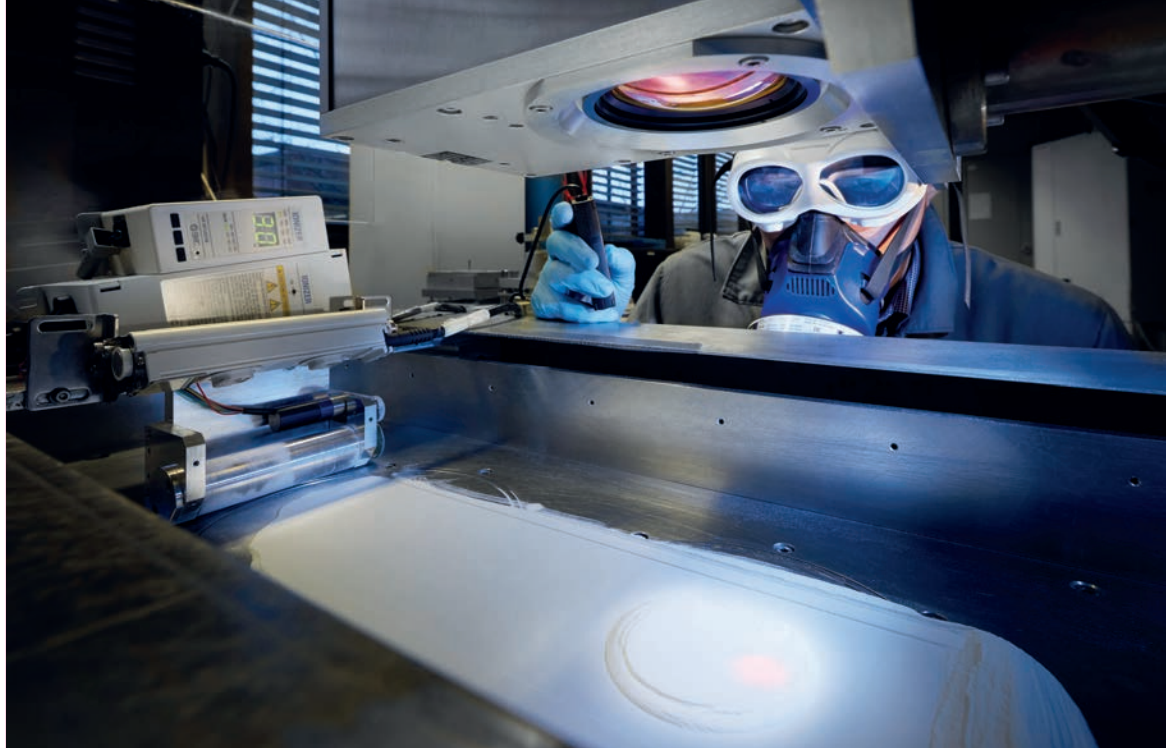

SLS laboratory system for processing novel materials.

Functionalization of novel polymer materials for SLS

While selective laser sintering (SLS) was initially used only for prototyping, it is increasingly being employed as a manufacturing process for series components. One disadvantage of SLS compared to injection molding, however, is that the choice of materials is currently limited. Among those are thermoplastic polyurethanes (TPU), which form one of the most important families of elastomers. They are suitable for various applications such as individual footwear or high-quality automotive components since they have such versatile mechanical properties (in particular large elongation at break > 700 percent). In the SLS Elasto research project, Fraunhofer ILT is advancing the process capability of novel TPU materials with small Shore A hardnesses of 50 to 60 so that parts with injection-molding properties can be printed with SLS.

Qualification of the TPU base material

The TPU base material researched in preliminary work is not yet suitable for industrial use in additive manufacturing. It will first be functionalized with trickling aids, additives and absorbers, and Fraunhofer ILT will investigate how the material properties influence processability. For a new powder material to be widely used, it must be qualified for the SLS machines established on the market. Therefore, an SLS process control specifically adapted to the material will be developed. Subsequently, the project partners will investigate various post-processing methods in order to improve the surface roughness. In parallel with the material qualification, a partner company is developing design guidelines for components with integrated functions made of extra-soft TPU.

Promising results

Initial material analyses and manufacturing trials show promising results. Particularly soft TPU materials can be used in medical technology, e.g. for individualized insoles and prostheses. Other fields of application include mechanical and plant engineering (e.g. gripper systems) as well as the production of prototypes, small series products and spare parts for various branches of industry.

The SLS Elasto R&D project underlying this report is being carried out on behalf of the German Federal Ministry of Education and Research (BMBF) under the grant number 03XP0466D.

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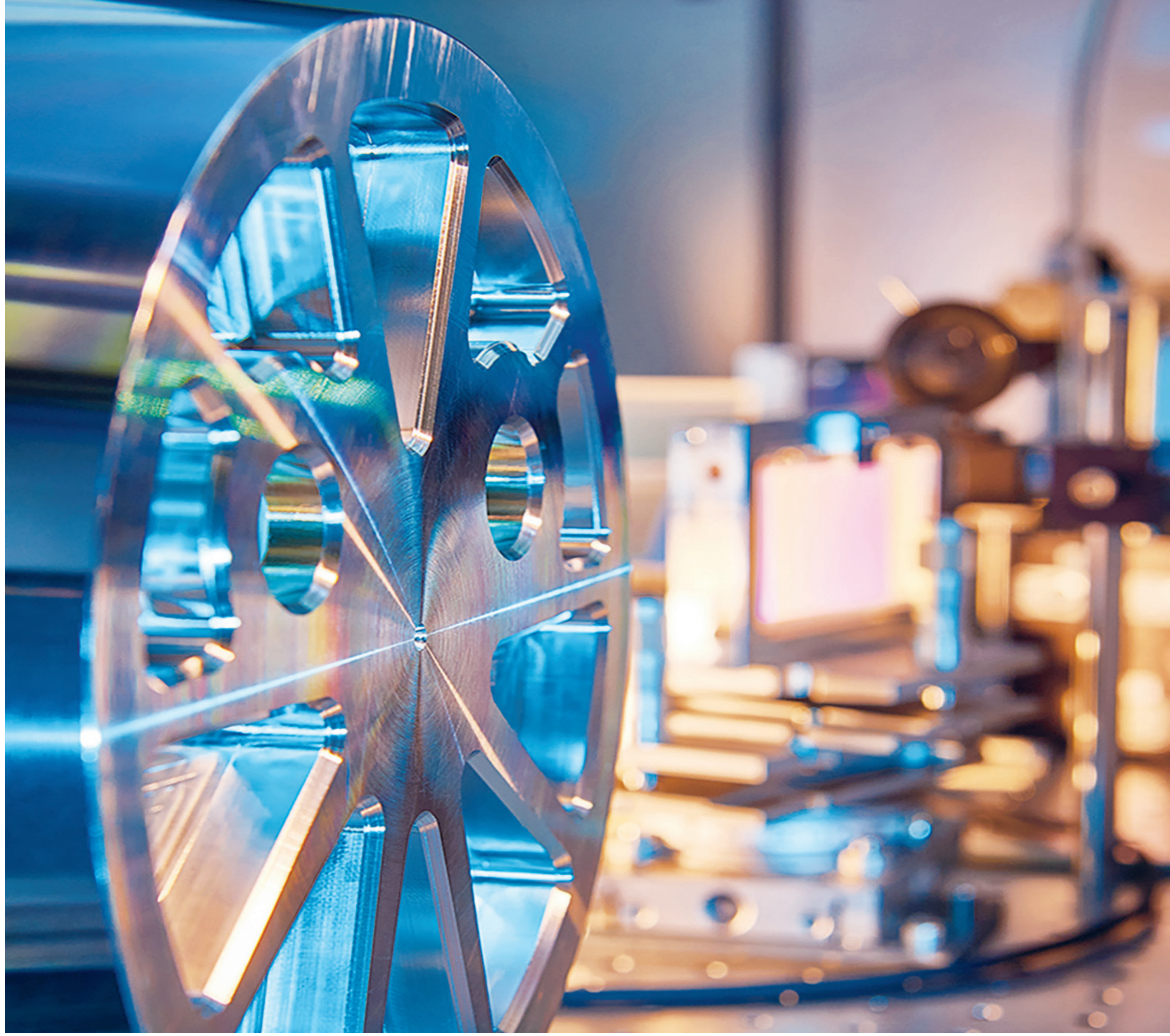
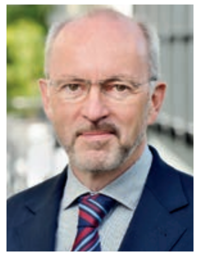
Innovative Beam Sources, Optical Components and Systems

Our experienced teams work in seven specialized groups to develop laser optics and beam sources with tailored spatial, temporal and spectral properties as well as output powers from picowatts to terawatts. Our activities range from diode, solid-state and fiber lasers to secondary and discharge sources. We also develop and use both proprietary and commercial software to design and simulate beam sources and optical systems.

Our ongoing projects reflect the current needs of society and industry. For example, we are developing LIDAR sources for climate and environmental research and weather forecasting. These beam sources are used from the ground, on helicopters and airplanes as well as on satellites. In the field of quantum technology, we are developing quantum frequency converters and optical systems for quantum computers and quantum sensors. We also focus on EUV sources and systems for semiconductor manufacturing. In addition, another group develops short and ultra-short pulse sources for ultra-precise high-rate manufacturing and the generation of secondary radiation for metrological applications.





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Design of 3D printed optics for terahertz beam shaping

The application areas of terahertz (THz) technology are diverse and range from spectroscopy and non-destructive material testing to wireless communication. In addition to off-axis parabolic mirrors, refractive optics made of polymers or silicon are used to form THz radiation. These lenses are manufactured from solid material by machining or from powder by compression molding. Compared to the commonly used polymer HDPE, TOPAS offers several advantages: It exhibits particularly low absorption and dispersion in the THz range, making it especially suitable for the fabrication of THz optics. Combined with commercially available, precise 3D filament printers, this material makes it possible to efficiently produce free-form lenses for THz beam shaping. This innovation is part of the Fraunhofer Prepare project TERAPID, currently being carried out jointly with Fraunhofer HHI.

Transmission optimization

When refractive lenses are designed for THz applications, the transmission of the material is a critical parameter, in addition to the image quality. Compared to conventional glass lenses for the visible or infrared spectrum, polymer lenses for THz frequencies exhibit significantly greater absorption. To minimize volume absorption and spherical aberrations, the partners in TERAPID selected a Fresnel design with aspherical segments for the imaging optical system.

