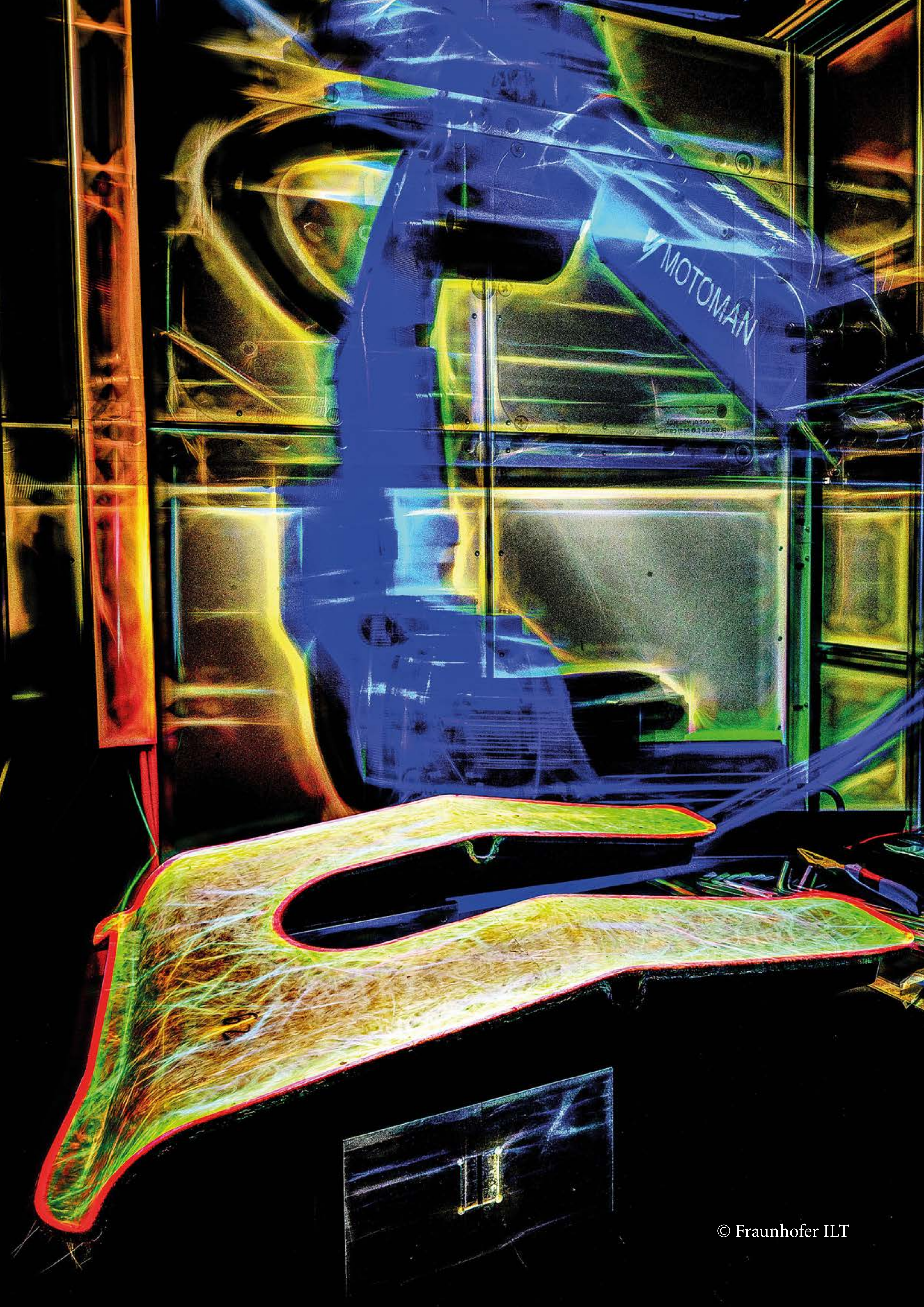
Photonics in Germany

2019

Optische Technologien in Deutschland


MOTOMAN

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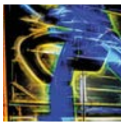

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Preface

Anja Karliczek
Federal Minister of Education and Research
Bundesministerin für Bildung und Forschung

Whether we think of bright summer evenings or candlelight and fireside in winter, we associate light with pleasure and warmth. But light can do so much more. We can concentrate it on a millionth of a millimetre. We are capable of high technological feats, creating up to billions of megawatts. And nothing moves faster than light.

Photonics helps us take advantage of these properties of light. Photonics is an important key technology that many areas can no longer do without. Just think of medicine: Whether X-rays or computer tomography – imaging techniques often provide the basis for precise diagnosis. And minimal invasive surgery is only possible thanks to small cameras that serve as the surgeon's eyes inside the patient's body. Photonics "made in Germany" is used for this purpose. It helps to restore people's health.

Photonics also provides essential assistance in industrial production, for example when laser systems separate or join various components or when production processes are monitored. And one last example: Autonomous driving, which needs complex optical sensors. We already know how they work in car parking assistants which beep when we move too near another car.

All this makes photonics an important sector which has created more than 130,000 jobs. At the same time, photonics is a major driver of innovation for digital transformation. Germany needs innovations which serve the people while increasing prosperity and growth. This helps us remain competitive on the international stage. Photonics makes a substantial contribution to this, as the brochure "Photonics in Germany" impressively shows. Enjoy the read!