Diffraction limited optics

Fraunhofer ILT designed different lenses with identical focal lengths, diffraction limited imaging for axis-parallel beams and a different number of Fresnel zones with an aspherical surface. The TOPAS lenses were 3D-printed in different qualities by the project partner Fraunhofer HHI. To compare imaging performance and transmittance, HHI had HDPE lenses with the same focal length and design conventionally machined. Compared with an aspherical lens without segmentation, the center thickness of both Fresnel lenses with three zones was reduced by about 50 percent. The lenses are diffraction limited, but scattering losses occur at the edges of the Fresnel zones. In the next step, a bi-aspherical f-theta lens was designed and fabricated from TOPAS. The diffraction-limited imaging could be shown over the 15 mm x 15 mm scan field with a mirror scanner.

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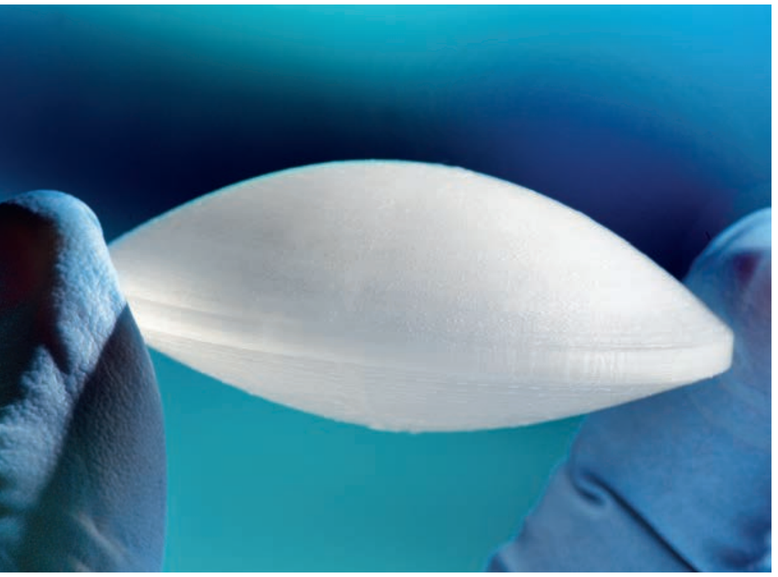

3D-printed TOPAS aspherical lens for terahertz beam shaping.

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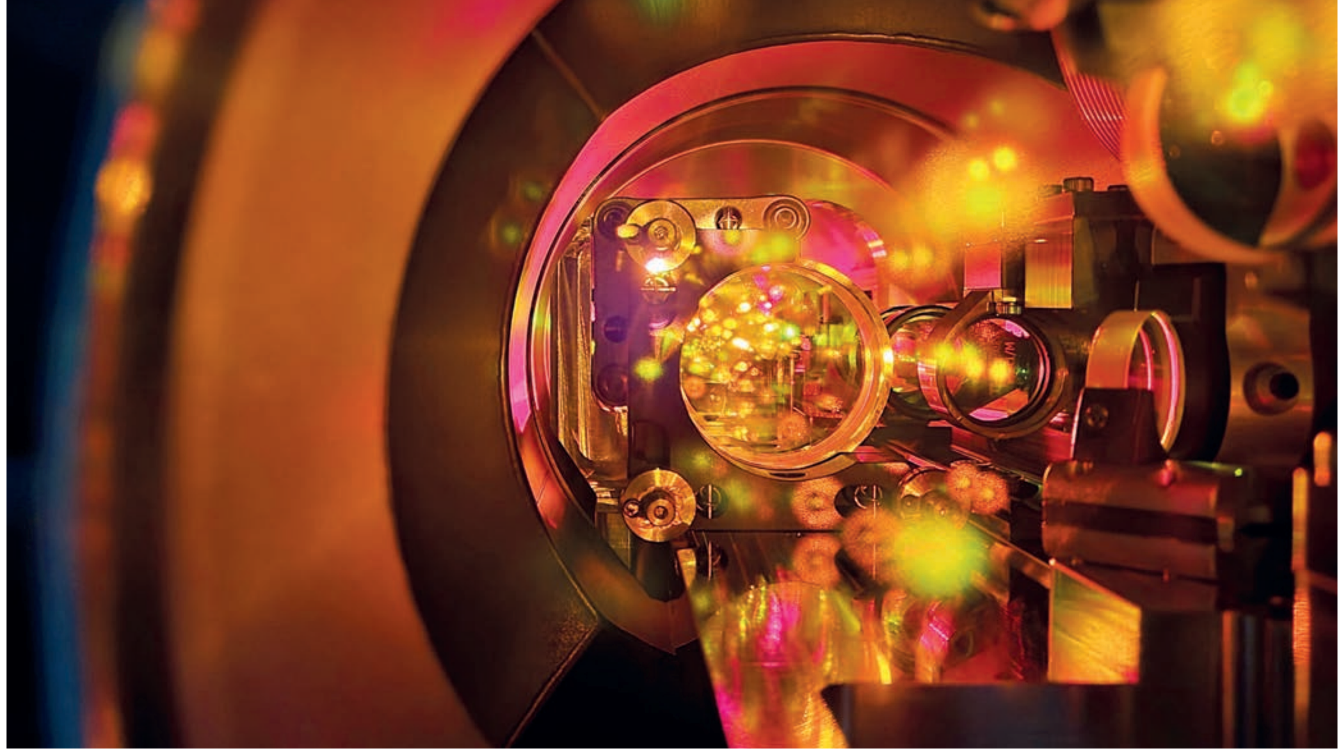

View through an observation window during MPC operation.

Development of a multipass cell for pulse compression in the near infrared range

In recent years, there has been an increasing interest in laser sources with a high pulse energy and high repetition rate in the shortwave infrared range (1.4–3 µm) for scientific and industrial applications. Compared to the 1 µm wavelength of established radiation sources, the longer wavelength offers fundamental advantages for some nonlinear conversion processes such as THz or soft X-ray generation. Moreover, pulse durations of only a few cycles per pulse are required for efficient frequency conversion, e.g., by generation of high harmonics (HHG). However, lasers based on thulium (Tm)-doped fibers or crystals emitting at 2 µm cannot directly generate these short pulse durations.

Shortening the pulse duration with a multipass cell

Besides spectral broadening in gas-filled capillaries, multipass cells (MPC) have emerged as an approach for subsequent pulse duration shortening. They preserve the beam quality of the input beam and offer the highest overall transmission of all pulse shortening techniques. Fraunhofer ILT already showed this, at 1 µm wavelength, during the first demonstration of this technique in 2016. However, as things stand today, neither more than 1 mJ pulse energy nor more than 100 W average power was spectrally broadened at 2 µm wavelength in an MPC and subsequently compressed.

Great potential of MPC technology

With a Tm fiber laser from Fraunhofer IOF, it was possible to spectrally broaden pulse energies of 1.6 mJ at a repetition rate of 100 kHz at a wavelength of 1.9 µm in a krypton-filled MPC. With subsequent temporal compression, an overall transmission of 95 percent with pulse durations of 25 fs was achieved, corresponding to four optical cycles. These unique results demonstrate that the MPC technology can be transferred and has enormous potential in the short-wavelength infrared range. Furthermore, these results represent an important milestone on the path to efficiently generating soft X-rays in the water window. The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research (BMBF) under the grant number 01DR20009A.

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Laser beam source for satellite-based wind measurement

The AEOLUS mission of the European Space Agency ESA measures, among others, the global wind distribution in the atmosphere with a satellite-based Doppler LIDAR instrument. The follow-up mission AEOLUS-2 planned by ESA and the satellite operator EUMETSAT requires a more powerful laser beam source with longitudinally monofrequency laser pulses of 150 mJ energy at a pulse repetition rate of 50 Hz and a wavelength of 355 nm. In cooperation with Airbus Defence and Space, Fraunhofer ILT is developing an engineering model of the laser beam source for AEOLUS-2.

Development of a thermal system

The laser design is based on the results from the NIRLI project completed in 2016, in which the ILT set up a configuration consisting of a Q-switched oscillator and two subsequent Nd:YAG INNOSLAB amplifiers. This system demonstrated more than 500 mJ of pulse energy at a wavelength of 1,064 nm. The frequency is converted to a pulse energy of 150 mJ in the UV with the aid of two LBO crystals. Based on the experience gained in the MERLIN project, Fraunhofer ILT is developing a thermal system to dissipate the heat loss under space conditions. The dissipated heat of about 300 W can vary depending on possible applications and aging effects. Comparatively narrow temperature windows must be maintained in the thermal system during its entire period of use. The development is being carried out in close cooperation with Airbus Defence and Space and SpaceTech.

Years of stable and maintenance-free operation

A detailed design of the laser beam source was created and accepted by ESA as part of a Detailed Design Review (DDR). In the model, the dissipated heat is efficiently conducted out of the housing by means of heat pipes, so that only a small fraction of the power dissipation couples into the baseplate. This allows stable operation over a wide temperature range. The components are currently being procured, and the baseplate is being manufactured in the ILT's own mechanical workshop. The institute will begin integrating the demonstrator in the next few months. The results obtained are primarily of interest for LIDAR laser beam sources used in harsh environments such as satellites, aircraft or helicopters. Since the setup technology ensures stable and maintenance-free operation for many years, the findings can also be used to develop solid-state lasers suitable for industrial use or small compact beam sources.

The work is being carried out on behalf of ESA under contract numbers 40001323/20/NL/AD and 4000137280/22/NL/IA.

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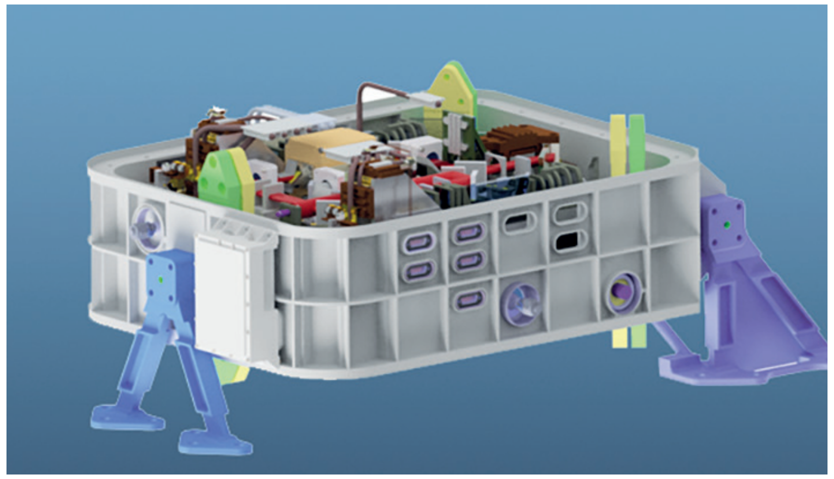

CAD model of the AEOLUS-2 – Laser Transmitter-EM.

200 mm long laser drilled PCF geometry in BK7.