Anja Karliczek
Member of the German Bundestag
Federal Minister of Education and Research

Grußwort

Egal ob wir an lange helle Sommerabende denken oder an gemütliche Stunden bei Kerzenlicht und Feuerschein im Winter – Licht gilt uns als Quelle von Freude und Wärme. Licht kann aber noch viel mehr. Wir können es auf den millionsten Teil eines Millimeters fokussieren. Wir können technologisch Höchstleistungen erzielen, bis zu Milliarden von Megawatt. Und nichts ist schneller als Licht.

Mit Hilfe von Photonik nutzen wir diese Eigenschaften von Licht. Sie ist eine wichtige Schlüsseltechnologie, die aus vielen Bereichen nicht mehr wegzudenken ist. Nehmen wir nur die Medizin: Ob Röntgenaufnahmen oder Computertomographie, bildgebende Verfahren stehen oft am Anfang einer präzisen Diagnose. Und minimalinvasive Eingriffe sind nur deswegen machbar, weil es kleine Kameras gibt, die für den Chirurgen zu Augen im Körperinneren werden. Photonik „made in Germany" wird hierfür genutzt. So hilft sie, Menschen gesund zu machen.

Auch in der industriellen Produktion leistet Photonik unerlässliche Hilfestellungen, wenn etwa Lasersysteme verschiedene Teile trennen beziehungsweise zusammenfügen, oder wenn es um die Überwachung von Fertigungsprozessen geht. Und ein letztes Beispiel: autonomes Fahren, das eine komplexe optische Sensorik benötigt. Wie sie wirkt, merken wir schon jetzt, wenn der Parkassistent laut piept, weil wir einem anderen Auto zu nahe gekommen sind.

All das macht Photonik zu einer bedeutenden Zukunftsbranche. Mehr als 130.000 Menschen arbeiten in diesem Bereich. Photonik ist gleichzeitig ein wichtiger Innovationsmotor für die Digitalisierung. Deutschland braucht solche Innovationen, die dem Menschen dienen und gleichzeitig Wohlstand und Wachstum mehren. So bleiben wir international wettbewerbsfähig. Die Photonik leistet dazu einen wichtigen Beitrag. Die Broschüre „Photonics in Germany" macht dies auf eindrucksvolle Weise deutlich. Ich wünsche allen Leserinnen und Lesern eine spannende Lektüre.

Anja Karliczek

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Standort Deutschland

Location Germany

Germany's Strengths as a Business Location

Gerhard Hein,
VDMA Laser
and Laser Systems
for Material Processing,
Photonics Forum

Germany is a leading hub for business and diversified research. With its rational regulatory framework and systematic research funding that is oriented towards feasibility but at the same time open to future-oriented foundations, it is a guarantor of innovativity. Research funding is of particular importance in Germany: in many cases it results from industry-oriented agenda processes or is based on an holistic approach and follow-up measures which cover all programme content and collaborative projects over time. Particular importance is attached to the fact that the market-driven development concerns of industry are addressed, while the expertise of highly qualified institutes – especially with regard to preliminary research – is taken fully into account.

The funding guidelines of the Federal Ministry of Education and Research on "Line integration of additive manufacturing processes" provide a striking illustration of Germany's strengths in this area. From a technical point of view, the main objective is to make the transition from potent prototype and small series production to productive series production under exacting industrial conditions. This involves a huge increase in deposition rates, for example through innovative multi-beam systems for the powder bed-based LMF (Laser Metal Fusion) process, as well as complete solutions involving sophisticated concepts for parts and powder management in order to increase machine utilisation rates. New generations of multilaser systems now permit the production of competitive series components. However, industrial solutions must cover the entire process chain and take into account intelligent digitalisation, specific requirements of individual user industries, process robustness and high availability as well as integrated services. Industrial software and monitoring solutions are gaining in significance, specifically the visualisation of current conditions and the prediction of possible failures using trend and pattern recognition. The main challenges in the future will be the linking of additive manufacturing with the objectives of Industry 4.0, networking across all process steps and the establishment of standard industrial processes in the area of "Additive Manufacturing" (AM).

Constructor of a Titanium Impellor. © DMG-MORI

Differentiated consideration of opportunities and demands now required

This applies in rather general form to the set of principal goals. Of course, it could be left to the equipment manufacturers themselves to overcome obstacles to further market penetration that have not yet been removed. These are not difficult to identify, but are actually relatively difficult to deal with:

In small series production as well as in the production of complex individualised components, cost advantages can certainly be obtained from additive processes without tools. Considerable added value can be generated through lightweight construction, internal cooling ducts or facilitating undercut contours. In such cases, it may also be possible to eliminate cost disadvantages that are currently enjoyed by medium and large series production.

Of particular interest are also hybrid machines – for example laser deposition welding systems – which allow specific processing functions of a different kind to be carried out during the build-up phase. However, this requires "3D printing"-compliant design and new approaches in production planning.

In the case of large components, on the other hand, the focus is on the necessary increase in the build-up rates, the comparatively high prices of the systems themselves as well as the limited variety of (suitable) material powders available. Added to these are the requirements of automated powder feeding, powder handling, powder disposal, dust pollution in the environment due to "unpacking" of the parts, process chains for the removal of supporting structures, non-destructive quality testing of the additive components and finally the proof of faultless reproducibility.

The above production-related development requirements are acknowledged and are being addressed by reducing diffusion barriers and through the development activities of plant, component and substrate manufacturers or research by renowned institutes.

Location-specific research policy

The coordinating and supportive research policy in Germany could not have yielded its current achievements if the Ministry of Research and project sponsorships did not look beyond the immediate production technology. This is where the aforementioned enhancement through support measures comes in: certification of additively manufactured components, establishment of standardised AM processes, sustainable standards in the initial and further training of workers, production planners, designers and university graduates in the form of additional qualifications through specialised advanced courses. The research policy, industrial partners and sponsors of the highly effective German institutes (for which the country is justly envied worldwide) form a virtuous circle! Prime examples here include "transverse" research topics in the context of training requirements or standardization-related studies on the selection of reference components for the purpose of illuminating the entire chain. As far as standards are concerned, a certain conflict arises due to the fact that the application portfolio changes every six months or so, or receives notable additions. Difficulties also arise in machine acceptance, where particular components are of great importance and relevant guidelines exist. Highly promising applications are held back because they are difficult - or impossible - to reconcile with these guidelines. The definition of approval criteria for a constant stream of new applications is problematic!

No genuine line integration without connectivity

Last but not least, with the increasing implementability of additive processes in industrial process chains, the eventual emergence of customer demands will have to be met by "connectivity" as a prerequisite for Industry 4.0 concepts. Semantics and parameters will need to be standardised in order to implement a universal, globally accepted interface based on the OPCUA Companion Specification that can reliably and seamlessly integrate machines and plants into customer- and user-specific IT systems. The VDW association, which is responsible for the machine tool industry and whose project also feeds into relevant VDMA activities spanning several mechanical engineering sectors, recently unveiled a "Universal Machine Tool Interface" (umati) at the AMB trade fair in Stuttgart in October 2018 and successfully exhibited it on the stands of project partners. Different machines and controls were connected to various communication partners for demonstration purposes.

Project-oriented versus basic research

There are currently signs of a reorientation in research policy, both at the national and European level, towards addressing future opportunities in the overall field of "quantum technologies". In view of the foreseeable directional correction in favour of increased support for basic research, backing should also be given to laser technology and photonics being seen as important integral components of quantum technologies. Currently being intensively propagated in connection with quantum technologies are sensor technology and highly sensitive imaging techniques, quantum computing with a focus on simulating highly complex phenomena and overcoming the current limitations, as well as communication technology including associated encryption aspects. Ongoing and planned activities are still very much laboratory-based, and potential market readiness is unlikely to be reached within the next few years. Accordingly, the VDMA, specifically its Laser and Laser Systems Working Group and the Photonics Forum, advocate networking physical research with engineering and the enabler function of important branches of photonics in the future. The challenges lie in coordinating the research disciplines and creating transparency in terms of access to appropriate infrastructures. The effects chain will be complex and relatively costly, ranging from the equipment market for laboratory technology to application development.

Additive Manufacturing. © DMG-MORI

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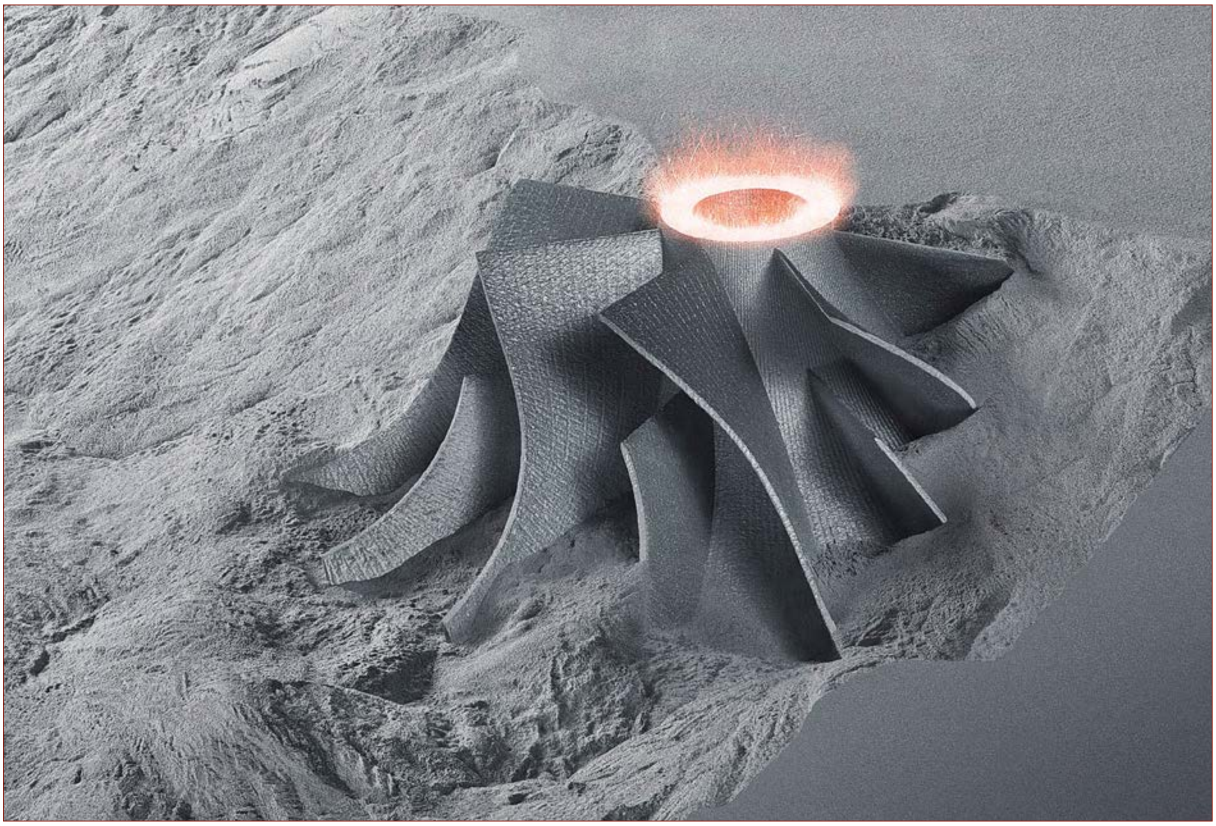
Digital Change Driven by Photonics and Other Quantum Technologies