Inverse laser drilling for the production of fiber preforms

The state of the art for manufacturing preforms for low-loss hollow structural fibers is the stack-and-draw process. However, stacking the preforms is not only very costly, but also limits the geometry of the mold and arrangement of the hollow structures, since asymmetric structures or changing the hole spacing cannot be stacked at will. In principle, it is simpler and more advantageous to drill out the corresponding openings from a high-purity fused silica rod.

Further development of inverse laser beam drilling

In collaboration with the Max Planck Institute for the Physics of Light MPL and the Fraunhofer Institute for Silicate Research ISC, Fraunhofer ILT is continuing to develop inverse laser beam drilling (ILB) to produce preforms for hollow structural fibers with new geometries. In ILB, pulsed laser radiation is focused from above through the workpiece onto its underside. For the hole, the desired geometry is now ablated layer by layer from bottom to top. The MPL identifies advantageous geometries, draws the fibers and tests them. The ISC supports the process development on the material side. First, ILB produces preforms, which can also be stacked to compare the two methods. Subsequently, new, non-stackable geometries are tested.

Results and applications

To date, Fraunhofer ILT has successfully drilled several different geometries, both stackable and non-stackable, over 50 mm in length in BK7 and have developed better process understanding. In addition, the institute has fabricated a single ring hollow core fiber preform using ILB. In the next steps, further geometries will be drilled in fused silica (e.g. Heraeus F-300) and the corresponding preforms will be drawn to the fiber. In principle, ILB is suitable for drilling hollow structures with large aspect ratios or for stress-free insertion of filigree hollow structures into dielectric materials. The project is being funded as part of an internal cooperation between the Fraunhofer-Gesellschaft and the Max Planck Society.

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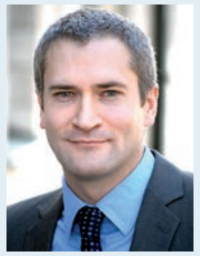

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Short-pulsed fiber amplifiers at 2 µm wavelength

As part of the ZIM project Diofast2, Fraunhofer ILT and the industrial partner PicoLAS are developing a compact and cost-effective short-pulsed fiber amplifier for wavelengths around 2 µm for various potential applications in materials processing, medical technology or metrology. The pulses shall be generated directly by a laser diode and amplified with subsequent fiber-based gain sections to several 10 W of average power at pulse durations below 500 ps. This approach offers technical and economic advantages over commercially available laser systems with comparable pulse durations, which are largely based on mode-locked oscillators.

Simulation and experimental realization

With updated simulation software, Fraunhofer ILT has developed a concept for the multistage amplification of thulium doped fibers to > 20 W average power for short pulses. Based on this, it built a polarized cladding-pumped fiber amplifier with pump diodes running at about 800 nm. As signal source a suitable DFB laser diode is used, which is gain-switched with novel electronics developed by the project partner PicoLAS, thereby providing pulse durations in the range of 50 to 200 ps.

Results and fields of application

The three-stage, single-mode fiber amplifier achieves a spectrally cleaned average output power of > 20 W at a center wavelength of approx. 1950 nm. With this system, peak powers of up to approx. 10 kW are achieved, with slightly broadened pulse durations in the range of 300 to 350 ps due to nonlinear effects. In addition to its use as an eye-safe beam source for LIDAR applications, these laser or individual amplifier stages of the overall system can be used for material processing, e.g. of plastics transparent in the visible wavelength range. Due to the high absorption in water and the hemostatic effect due to the coagulation effect, use for surgical precision applications is also possible.

The project was carried out in cooperation with PicoLAS GmbH within the framework of the ZIM program (Central Innovation Program for SMEs) under the grant number 16KN053058.

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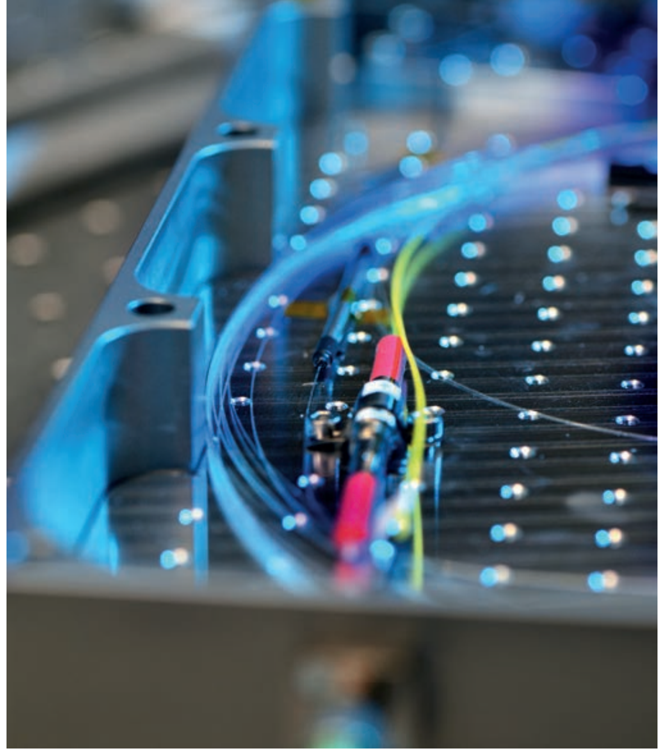
Thulium-doped short-pulsed fiber amplifier.



Holmium-doped fiber amplifier.

Highly stable fiber amplifiers for gravitational wave detection

Gravitational wave detectors provide an alternative access to interstellar processes, such as the collision of black holes and neutron stars, which can be detected by specific signatures in the form of gravitational waves. For next-generation gravitational wave detectors, Fraunhofer ILT is developing power-stabilized, spectrally narrow-linewidth fiber amplifiers in two projects: the LISA mission by the European Space Agency ESA and the Interreg project E-Test. While there are differences between these two applications – mainly due to the central wavelength of the radiation (1064 nm and 2090 nm) as well as the area of application in space and on earth, respectively – there is a great deal of agreement between them, especially with regard to the technology used for power stabilization.

Tailor-made fiber amplifier concepts

To meet the extreme stability requirements, Fraunhofer ILT has designed different fiber amplifier concepts while taking into account nonlinear effects, and compared the amplifiers experimentally. In all cases, a seed laser is amplified in a power-stabilized fiber amplifier to the output power required in each case.

Deployment in space and on earth

At a wavelength of 1064 nm (LISA mission), the system delivered an output power of 10 W with a spectral linewidth of < 10 kHz. In addition to meeting the power stability requirements of the LISA mission for the first time, the system successfully passed 1000-hour operational thermal vacuum tests in the current project phase. By doing this, Fraunhofer ILT can investigate how suitable the chosen components are for use in space. In parallel, a project partner is building an engineering model of the laser developed by Fraunhofer ILT. The institute successfully demonstrated amplification to more than 10 W at a spectral linewidth of about 2 MHz and a degree of polarization > 20 dB at a wavelength of 2090 nm (E-Test). The next step is the active stabilization of the output power to fulfill the stringent stability requirements.

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Brilliant light source based on a barrier discharge

Many analytical applications require light sources of high brilliance in the ultraviolet to visible spectral range. According to the current state of the art, deuterium- or xenon-based high-pressure lamps are commonly used for this purpose. A significantly higher brilliance over an additionally broader spectral range can be achieved with beam sources in which a laser excites a plasma to glow. For some applications, however, both the high-pressure lamps and the laser-driven source are not sufficiently compact or cost-effective. This problem is currently being addressed with a new approach that uses the light from a stationary single-filament barrier discharge. High brilliance is achieved by coupling out the light along the filament axis.

Efficiencies of up to 50 percent

The figure below shows the principle of the experimental setup. The electrode system consists of a pointed HV electrode, which establishes the position of the filament, and either a transparent or apertured metallic ground electrode, which is used to outcouple the light. When an HV AC voltage is applied, short-lived plasma filaments are formed in each half-wave, which can be used to efficiently convert electrical power into light. For example, efficiencies of up to 50 percent are possible with excimer gases.

Mobile probe for pollutant analysis in wastewater

For operation with nitrogen, an emission spectrum with spectral wave packets in the range of approx. 200 to 400 nm could be demonstrated. The bandwidth of the individual wave packets here is typically < 5 nm. Based on the available data, a source thus appears feasible that can emit about 0.4 mW/sr in a wave packet at a brilliance > 1 mW/mm²/sr with an average electrical input power of 5 W. A possible field of application is the on-line 2D fluorescence analysis of pollutants in wastewater, where the characteristic fluorescence radiation is excited at several wavelengths. Thanks to the single-filament light source, a compact and cost-effective probe for mobile use of this application can be built.

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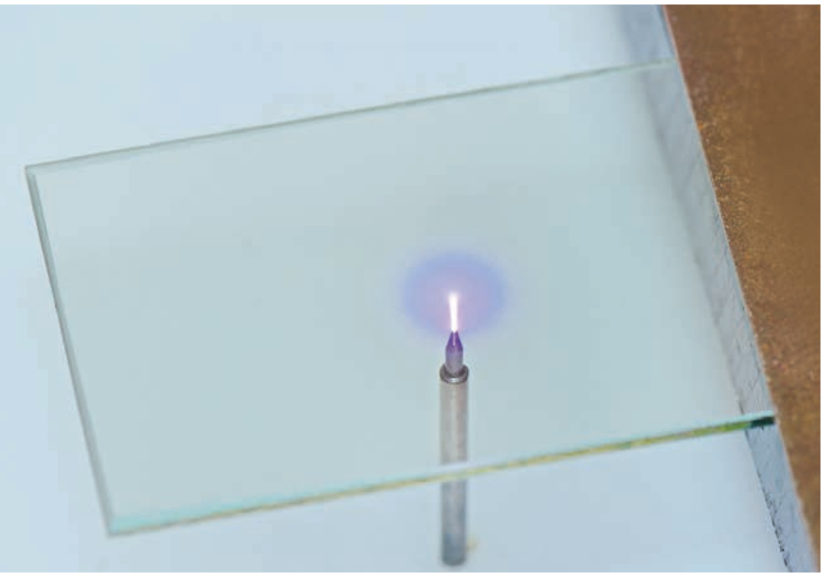
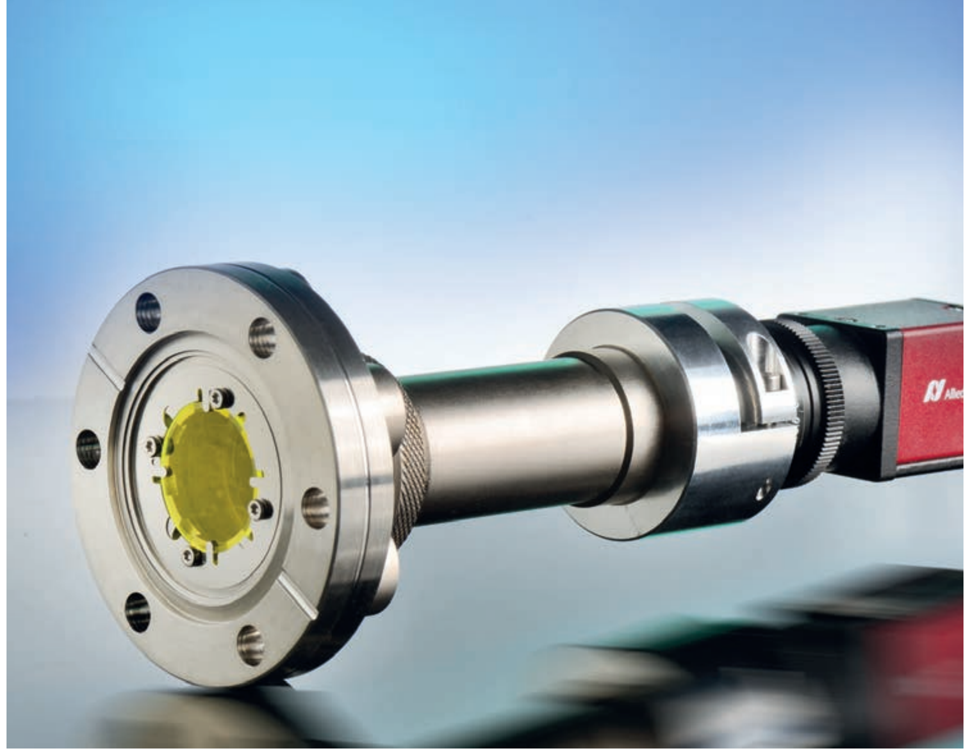