Photonics is an important key technology for Germany as a location for innovation. It provides solutions for tomorrow's markets. Increasingly, photonics is driving digitization. Take additive manufacturing, autonomous robots or vehicles – photonics provides an indispensable technology basis. This creates enormous opportunities for our companies. But the challenges are also immense: new competitors are pushing their way into international markets. Classical, discrete components are being replaced by highly integrated photonic technologies; new production chains and new business models are being created on the basis of photonic processes. It is necessary to shape this change, to optimally position the photonics industry for future tasks and growth markets, to join forces, to strengthen small and medium-sized enterprises and to finance growth.

Guiding principles of technological change are:

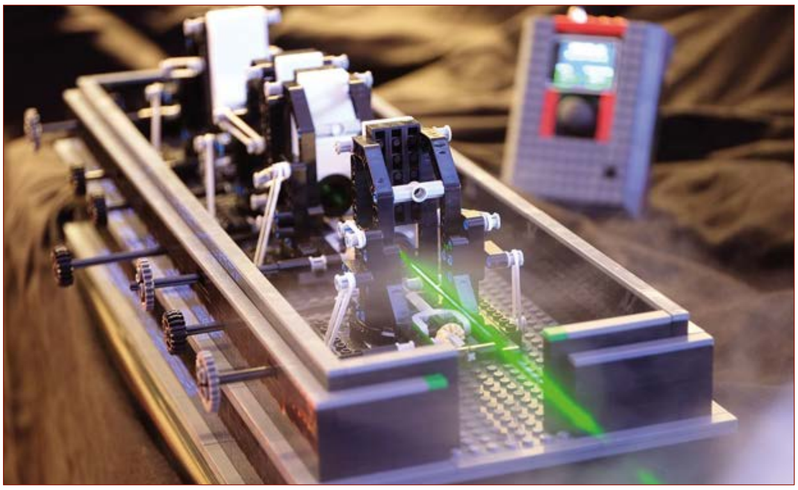
- the combination of individual photonic technologies to form integrated photonic systems; photonic micro integration,
- digital optics for applications ranging from medicine to industry 4.0 – from image capture via sensor-based data evaluation and storage to data and image processing for user needs (multimodal imaging, computational imaging, 3D vision) as well as
- technologies, integrated systems and standards for photonic-based human-machine interfaces (gesture control, gaze control, near-field displays, 3D displays).

These challenges imply much more than application development. It is about providing a comprehensive technology base for future photonic system solutions - with enormous

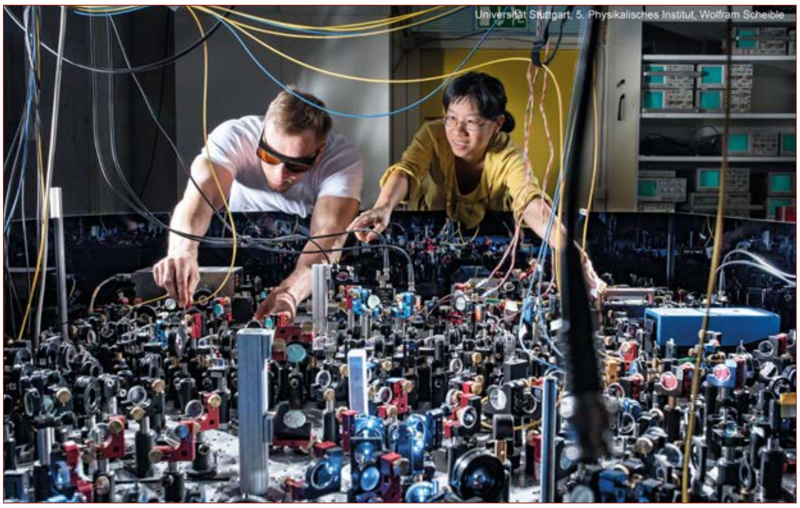


Additive Manufacturing using Laser Metal Fusion (LMF). Image: TRUMPF Gruppe

MinR Dr.
Frank Schlie,
Bundesministerium
für Bildung
und Forschung



First diode-pumped, intra-cavity frequency-doubled Nd:YAG laser (DPSS) made of LEGO® bricks, Image: Prof. Dr. Mirco Imlau.