Single filament barrier discharge with transparent electrode.



1 EUV detector with converter crystal.
2 EUV spectrograph for the spectral range of 10–20 nm.

Inline EUV diagnostics

EUV systems equipped with plasma-based radiation sources are commonly used to irradiate samples or to analyze defects on EUV masks for semiconductor lithography. Pulsed plasma radiation sources, both laser and discharge-based sources, fundamentally exhibit variations in spectral distribution and total emission that affect the outcome of each application. By implementing an industry-grade metrology that accurately monitors the emission characteristics, an inline control system can improve the quality of the obtained results significantly.

Cost effective alternative using a converter crystal

In the present case, Fraunhofer ILT set up an EUV camera and an EUV spectrograph to monitor a xenon-based pinch plasma source for use in an irradiation system. Both diagnostic devices are equipped with a detector in which the EUV light is converted to visible light with a converter crystal and then recorded using a commercially available camera. The use of the converter crystal is a particularly cost-effective alternative compared to a back-thinned CCD or a chip directly coated with a luminescent material that would otherwise be used.

Results and applications

The EUV detector is shown in Figure 1. A Ce:YAG disk is used as the converter. The optical system for recording the fluorescence light consists of lenses with a magnification of either 1:1 for the EUV camera or 1:2 for the spectrograph and a camera with a pixel size of 3.45 micrometers. Figure 2 shows the EUV spectrograph with a grating reflecting in grazing incidence. The total length is approximately 68 cm. The detected spectral range is between 10 and 20 nm. The spectral resolution $\lambda/\Delta\lambda$ is about 800. In the EUV camera, a system of a spherical and a flat multilayer mirror is used to image the source at a wavelength around 13.5 nm. The spatial resolution is approx. 10 µm.

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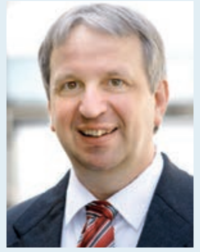

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Noise-free frequency converters for the quantum internet

To set up a quantum internet, quantum systems must be entangled over long distances to share information efficiently and securely and to significantly raise the computing power of quantum computers. A prerequisite for such networks is the lossless transmission of information encoded in single photons through optical fibers. To achieve this, the frequency of these signals must be converted in wavelength while preserving their quantum state, without unintentionally generating additional photons that reduce the signal-to-noise ratio.

Development of novel QFC

Quantum frequency converters (QFCs) based on nonlinear optical processes are commonly used for this conversion. Previous systems used periodically poled crystals with waveguides. They achieve efficiencies up to 50 percent, but are the major source of noise photons. Novel QFCs for conversion from 637 nm to 1588 nm have been developed at Fraunhofer ILT for a quantum internet demonstrator in the Netherlands. In this setup, this approach combines a nonlinear crystal without periodic poling and waveguides with an enhancement cavity.

Key component for quantum technology

The novel converter was implemented as a compact, modular and stable system, tested at QuTech in Delft and subsequently integrated as a permanent component in the quantum internet demonstrator. The rate of generated noise photons was reduced by a factor of 100 down to 2 Hz/pm compared to previous QFCs, without sacrificing conversion efficiency; thus these novel QFCs define this system as the new state of the art. Compared to all other network components, the QFC is effectively noise-free.

Efficient, low-noise frequency converters are a key component for a quantum internet, quantum networks and quantum repeaters of the future. The novel design can be adapted to convert quantum signals at other wavelengths in the visible and near-infrared range.

The work was financially supported by the Fraunhofer-Gesellschaft as part of the ICON project QFC-4-1-QID.

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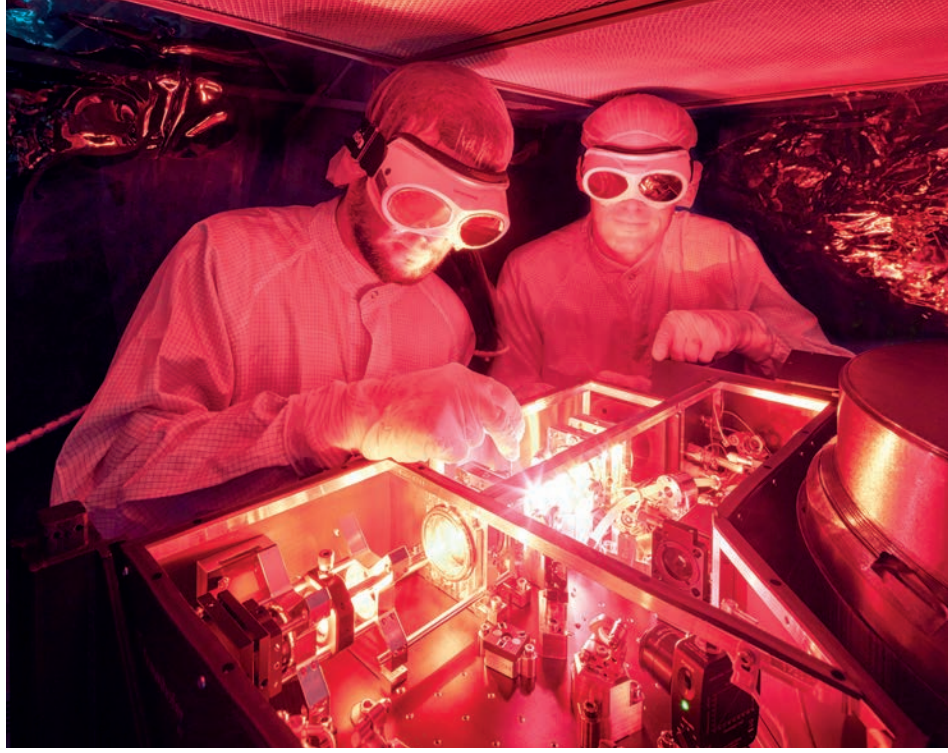
Adjustment of the converter using an attenuated red laser to emulate the single photons.



*1 LIDAR system with five fields of view during (atmospheric) measurement.
2 Integration of diode-pumped alexandrite laser.*

Diode-pumped alexandrite laser for atmospheric LIDAR array

It has become dramatically important to better understand and monitor the atmosphere in recent years owing to anthropogenic impacts on the climate. For this reason, the Leibniz Institute of Atmospheric Physics (IAP) has set its focus on measuring atmospheric wind and temperature profiles over large areas and up to altitudes of 120 km. To do this, it mainly uses mobile resonance LIDAR systems. When several such systems are used with overlapping observation areas, an array with unrivaled resolution and coverage is obtained. The data from these arrays are also acquired at remote locations under difficult environmental conditions, e.g. in polar or tropical regions, and are collected continuously over long periods of time. Therefore, rugged LIDAR systems must not only be compact, easy to transport and autonomous, but also require low maintenance.

Novel compact LIDAR system

Novel high-efficiency diode-pumped alexandrite lasers and innovative LIDAR technology were used to develop – in collaboration with Leibniz IAP – a novel compact LIDAR array (~ 1 m³), a system that has the potential to be mass-produced at low cost.

European atmospheric LIDAR array

Fraunhofer ILT integrated the four prototype LIDAR emitters into the new systems with five fields of view and tested them extensively. The new systems are 50 x smaller and over 200 x more efficient than their predecessors. In measurements up to altitudes of more than 100 km, the new systems were demonstrated to be superior – even during the day. Furthermore, the robustness and freedom from maintenance have been confirmed in changing climatic conditions. The next steps will be commercializing the technology with a German industrial consortium and developing a European atmospheric LIDAR array. These steps will pave the way for continuous, area-wide observation of large-scale atmospheric processes to improve climate models and thus weather forecasting.

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Assembly of the $LiNbO_3$ waveguide for quantum applications

Quantum technology is playing an increasingly important role in many fields, including telecommunications. For such applications, quantum telecommunication modules are needed, which can be built with periodically poled $LiNbO_3$ waveguides. In order to achieve the necessary optical frequency conversion, the waveguide must be tempered differently in two zones and the transition region between the zones must be minimal. The central challenge of the joining technique is the different thermal expansion of the waveguide zones.

Use of active soldering technology

In addition to how the module is designed, selecting the joining technique plays a central role in the present task. To ensure sufficient thermal conductivity and elasticity of the joint, Fraunhofer ILT used an indium-based brazing material. Since the waveguide cannot be readily metallized, an active soldering technology was used for assembly. This way, sufficient wetting was achieved on both the $LiNbO_3$ waveguide and the additively manufactured holder.

Result and fields of application

The temperature control tests showed that the two zones can be thermally separated with a 40 mm long waveguide. A temperature of 20 °C over a length of 10 mm was achieved in the 15 mm zone and a temperature of 30 °C over a length of 20 mm in the 25 mm zone. The waveguide remained intact after tempering. The joining concept described can be used in other areas such as medical or measurement technology.

This project was financially supported by the Fraunhofer-Gesellschaft.

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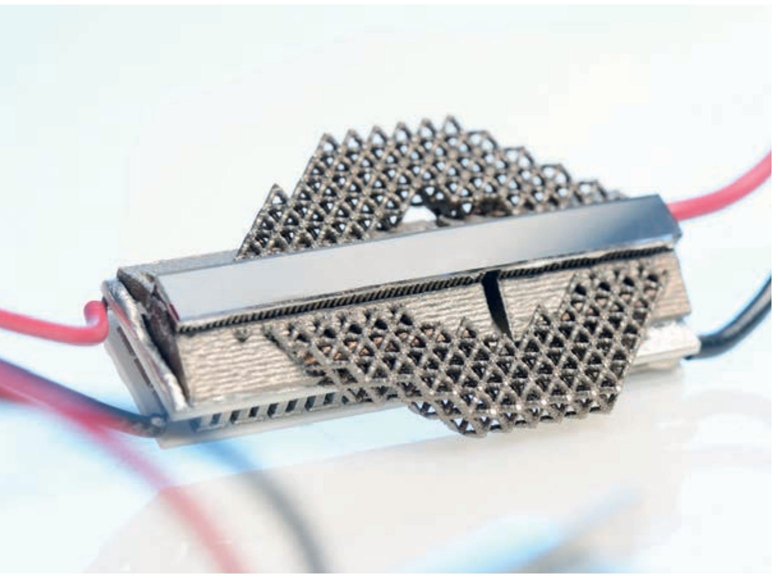

Waveguide soldered onto the holder..

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Funding Bodies

Some joint projects presented in this annual report have been supported with public funding. We would like to express our gratitude to the public donors for their support at this point.

Bundesministerium für Bildung und Forschung

Bundesministerium für Wirtschaft und Klimaschutz

Die Landesregierung Nordrhein-Westfalen

DFG Deutsche Forschungsgemeinschaft

EFRE.NRW Investitionen in Wachstum und Beschäftigung

esa European Space Agency

EUROPÄISCHE UNION

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

Fraunhofer Locations in Germany

Fraunhofer Networks

The Fraunhofer ILT together with other Fraunhofer Institutes bundles its competencies in clusters and lighthouse projects and develops applications for industry and research.

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, based in Germany, is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. A trailblazer and trendsetter in innovative developments and research excellence, the Fraunhofer-Gesellschaft supports science and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work with partners from industry and government to turn pioneering ideas into innovative technologies, coordinate and implement system-relevant research projects and strengthen the German and European economies with a commitment to value creation that is based on ethical values. International collaboration with outstanding research partners and companies from around the world brings the Fraunhofer-Gesellschaft into direct contact with the most prominent scientific communities and most influential economic regions. Founded in 1949, the Fraunhofer-Gesellschaft now operates 76 institutes and research units throughout Germany. Currently around 30,800 employees, predominantly scientists and engineers, work with an annual research budget of about 3.0 billion euros, 2.6 billion euros of which is designated as contract research.

Around two thirds of Fraunhofer contract research revenue is generated from industry contracts and publicly funded research projects. The German federal and state governments contribute around another third as base funding, enabling the Fraunhofer institutes to develop solutions now to problems that will drastically impact industry and society in the near future.

The impact of applied research goes far beyond the direct benefits to the client. Fraunhofer institutes strengthen companies' performance and efficiency and promote the acceptance of new technologies within society while also training the future generation of scientists and engineers that the economy so urgently requires.

As a scientific organization, the key to our success is highly motivated employees engaged in cutting-edge research. Fraunhofer therefore offers its researchers the opportunity to undertake independent, creative and, at the same time, targeted work. We help our employees develop professional and personal skills that will enable them to take up positions of responsibility within Fraunhofer itself or at universities, within industry and in society at large. Students involved in projects at Fraunhofer institutes have excellent career prospects on account of the practical vocational training they enjoy and the opportunity to interact with contract partners at an early stage in their career.

The Fraunhofer-Gesellschaft is a recognized non-profit organization named after Joseph von Fraunhofer (1787–1826), an illustrious researcher, inventor and entrepreneur hailing from Munich

At a glance

- 76 institutes
- 30,800 employees
- Research budget of about 3.0 billion euros
- 2.6 billion euros of which designated as contract research

Figures as of: March 2023

ICTM Conference online in February 2022.

Drilling with Laser Radiation.

Fraunhofer Group Light & Surfaces

The Fraunhofer Group for Light & Surfaces combines the scientific and technical expertise of the Fraunhofer-Gesellschaft in the fields of optics, photonics, laser and surface technology. Fraunhofer ILT is one of the eight member institutes in the group. In these institutes, more than 1,900 scientists conduct research to solve complex technological questions from industry and business, and to develop concrete applications for them. The core competencies of the group are in the following areas:

- Optical and photonic components and systems
- Layer and surface processing
- Manufacturing technology
- Measuring and testing technology
- Quantum technology

www.light-and-surfaces.fraunhofer.de/en.html

Fraunhofer Cluster of Excellence CAPS

The Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS aims to become the international technology leader in laser systems that achieve maximum power with ultrashort pulses (UKP). Furthermore, it intends to explore their application potential in cooperation with 13 Fraunhofer institutes. CAPS is coordinated by Fraunhofer ILT in Aachen and Fraunhofer IOF in Jena, both of which provide interested users from industry and science with two application laboratories with multi-kW UKP laser sources and the necessary system technology at their respective locations.
www.caps.fraunhofer.de

Fraunhofer lighthouse projects

With its lighthouse projects, Fraunhofer sets strategic priorities geared to the needs of industry. The aim is to quickly turn original scientific ideas into marketable products. The participating Fraunhofer institutes pool their expertise and involve industrial partners in the projects at an early stage. Fraunhofer ILT is involved in lighthouse projects covering areas such as energy technology, production and quantum technology.
www.ilt.fraunhofer.de/en/clusters.html

Innovation Cluster at the Aachen Location

In Aachen, Fraunhofer ILT has been operating innovation clusters for many years, ensuring close local interaction between industry and science in the field of photonics.

Cooperation on site

Innovation clusters not only enable the transfer of know-how, but also promote young talent and encourage spin-offs. The advantage of a single location makes both personnel and infrastructural networking much simpler. For example, Fraunhofer ILT – thanks to its constantly updated infrastructure – has one of the largest laser system parks in Europe. Its proximity to RWTH Aachen University, in turn, guarantees the institute has an influx of very well-trained engineers and scientists. Systematic and long-term cooperation between the university, Fraunhofer ILT and industry takes place, in particular, at the Research Campus Digital Photonic Production (DPP). Spin-offs are also generated from this environment, continuing the long spin-off tradition of Fraunhofer ILT with over 40 spin-offs in 30 years.
www.forschungscampus-dpp.de

Industry cooperation at the Aachen site

On the laser industry side, numerous medium-sized companies have joined forces to form LASER.region.Aachen. The consortium intends to position the Aachen region as a center for agile laser-based production solutions, thereby creating sustainable jobs.
www.laserregionaachen.de

On the laser user side, companies at the Aachen site are also bundling some of their relevant research activities together. For example, the Fraunhofer Institutes for Production Technology IPT and Laser Technology ILT as well as the Machine Tool Laboratory WZL and the Chair for Digital Additive Production DAP at RWTH Aachen University, together with 19 industrial partners, established the International Center for Turbomachinery Manufacturing - ICTM in 2015. The network's industrial partners include large and medium-sized companies from the fields of turbomachinery, automation and machining technology, and additive manufacturing, among others. The center focuses on research and development for the manufacture and repair of turbomachinery components, which is covered by the partners in all areas.
www.ictm-aachen.com

Innovation clusters as a source of transferring know-how, promoting young talent and founding spin-offs.

Networks and Clusters

Laser Technology at RWTH Aachen University

The RWTH Aachen University with its Chairs for Laser Technology LLT and Technology of Optical Systems TOS as well as the Instruction and Research Department for Nonlinear Dynamics of Laser Manufacturing Processes NLD represents an outstanding cluster of expertise in the field of optical technologies in close cooperation with the Fraunhofer ILT.

The RWTH Aachen University in numbers (Status: 2022)

- About 47,000 students
- 14,150 international students
- 1,192 Mio. € financial volume
- University of Excellence
- 3 Clusters of Excellence
- 173 courses of study

Jointly shaping the future

The RWTH Aachen University Chairs for Laser Technology LLT and Technology of Optical Systems TOS as well as the Instruction and Research Department NLD represent an outstanding cluster of expertise in the field of optical technologies. This permits supercritical treatment of basic and application related research topics. The close cooperation with the Fraunhofer Institute for Laser Technology ILT not only permits industrial contract research on the basis of sound fundamental knowledge, but also provides new stimuli for the advanced development of optical methods, components and systems. The synergy of infrastructure and know-how is put to active use under a single roof.

This structure particularly benefits up-and-coming young scientists and engineers. Knowledge of current industrial and scientific requirements in the optical technologies flows directly into the planning of the curriculum. Furthermore, undergraduates and post-graduate students can put their theoretical knowledge into practice through project work at the chairs and at Fraunhofer ILT. University courses are drawn up jointly as well. Teaching, research and innovation – those are the bricks with which the three university departments and Fraunhofer ILT are building the future.

Chair for Laser Technology LLT

The RWTH Aachen University Chair for Laser Technology has been engaged in basic and application-oriented research and development in the fields of laser measurement technology, development of beam sources, laser material processing as well as digital photonic production since 1985.

A great part of the research activities is carried out in the framework of some big projects as e.g. the Cluster of Excellence "Internet of Production", the BMBF Digital Photonic Production Research Campus and the Collaborative Research Center SFB 1120 "Precision Melt Engineering". Furthermore, the Chair for Laser Technology is coordinator of the Research Center for Digital Photonic Production. Present topics of research are:

- Interaction of ultra-short pulsed laser radiation with the material in ablation, modification, drilling or melting
- Future concepts for beam sources such as direct diode-pumped Alexandrite laser or EUV radiation by means of ultrashort pulses
- New concepts for innovative laser-based processing and strategies

Prof. Constantin Haefner (Director of the chair)
www.llt.rwth-aachen.de

Chair for Technology of Optical Systems TOS

By establishing the Chair for Technology of Optical Systems in 2004, RWTH Aachen accorded recognition to the increasingly central role of highly developed optical systems in manufacturing, the IT industries and the life sciences. Research activities focus on the development and integration of optical components and systems for laser beam sources and laser devices.

Highly corrected focusing systems for a high laser output, beam homogenization facilities and innovative beam shaping systems are all key components of laser systems used in production engineering. These include adaptive optics and free-form optics for innovative beam shaping for process adapted intensity distributions. The chair develops micro and macro-optical components for high-power diode lasers and combines them to form systems. It also investigates lithography and material analysis with resolutions smaller than 50 nanometers in the field of EUV technology.