Photonics is a key enabler for Quantum Technologies, Image: Universität Stuttgart, 5. Physikalisches Institut, Wolfram Scheible

significance for flexible production, medical and environmental technology and for networked infrastructures.

At the same time, photonics lays the ground for completely new fields of technology with enormous dynamics in the global competition in innovation. Today, photonic-based processes enable quantum technologies for ultra-precise sensor technology or secure communication.

The German Federal Ministry of Education and Research (BMBF) supports collaborative research at the frontiers of science and technology with closely interlinked programs on photonics and quantum technologies. The aim is to establish and expand successful innovation networks. We aim to be leaders and partners for these future fields of our industries.

The tasks in research and development are immense, and the course is now being set in international competition - from basic research via systems solutions in photonics and quantum technologies to applications for industry and society. To be successful here, we need science, research, industry and politics to work shoulder to shoulder. Together, we must invest in research and development. We need to open our technologies as platforms for inventors and makers. We will need to attract the best minds and committed young talent - because innovation is made by people.

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International Investment in Germany's Photonics Industry

The photonics industry plays a central role in the development of a number of German economic sectors in the coming years; being driven by strong German companies, internationally renowned R&D institutes and generous government support.

But just how attractive is Germany's photonic sector for international investors? In which fields are foreign companies investing in in Germany? Are foreign direct investment (FDI) projects being carried out in areas where the domestic industry has existing strengths? And how have the results changed compared to my last report?

Compared with the last report 2 years ago, photovoltaics have significantly lost ground. This is because the temporary boom in investment caused by the German feed-in tariff law is waning after 2012. A rapid drop in prices – caused by international competition – has caused investment in this segment to stall in recent times. Somewhat surprisingly, light sources takes the top spot. Measurement & automated vision shows up in second place after hitting spot number 5 two years ago. Let's examine these two categories in more detail.

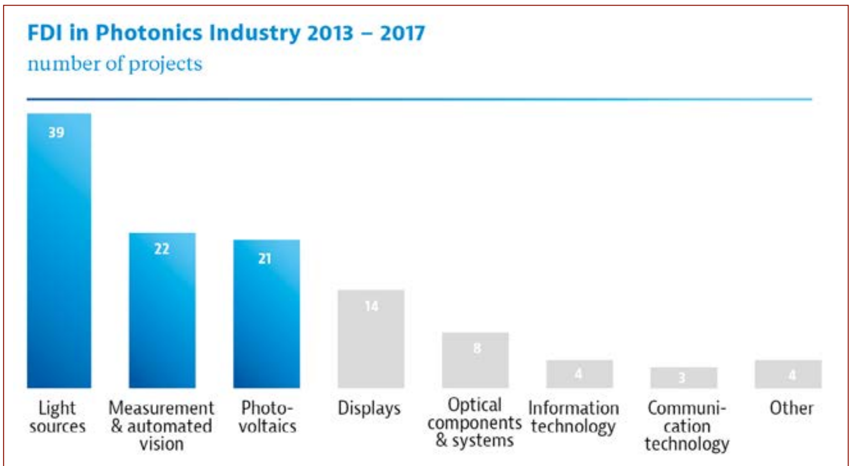
FDI projects in the field of displays were almost entirely carried out by Asian companies and exclusively in the fields of sales marketing, support or distribution. No projects adding value to the products locally were recorded in the last five years.

Germany is attractive as a location in the light sources business but with much less manufacturing activity than in the last report. Both displays and light sources are largely destined for consumer markets. It can be seen that most of the FDI projects were primarily attracted to the large German consumer market, as opposed to establishing projects to serve world markets from a manufacturing base in Germany. 38% of all light source projects were sales, marketing and support acitivites from East Asian companies tapping into the European and German markets.

There is a clear trend towards FDI projects from China into Germany in recent years. In the photonics sector of measurement & automated vision most of the projects originated in classic industrialized countries. The US and Japan play the major roles in this category. This implies that the so-called triade of the US, Japan and Western Europe (Germany in particular) are still ahead of the competition from emerging markets in this field.

Production technology as well as medical technology and life sciences have seen relatively few international investment projects compared to the levels of domestic production. Possible reasons include barriers to entry such as rigid regulations (e.g. in life sciences) or specific strengths of the German industry making these segments unattractive to new entrants.

Measurement & automated vision has received a significantly higher share of FDI projects compared to the last report. This fact could hint at the big trend of Industry 4.0 impacting international interest and investment



Source: GTAI analysis based on FDI markets, November 2018

Max Milbredt,
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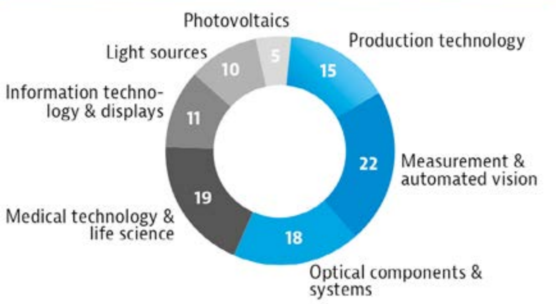
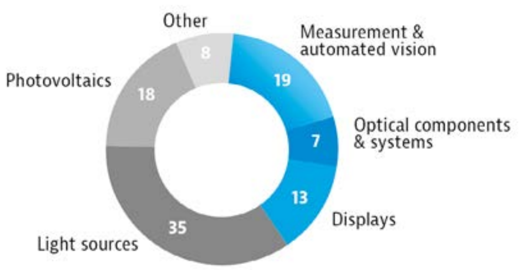
Domestic Production Germany 2016
in percent



Source: Photonics Industry Report

FDI Projects in the German Photonics Sector 2013 – 2017
in percent



Source: GTAI analysis based on FDI markets, November 2018

into Germany in this field. The share of projects has risen to 19% from 8% just two years ago.

One particularly interesting example of an investment in photonics technologies in the period examined was Samsung's investment in Novaled in 2013. Novaled, based in the eastern German city of Dresden, is a manufacturer of OLED materials. These materials are used in novel applications such as OLED televisions and OLED lighting. The investment was one of Germany's most successful venture capital exits to date, and a prime example of how new technologies developed in Germany's photonics sector can trigger the interest and commitment of international investors.

To return to the initial questions, it is clear from examples like these that Germany's photonics sector is attractive to international investors. The German consumer market for lighting and the sector of measurement & automated vision – possibly due to the rise of Industry 4.0 - are especially attractive for foreign investors. Germany's inherent strengths in medical technologies & life sciences and production technology mean the country still has the potential to attract foreign investment to its manufacturing sector. Germany Trade & Invest actively approaches international companies to encourage investment in all of these segments of the photonics industry in Germany.

About Germany Trade & Invest

Germany Trade & Invest provides free consulting services to photonics companies looking to invest in the country. We consult on all matters concerning the market: from tax and legal issues and investment funding through to site identification. Germany Trade & Invest is funded by the Federal Ministry for Economic Affairs and Energy (BMWi).

* The Financial Times fDi Markets foreign direct investment database was used to derive the data for this article. The sector definitions are based on those used in the Photonics Industry Report 2013 (jointly published by the German Federal Ministry of Education and Research and the SPECTARIS, VDMA, and ZVEI German trade associations).146 FDI projects were identified for the six-year period from January 2011 to December 2015.

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Why the Photonics Manufacturing Industry will Remain a Domestic Value Generator, Unlike the Photovoltaics Industry

A German view on the nature of high-tech photonics

Germany is seen as a leader in various technologies, strong in innovation and academics but weak in exploiting its leadership in large-scale market uptakes. Take television technology, mobile phones or semiconductors. In none of these segments Germany transferred its innovative capacity into sustainable big business.

Is there reason to assume that the photonics industry could face a similar fate? In the search for a plausible prognosis, it helps to look at an industry that not only has a similar name, but also operates with similar technologies: Photovoltaics (PV).

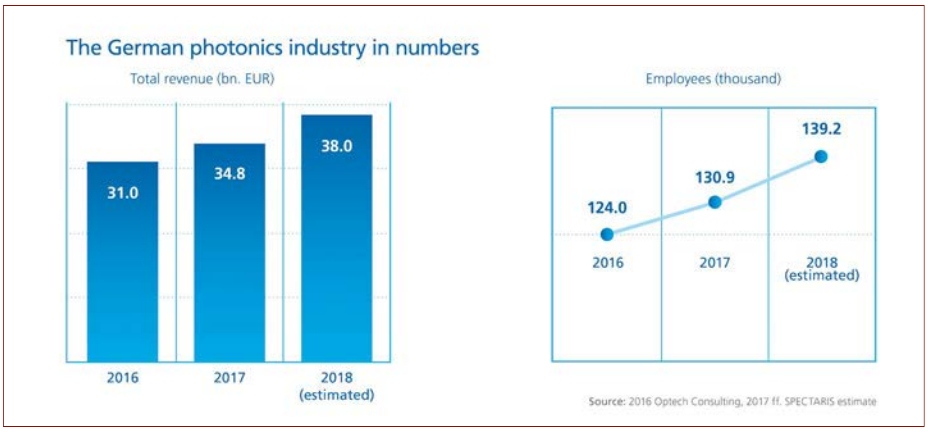
Considerable market uptake was not seen before the late 1990s. Fuelled by the societal desire to introduce measures for climate protection and non-nuclear energy supplies, government support was introduced, which guaranteed a fixed payment for every injected kilowatt hour. Hence, the demand rose significantly. By the mid-2000s, capacities for manufacturing PV modules emerged close to where the demand was, meaning mainly in Germany. But the industry was too slow in adapting its capacities and development efforts to the growing global demand. In this seller's market, many producers were lulled into a false sense of security. The Chinese government recognised the potential of the rising number of guaranteed markets and a trend towards national energy transitions. In its 12th Five-Year Plan from 2011, it named PV as a key technology and thereby laid the foundation for massive domestic growth in manufacturing. For years, this industry's production far exceeded domestic demand, as a result of which the excess was distributed at low prices to markets that yielded stable returns. Europeans could not withstand this price pressure. After a transition period with punitive tariffs on Chinese imports, even the last major German manufacturer was forced to throw in the towel in 2018. Although it harboured great hopes at the start, the large-scale German PV industry experienced a short lifecycle, basically in a time lapse compared to the lifecycles of other industries.