Prof. Carlo Holly (Director of the chair)
www.tos.rwth-aachen.de

Instruction and Research Department for Nonlinear Dynamics of Laser Manufacturing Processes NLD

Founded in 2005, the Instruction and Research Department for Nonlinear Dynamics of Laser Manufacturing Processes NLD explores the basic principles of optical technology, with emphasis on modeling and simulation in the fields of application macro welding and cutting, additive manufacturing, precision processing with ultrafast lasers and PDT in dentistry and dermatology.

Mathematical, physical and experimental methods are being applied and enhanced to investigate technical systems. The application of mathematical models is helping to achieve a better understanding of dynamic interrelationships and to create new process engineering concepts. The results of these analyses are made available to industrial partners in the form of practical applications in collaboration with the Fraunhofer Institute for Laser Technology ILT. The main educational objective is to teach a scientific, methodological approach to modeling on the basis of practical examples.

Prof. Wolfgang Schulz
(Head of the department)
www.nld.rwth-aachen.de

Main building and "SuperC" of the RWTH Aachen University, © RWTH Aachen University / Peter Winandy.

Research Campus DPP and RWTH Aachen Campus

The Research Campus Digital Photonic Production DPP in Aachen is investigating new methods and fundamental physical effects for using light as a tool in the production of the future.

The RWTH Aachen Campus acts as a catalyst for successful start-ups.

Research Campus DPP

Funded by the German Federal Ministry of Education and Research BMBF since 2014, the Research Campus DPP has established a new form of long-term and systematic cooperation between RWTH Aachen University, the Fraunhofer-Gesellschaft and industry. Jointly agreed technology roadmaps define how the two Fraunhofer Institutes ILT and IPT, the cooperating RWTH Chairs and around 30 industrial companies cooperate, a collaboration that spans three fields of expertise and two fields of application.

The Research Campus DPP takes advantage of its proximity to the RWTH Aachen Campus. Interested companies can set up shop there in thematically focused clusters for rent in investor buildings or in their own building. The photonics cluster specializes in researching and developing processes for generating, shaping and using light, especially as a tool for industrial production. Currently, there are two buildings in the Photonics Cluster: the Research Center Digital Photonic Production (DPP) and the Industry Building Digital Photonic Production (DPP).

Competence area: digital
- Digital process chain
- Digital shadow
- Artificial intelligence
- Automated algorithmic design
- Industry 4.0 and cloud-based production

Competence area: photonics
- Novel scanner concepts
- Multi-beam systems
- Application-adapted, local and temporal intensity distributions
- Process sensor technology

Competence area: production
- Systematic cost and benefit assessment
- Materials development

Application fields: additive production and subtractive production
- Interaction
- Scaling

Research Center DPP

To shorten innovation cycles, different research areas need to network in an inter- and transdisciplinary manner. Scientists from different institutes and chairs at RWTH Aachen University conduct research together on different topics with common goals over a relatively long period of time. The Research Center DPP, which opened in 2019 and was fully operational in 2020, offers researchers space for fundamental research in the field of photonics on approximately 4,300 square meters of floor space – including 2,800 square meters of laboratories, clean rooms and halls. The institutes and chairs currently involved come from six faculties at RWTH Aachen University: Mechanical Engineering, Mathematics, Computer and Natural Sciences, Electrical Engineering and Information Technology, Georesources and Materials Engineering, Medicine and Economics.

Industry Building DPP

Companies can set up shop in the Industry Building Digital Photonic Production – which is in the immediate vicinity of the Fraunhofer Institute for Laser Technology ILT – to develop new components, systems, processes, process chains or business models in the field of optical technologies, especially for production technology. The Industry Building DPP thus offers the necessary infrastructure for long-term, strategic cooperation within the framework of the Research Campus DPP. Premises such as laboratories and offices can be rented as needed through the private operator. Mixed teams from industry and science can interact and inspire each other in open space structures and jointly occupied laboratories. Education and training as well as access to scientific events on site are also very efficient since companies "enroll" at RWTH Aachen University.

1 Industry Building DPP (right) and Research Center DPP (left) in the photonics cluster, © Research Campus DPP, Aachen.
2 Entrance area of the Industry Building DPP in the Photonics Cluster, © Research Campus DPP, Aachen.

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www.forschungscampus-dpp.de

Spin-Offs

Together with the Research Campus Digital Photonic Production DPP and the RWTH Aachen Campus, Fraunhofer ILT offers an ideal environment to found a company in the field of photonic production.

Headquarters of the spin-offs EdgeWave GmbH in Würselen, © EdgeWave GmbH and RJ Laser Technology GmbH in Übach-Palenberg, © RJ Lasertechnik GmbH.

Intensive spin-off culture at Fraunhofer ILT

The Fraunhofer Institute for Laser Technology ILT has cultivated an intensive spin-off culture since the early 1990s, which has led to more than 40 new companies in the last 30 years. In this context, Fraunhofer ILT acts as a know-how partner that is more or less involved in the development of new technologies, depending on the cooperation agreement. Through corresponding license agreements, the spin-offs also have access to those patents that the founders obtained while at Fraunhofer ILT. Innovative founders are both impulse generators in the industry for new technological solutions and perspectives as well as classic entrepreneurs who keep an eye on sustainable business development and secure jobs

Spin-offs generate added value for the laser industry

The more than 40 spin-offs of Fraunhofer ILT not only generate new revenue, but also expand the market potential of the laser industry. They are also attractive employers in an industry that has been showing outstanding growth rates for years.

The spin-offs' product spectrum ranges from innovative cleaning processes, customized additively manufactured implants and new high-power diode lasers all the way to powerful ultrashort pulse lasers.

Co-creation at the Aachen location

The Research Campus DPP provides a platform for intensive exchange with companies, institutes and consultants working in the field of photonic production. Co-creation areas and open innovation concepts are also used on demand at the research campus. In the Industry Building DPP on the RWTH Aachen campus, start-ups can rent their own offices and laboratories on 7,000 square meters of floor space. Around 30 companies have already set up shop here, including research groups from major corporations such as Siemens, TRUMPF and MTU. The entire campus environment acts as an incubator for successful spin-offs.

Customer References

Customer references

The companies listed here are a representative cross-section of Fraunhofer ILT's extensive customer list.

Status December 2022.
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»Electromobility is held back by the limited range and charging time of batteries. This is precisely the bottleneck we are working on.«

Dr. Alexander Olowinsky,
Head of Department Joining and Cutting

Location Initiatives – Battery and Hydrogen Lab

The energy transition requires sustainable energy from photovoltaics and wind power, for which energy storage systems such as batteries and green hydrogen are needed. For this purpose, Fraunhofer ILT has established the Battery Lab and the Hydrogen Lab at its Aachen location.

With lasers, metallic bipolar plates can not only be welded together, but also be cut directly to their final contour.

With the Battery Lab to the next battery generation

Batteries not only store solar and wind energy and stabilize our power grid, but also provide energy for portable devices such as cell phones and tools, as well as electric vehicles. They provide energy in emergencies, such as power outages, and support medical devices and space applications. The better batteries become, the more tasks they take on in our everyday lives.

Key parameters of rechargeable batteries are capacity and energy density, power, weight, charging time and charging cycles, as well as chemical composition and production parameters. In the battery development laboratory Battery Lab, Fraunhofer ILT scientists are working on optimizing these specific properties. They develop high-performance, safe and cost-effective batteries that best meet the requirements of the respective tasks.

The Fraunhofer team has access to state-of-the-art technology and a wide range of equipment on an area of almost 140 square meters to research new materials and processes for laser-based battery production. Electrical and mechanical test stands allow them to directly evaluate the laser processes for today's lithium-ion batteries with liquid electrolytes and for future solid-state batteries.

The Battery Lab has an argon-powered glove box system that integrates vacuum-based PVD coating technology and a high-temperature furnace. This allows solid-state cell materials sensitive to air to be coated and then assembled into test cells.

Battery components can be cut and welded with lasers; applications are being tested in the Battery Lab to replace conventional production processes. UKP lasers can be used to process electrode foils without damaging them; here, the Fraunhofer team connects battery cells to battery modules and modules to battery packs.

Hydrogen Lab – the future belongs to green hydrogen

Hydrogen is a versatile energy carrier that requires a great deal of energy for its production, but has a number of advantages over batteries: Green hydrogen can be stored for a long time and can use the existing natural gas infrastructure. It can be used to power many industrial processes that currently still use natural gas, oil or coal. In the future, hydrogen-powered peak-load power plants will ensure that power supply remains secure by feeding electricity back into the grid. But sustainable hydrogen is still too expensive, and we need a lot of it.

By constructing its own hydrogen laboratory, the Hydrogen Lab, Fraunhofer ILT has created the best possible framework for perfecting the fuel cell as the heart of hydrogen technology – from the basics to series production.

The Hydrogen Lab's wide range of technical equipment opens up a variety of possibilities for seamless interdisciplinary collaboration. For public projects and industry cooperation, it offers a unique space to achieve synergy effects at the highest scientific and technological level.

Fraunhofer scientists are conducting research in various projects to drive forward the cost-optimized and demand-oriented series production of fuel cells. They help industry and society tap the technological and economic potential of this technology and accelerate its structured rollout.

On 300 square meters, the new Hydrogen Lab offers a wide range of laser test facilities for different dimensions and designs. The facilities cover the laser-related manufacturing steps along the process chain for the production of metallic bipolar plates used in fuel cells.

Individual production steps as well as process chains can be examined and evaluated on equipment for structuring with ultrashort pulse lasers, for laser-based coating and for high-speed welding and cutting. The existing test rigs can be used to test the hydrogen tightness and efficiency of the laser-manufactured components.

»Our new Hydrogen Lab is unique in the German research landscape since it enables users to test a great deal of ideas in praxis.«

Dr. Alexander Olowinsky

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Networks and Associations

Through its networks, Fraunhofer ILT expands the know-how of its own industry and thus contributes significantly to further developing science and technology.

AKL e.V. event with visit to the Mechanical Engineering Campus of Leibnitz University Hannover, © Arbeitskreis Lasertechnik e.V.

Fraunhofer ILT cooperates closely with domestic and foreign research centers, universities and companies and maintains close contacts with associations, innovation clusters, chambers of industry and commerce, testing institutes, standards committees and ministries.

Regional networks

On a local level, Fraunhofer ILT cooperates with RWTH Aachen University, the Aachen University of Applied Sciences and Forschungszentrum Jülich on many fundamental issues. The Aachen Center for 3D Printing – a cooperation between the Aachen University of Applied Sciences and Fraunhofer ILT – provides support for small and medium-sized enterprises in all aspects of additive manufacturing. In life sciences, Fraunhofer ILT is regionally well networked via the association MedLife e.V., while the professional association IVAM e.V. gives the institute access to numerous experts in microtechnology. In the state cluster NMWP. NRW, Fraunhofer ILT is involved in the fields of nanotechnology, photonics, microsystems technology, aerospace and quantum technology. Especially in the new field of quantum technology, Fraunhofer ILT contributes its photonics expertise and forms a strong scientific pillar together with the Forschungszentrum Jülich and RWTH Aachen University.