Why photonics is different

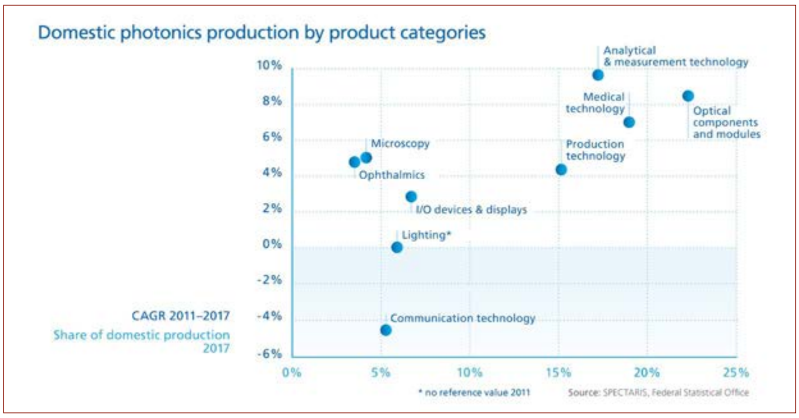
The industrial application of light – photonics – that emerged around the same time as PV, has so far been spared from similar developments. Or is it merely experiencing similar progress in slow motion? Are global competition, increasing price pressure, and market concentration also endangering this industry?

Let us first look at what photonics constitutes. Photonics is not a singular technology, but instead serves as an umbrella term for a series of different optical technologies such as the light sources lasers/LED/OLED, imaging optics, fibre optics, optical sensors, displays, and – here we are again – solar cells. All these technologies trigger great leverage effects in their application areas. They contribute to the value of the end product or service, either by enabling/enhancing the productivity of the manufacturing process, or by providing/enhancing functionality in the end device. Example: to produce optical and electronic products, prognoses indicate that nearly 80% of revenues will depend on photonics in 2020 as analysts say.

The steady development and growth of these applications is forcing photonics itself to conduct intensive research and development activities. Not least because



Jörg Mayer
Managing Director
SPECTARIS



of this can photonics be described as a key enabling technology.

In Germany, photonics has recently steered onto an impressive road to success. After generating turnover of €31 billion in 2016, this value is expected to rise by more than 22% to €38 billion by the end of 2018. In the same period, the number of employees in Germany is anticipated to grow to nearly 140,000 - an increase of 13%.

When observing the product segments that deliver both a high production volume in Germany and high growth rates at the same time, optical components and parts, analysis and measuring technology, production technology, as well as medical technology stand out. Since these segments hold a strong German position in the global market with a consistent share of more than 15% of the global production, photonics is maximising its value contribution to the domestic value chain.

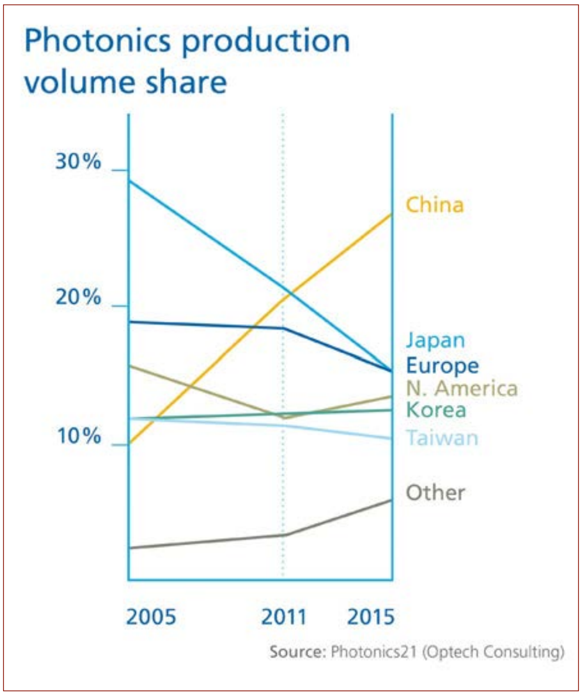
Is the German position sustainable?

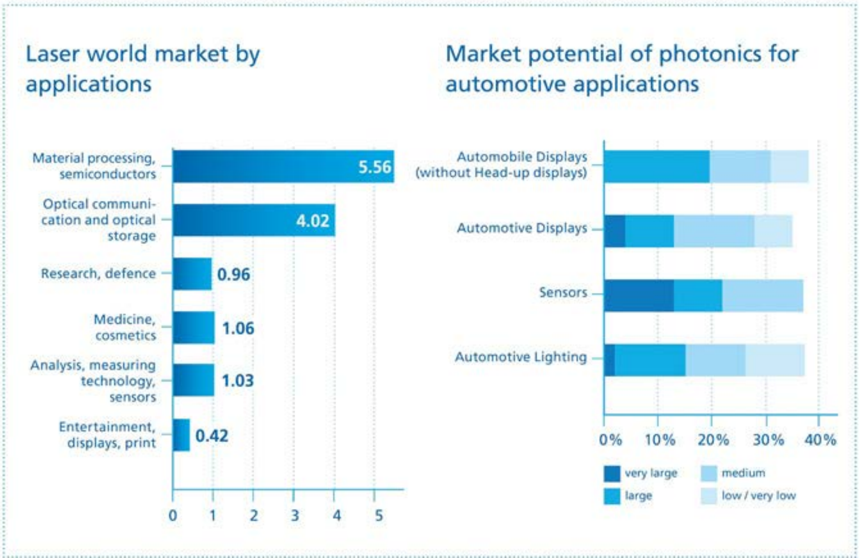
China is catching up. While Japan and Europe have recorded a slightly declining share of the worldwide production volume, China managed to reach nearly 30% of the global production market share, following an upward trend. However, it is expected that the overall global market will increase from €530 billion (2017) to €800 billion by 2022. Therefore, everyone will profit.