Building on this, the institute – together with the industry in the region of Aachen and Jülich – is creating a quantum technology hub that is relevant nationally while oriented internationally.

National cooperation

Together with around 70 other research institutes, Fraunhofer ILT is embedded in the Fraunhofer-Gesellschaft, which is the largest organization for application-oriented research in Europe. R&D customers benefit from the combined expertise of the cooperating institutes. Laser users, manufacturers and researchers can network easily on a national level in the Arbeitskreis Lasertechnik e.V., in the Wissenschaftliche Gesellschaft Lasertechnik e.V. and in various industrial associations such as DVS, SPECTARIS, VDE or VDMA.

Fraunhofer ILT is actively involved in national standards committees such as DIN NWT and in initiatives such as the BMBF's Research Campus Digital Photonic Production DPP or the BMWi's "go-cluster" program. In all committees, ILT staff members provide impulses to further develop both the field of laser technology and forms of cooperation between science and industry for the benefit of society.

Internationally networked

With foreign companies and branches of German companies abroad, Fraunhofer ILT carries out bilateral as well as joint projects. In addition, Fraunhofer ILT participates in major international projects, such as in climate research with the Franco-German space mission MERLIN or in the design of research programs, such as with the European Commission via the technology platform Photonics21.

Fraunhofer ILT also coordinates advisory bodies for ministries on internationally relevant topics such as nuclear fusion research and enters into strategic partnerships such as with the Lawrence Livermore National Laboratory LLNL in California, USA. The institute's staff accompanies its international developments by being involved in selected associations and networks such as the European Photonic Industry Consortium EPIC at the European level or OPTICA and the Laser Institute of America LIA at the transatlantic level.

Fraunhofer and QuTech get the quantum internet off the ground

In a long-term partnership, the Fraunhofer-Gesellschaft and QuTech – a collaboration of the TU Delft and the Netherlands Organization for Applied Scientific Research TNO – are working together on the development of the quantum internet gateway. Within this framework, the Ministry of Economic Affairs, Industry, Climate Action and Energy of the State of North Rhine-Westphalia is funding a quantum internet node in Aachen, which is being set up by Fraunhofer ILT in close cooperation with QuTech and will be used to test photonic system solutions.
www.ilt.fraunhofer.de/en/technology-focus/quantum-technology.html

From left to right: Prof. Raoul Klingner, Director of Research at the Fraunhofer-Gesellschaft; Sibylle Keupen, Mayor of the City of Aachen; NRW Economics Minister Mona Neubaur; Prof. Constantin Haefner, Director of Fraunhofer ILT, at the handover of the approval notification for the N-Quik project.

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Strategic Mission Initiative Quantum Technology

Thanks to its many years of experience, Fraunhofer ILT is an optimal partner for developing components, systems and processes for quantum technologies.

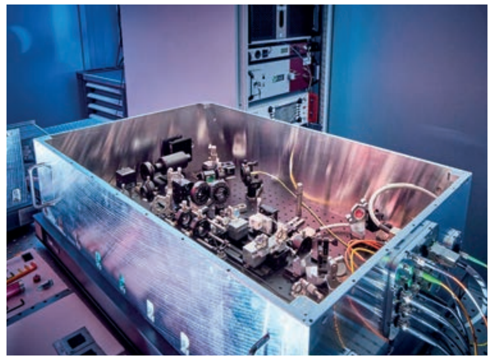
»N-Quik allows us to establish standards for quantum networks and to play an active role in setting the European agenda.«

Dr. Bernd Jungbluth

Laser technology is crucial in the development of quantum technologies

In recent decades, lasers have established themselves in our everyday lives: They not only make the fast Internet possible, but also help the industry produce motor vehicles more efficiently. Lasers are integrated into cell phones and generate the radiation used to manufacture the most advanced microprocessors. Fraunhofer ILT has made many substantial contributions to laser technology development – by advancing it from a pioneering technology to a standard method in industry and research.

With quantum technology, laser technology has gained a large new field of applications. Quantum sensing and quantum communication, for example, use highly sophisticated laser sources and receivers, and most quantum computers need several lasers per qubit to function.



The quantum frequency converter enables low-loss quantum networking of supernormal telecom optical fibers.

With their expertise in laser technology and the most diverse aspects of photonic technologies, the employees of Fraunhofer ILT are sought-after partners for the development of quantum technologies. The researchers translate scientific findings into applications close to the market and develop innovative photonic solutions with clear unique selling points for this purpose.

Photonic technologies for the quantum internet of the future

Quantum computers use entangled photons to communicate with each other. These are special photons that cannot be intercepted or amplified. Accordingly, it is complicated to interconnect several quantum computers. On the other hand, networking quantum computers is of great importance so that they can be scaled up.

Technologies for networking and for building quantum computers are being developed in Aachen. To this end, teams from Fraunhofer ILT work closely with research institutions and companies in the Federal State of North Rhine-Westphalia, Germany and Europe. Particularly intensive is the cooperation with QuTech, a joint research facility of the Delft University of Technology and the Dutch Organization for Applied Scientific Research TNO.

The first German node for the quantum Internet is being built in Aachen, Germany

The partners in the Netherlands are connecting three quantum computers in different cities via optical fibers. As part of the NRW-funded project N-Quik, the first setup of this kind in Germany is being built in Aachen. Partners from industry and science can test new products and applications there and tap the full potential of distributed quantum computing. A quantum frequency converter (ICON project QFC-4-1QID) from Aachen is being used to reduce photon losses to record lows.

Building quantum computers with lasers

Quantum computers need to become smaller and more robust, which is the only way to scale them up. In the joint project IQuAn, Fraunhofer ILT is continuing to develop the process for laser-based fabrication of a monolithic microchip ion trap for this purpose. It is based on selective laser etching SLE, which allows more geometric freedom and greater precision compared to established processes. At the same time, it reduces manufacturing complexity. Via SLE, the micro-optics can also be integrated into the ion trap, which further improves its scalability.

The quantum processor will later be connected to the Mainz high-performance computer MOGON II with low latency and made available as a user facility. In parallel, the SLE technology will also be further developed: Within the project "Implementing Quantum Algorithms from Finance and Chemistry on a Quantum Demonstrator" (ATIQ), the process will be transferred from fused silica to synthetic sapphire.

Making the invisible visible with quantum imaging

In quantum imaging, an object is illuminated with photons of wavelength A, while entangled photons of wavelength B strike a detector. In this way, materials can be examined with infrared light and the image recorded with a camera in the visible range. In the QUIN project, ceramic and polymer materials are examined with entangled photons in the mid-infrared using quantum OCT.

A similar method is used in the QEED project for imaging to detect biomarkers in personalized medicine both early and in a differentiated manner. Here, quantum imaging is applied in a special microscope used to examine tissue samples for the detection of cancer and to evaluate them in clinical studies.

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NRW Economics Minister Neubaur and Prof. Haefner at the launch of the N-Quik project, funded by the Ministry of Economic Affairs, Industry, Climate Action and Energy of the State of NRW.

»AKL'22 took place for the 13th time in Aachen with 86 presentations and over 500 participants«

Conferences

In 2022, Fraunhofer ILT again hosted many international conferences with speakers from industry and research on current topics. The highlight was the biennial International Laser Technology Congress AKL'22.

January 25–26, 2022, online
LSE'22 – Laser Symposium Electromobility

Speakers from industry and research illuminated the topics of laser processes in battery production, laser-beam sources in electromobility and process monitoring of laser manufacturing processes, among others, at the digital LSE'22 – Laser Symposium Electromobility.

February 16–17, 2022, online
ICTM Conference

In application-related presentations, experts from industry and research presented and discussed current market developments, new product concepts and challenges of manufacturing technologies in the context of turbomachinery production. The digital event organized by Fraunhofer ILT and Fraunhofer IPT was attended by around 90 participants.

May 4 –6, 2022, Aachen
AKL'22 – International Laser Technology Congress

For the 13th time, laser manufacturers and laser users from different industries met at the biennial AKL – International Laser Technology Congress.

Over three conference days, participants brought themselves up to date with the latest technology and gained insight into current research topics for production solutions in 86 presentations. Together with the exhibition accompanying the conference and the live demonstrations at Fraunhofer ILT, the AKL has established itself as the central networking platform for the laser community. On the evening of May 4, 2022, the Innovation Awards Laser Technology 2020 and 2022 were presented in the Coronation Hall of Aachen City Hall. The award is offered by the Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI e.V.
www.lasercongress.org/en

June 1–2, 2022, Aachen
Aachen Polymer Optics Days

The Aachen Polymer Optics Days 2022 provided an excellent networking opportunity for participants from industry and research to exchange ideas on the manufacturing possibilities and application potential of plastic optical products.

September 13–14, 2022, Aachen
LKH_2 – Laser Colloquium Hydrogyn 2022

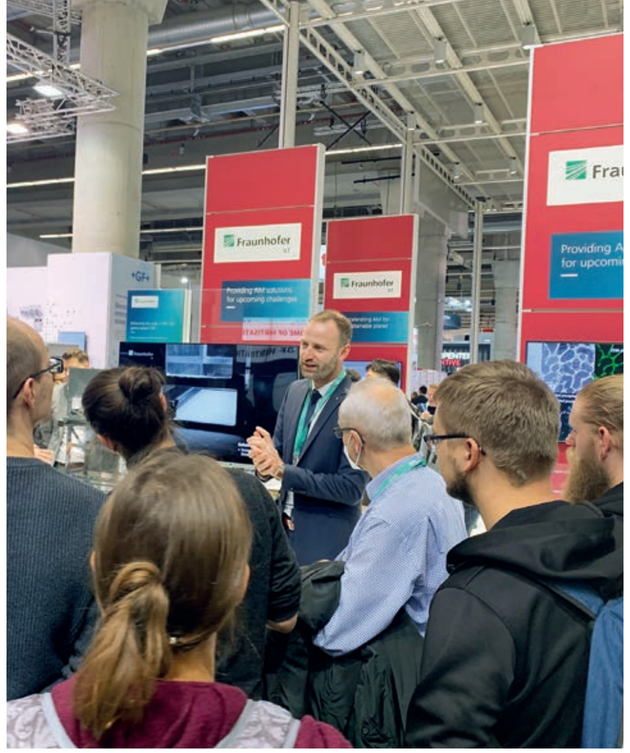
The use of regenerative energy sources is driving interest in fuel cells. For this reason, Fraunhofer ILT organized the third LKH_2 – Laser Colloquium Hydrogen. The presentations from industry and research focused not only on laser cutting and welding of bipolar plates, but also on the entire process chain and its monitoring.

October 12–13, 2022, online
5th Conference on Laser Polishing LaP

The conference presented scientific and application results on laser polishing and brought together people working in the field of laser polishing worldwide to stimulate discussions as well as promote new scientific collaborations. The event was attended by around 70 international guests.

Trade Fairs

Fraunhofer ILT regularly presents current research topics at trade fairs in Germany and abroad and, after a break due to corona, was once again represented at the Fraunhofer joint booth at LASER World of PHOTONICS & LASER World of Quantum in Munich in 2022.



January 22–27, 2022, San Francisco, USA SPIE Photonics West

Fraunhofer ILT was represented at the joint booth of the Federal Republic of Germany. In addition, there were three presentations by experts from Fraunhofer ILT and RWTH Aachen University at the accompanying LASE Conference.

April 26–29, 2022, Munich LASER World of PHOTONICS & LASER World of QUANTUM

Fraunhofer ILT was at the joint Fraunhofer booth at LASER World of PHOTONICS and at the joint Fraunhofer booth at the new and parallel LASER World of QUANTUM, and presented the following topics:

- Customized Lasers
- Additive Manufacturing
- Sustainable Production
- Digital Photonic Production

In addition, our experts were active as session chairs and speakers on the accompanying application panels.

Joint Fraunhofer booth at electronica 2022 in Munich, © Fraunhofer ZV / Markus Jürgens.

May 30–June 3, 2022, Munich IFAT MUNICH

Fraunhofer ILT presented the latest results from research and development in the field of materials analysis at the Fraunhofer joint stand at the world's leading trade fair for environmental technologies.

May 30–June 2, 2022, Hannover Hannover Messe

At the joint Fraunhofer booth, Fraunhofer ILT presented exhibits on the topic of "Circular economy for metallic components using laser-based process chains".

June 21–23, 2022, Stuttgart Surface Technology Germany

Fraunhofer ILT demonstrated a laser-based process chain for the sustainable repair of metallic components at the joint WOTech booth.

June 21–24, 2022, Munich analytica

At the joint Fraunhofer booth, Fraunhofer ILT presented "Process chains for isolation and analysis: from single cells to organoids".

October 19–26, 2022, Düsseldorf K 2022

At the world's leading trade fair for plastics and rubber, Fraunhofer ILT was at the Fraunhofer joint booth and presented exhibits on joining plastics and transparent materials.

November 14–17, 2022, Düsseldorf COMPAMED

At COMPAMED, Fraunhofer ILT was present at the joint IVAM (the International Microtechnology Business Network) booth and showed exhibits from the fields of laser medical technology and bioanalytics, microjoining, biofabrication, and micro- and nanostructuring. In addition, Dr. Georg Meineke gave a presentation at the COMPAMED HIGH-TECH Forum by IVAM.

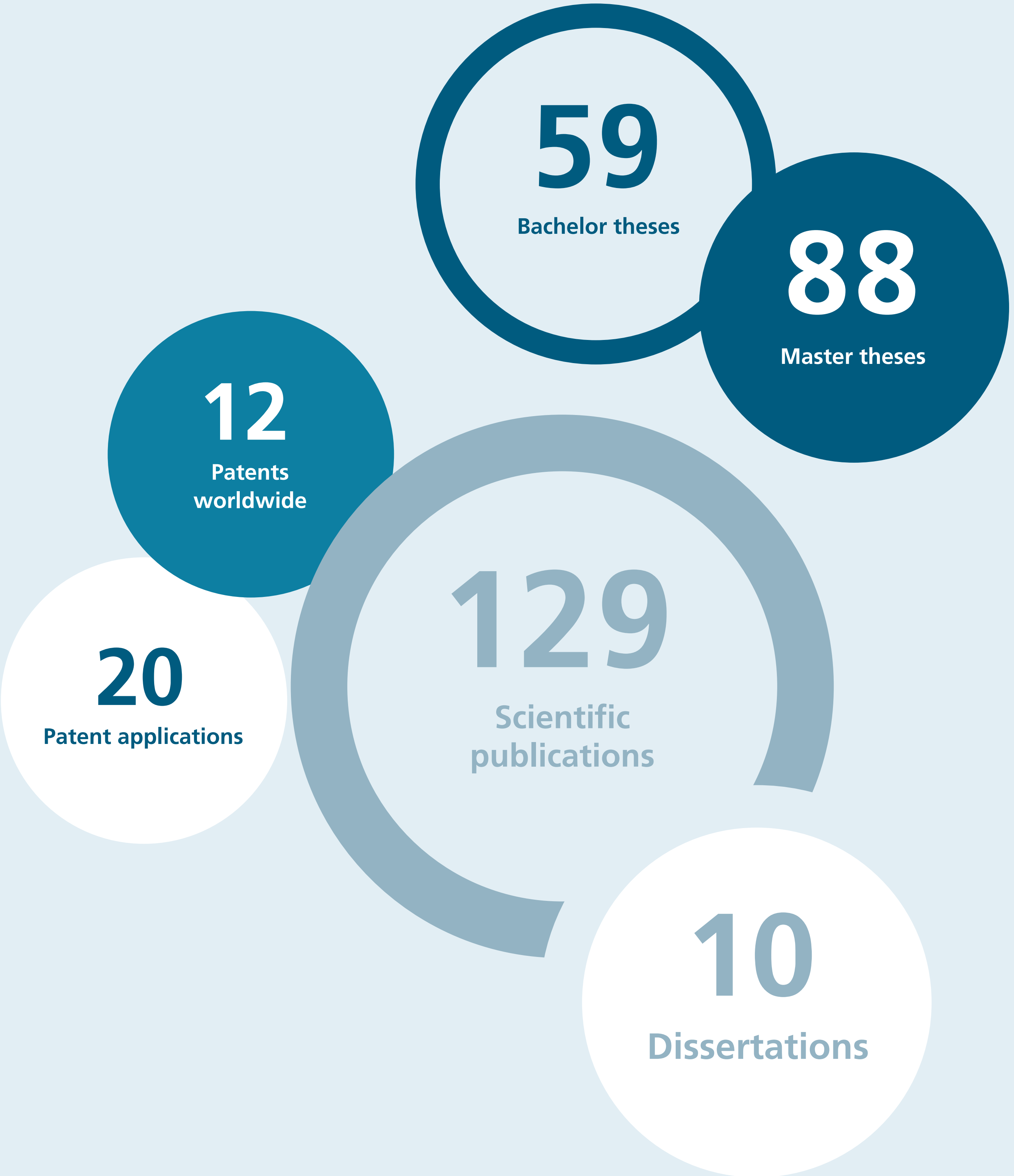
November 15–18, 2022, München electronica

At the joint Fraunhofer booth, Fraunhofer ILT showed technological highlights and the latest developments in laser-based manufacturing for batteries and electronics.

November 15–18,2022, Frankfurt a. M. formnext

Fraunhofer ILT presented current innovations in the field of laser powder bed fusion and laser cladding at the joint Fraunhofer booth. In addition, Tim Lantzsch gave a presentation on "Laser powder bed fusion using AFX – Towards processing of hard-to-weld materials".

1 Fraunhofer ILT at formnext in Frankfurt.
2 Fraunhofer joint booth at LASER World of PHOTONICS in Munich,
© Fraunhofer ZV / Markus Jürgens.



Events and Publications

Patents and Dissertations

Patents Germany

- **DE 102020131294A1**
  Verfahren zur Herstellung elektrischer Verbindungen hoher Stromtragfähigkeit sowie damit hergestellte elektrische Verbindung
- **DE 102016111531A1**
  Optischer Scanner
- **DE 102012008940A1**
  Verfahren und Vorrichtung zum Fügen von mindestens zwei Werkstücken
- **DE 102012002818A1**
  Vorrichtung zur Thermokoagulation mittels Laserstrahlung
- **DE 102020134653**
  Justierbarer Optikhalter für ein optisches Element

Patents Europe

- **EP 3406392A**
  Verfahren zur Verringerung der Reibung aneinander gleitender und/oder rollender Flächen
- **EP 3655190**
  Synchronisation von Werkzeug und Werkstück bei der Laserbearbeitung
- **EP 20178701.7**
  Verfahren zum Testen neuer Werkstoffzusammensetzungen für das pulverbettbasierte Laserschmelzen sowie dafür ausgebildete Vorrichtung
- **EP 3856446**
  Verfahren zum Glätten der Oberfläche eines Kunststoffbauteils
- **EP 3774289**
  Verfahren und Anordnung zur kontinuierlichen oder quasikontinuierlichen generativen Fertigung von Bauteilen

Patents China

- **CN 216039822U**
  Koaxiales Pulverdüsenspitzenmodul zur Oberflächenbearbeitung eines Werkstücks

Patents Japan

- **JP 2020-514075A**
  Verfahren zur Herstellung einer transmittiven oder reflektiven Optik und Linse

Dissertations

- **4.2.2022 – Christian Tenbrock (Dr.-Ing.)**
  Large-format machine for multi-scanner laser powder bed fusion
- **15.2.2022 – Martin Adams (Dr. rer. nat.)**
  Modellierung der katastrophalen optischen Degradation von Hochleistungslaserdioden unter externer optischer Rückkopplung
- **13.5.2022 – Jasmin Kathrin Saewe (Dr.-Ing.)**
  Untersuchung der Verarbeitbarkeit des Schnellarbeitsstahls HS6-5-3-8 mittels Laser Powder Bed Fusion
- **2.6.2022 – Andreas Hoffmann (Dr.-Ing.)**
  Photoharzentwicklung für die stereolithographische Herstellung implantierbarer polymerer Optiken
- **3.6.2022 – Tobias Pichler (Dr.-Ing.)**
  Adaptives Laser Powder Bed Fusion der Titanlegierung TiAl6V4
- **8.7.2022 – Jonas Zielinski (Dr. rer. nat.)**
  A holistic approach to understand laser additive manufacturing from melt pool to microstructure
- **18.8.2022 – Johanna Helm (Dr.-Ing.)**
  Prozessstabilität und Prozesseffizienz beim Laserstrahlfügen von hoch reflektiven Kupferwerkstoffen
- **19.8.2022 – Talu Ünal-Saewe (Dr.-Ing.)**
  Ortsaufgelöste Prozessüberwachung für die Additive Fertigung mittels laserbasierter Directed Energy Deposition
- **15.9.2022 – Georg Rödler (Dr.-Ing.)**
  Entwicklung des selektiven Laserstrahlschmelzens für Al-Ni-Legierungen
- **16.9.2022 – Dennis Haasler (Dr.-Ing.)**
  Tiefbohren in Metallen mittels ultrakurzen Laserpulsen

Scientific publications and lectures

You will find a list of Fraunhofer ILT's scientific publications and lectures as well as bachelor and master theses online in our media center on the Internet at:
www.ilt.fraunhofer.de/en/media-center.html

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