This development is driven by certain expanding markets. These include automotive applications with optical components, such as displays or LiDAR lasers for autonomous driving. Lasers for material processing or optical storage are also delivering favourable growth prognoses.

German Photonics must prove that it can master the growth. Other countries can scale up much more rapidly, as the example of PV has shown. The first area to consider is the availability of specialists and academics, which could otherwise be the greatest inhibiting factor to the upswing. The German university system is reacting quickly, partly driven by the federal structure in Germany which seeks to generate locational advantages through specific research and cluster programmes. Today, about 20 university locations offer a degree in the field of lasers and optics. Although the PV industry produced annual revenue of €14 billion (2011) at its peak, comparable numbers are considerably lower.

However, a dense education landscape is not the only benefit. Development partnerships are a major advan-





Source: Strategies Unlimited, Laser Focus World

Source: Assessment of manufacturers according to SPECTARIS member survey 2018 (Difference to 100% = not specified)

tage, since complex optoelectronic and optomechanical systems generally require a close-knit network of R&D and supplier companies, favoured by spatial proximity. Respective networks are supported by associations such as SPECTARIS, which represent the interests of the photonics industry as well as various customer industries such as medical and laboratory technology.

The German photonics industry knows: it can compete in areas that deal with complex solutions or high-precision products, in which a high customising or engineering effort is needed, and in those which focus on individual production or small batches. These fields particularly require engineers and qualified specialists such as precision opticians and mechatronics engineers. Germany has them!

But as soon as it comes to higher production amounts and more standardised products that have a greater fault tolerance, German companies struggle to keep up. Light technology, light, and sensors in car manufacturing, optical sensors in the consumer area, e.g., for smartphones, live off high volumes. Here, other locational factors such as higher labour costs and bureaucratic hurdles prove to be disadvantageous. A high degree of automation on par with Industry 4.0 may offer a solution, but one which Asian manufacturers are also increasingly turning to due to a lack of specialists.

And this brings us back to the beginning: PV was too late in recognising itself as more of a commodity product. The Asians recognised this earlier and invested in comprehensive production capacities that were often based on German plant engineering and required a relatively low number of highly qualified employees. In addition, PV is used in few fields that purely deal with power generation. Research was able to focus on increasing its efficiency. Combined with achieving lowest unit costs, this resulted in a nearly irreversible competitive advantage.

It is not foreseeable that many photonics technologies will turn into commodity products like PV did. Specialised applications for medical or measuring technology will continue to be driven by the technological advances of their components and the successful collaboration of research institutes, manufacturers, and users. This outlook fuels the hope that photonics as a key enabling technology will continue to have a home advantage for some time to come.

SPECTARIS

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Innovations in Growth Markets

Innovationen in Wachstums-märkten

Advanced Segmentation for Research and Industry Applications using Machine Learning

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Introduction

Segmentation is the division of images into defined regions for subsequent categorisation and analysis. It becomes a key task whenever quantitative information is to be extracted from microscopic images, and this step lays the foundation for subsequent image analysis steps. Since the development of the first digital cameras, researchers and manufactures face the challenge of extracting quantitative, actionable information from the acquired images to further their research and improve their processes. This task is crucial but turns out to be one of the most challenging stages in the whole microscopy workflow. But, almost every other subsequent workflow depends on the ability to transform the image data into rich digital models containing segmented data.

The Challenge

Despite segmentation being the core of quantitative image analysis, segmentation is often difficult and cumbersome. There is no one segmentation method for all problems and therefore the user must deal with various tools and techniques to segment images from many different applications. Standard segmentation techniques involve defining regions based on thresholding their greyscale value or their colour. Segmenting by colour/greyscale value alone is frequently challenging as regions may have similar colour and brightness and only be differentiable based on their texture, shape or their appearance under a particular contrast or imaging mode. The key aspect is that the user must be able to obtain actionable information from their images in some way.

The Concept of Actionable Information

The main task for a system or software platform in this case is the ability to extract information from images that can be used to create real value for the user. Figure 1 illustrates this in the general sense.

The value drivers for this can be the need for automation, time savings, increased robustness or the need to be able to segment structures or objects of interest at all, if this cannot be done by conventional means. Machine learning can provide a way of solving the segmentation problem, to obtain this actionable information.

Machine Learning – Choice of technologies

The field of machine learning is developing rapidly and therefore it is critical to choose a technology stack that is scalable and extendable. ZEISS ZEN Intellesis uses established and proven open-source machine-learning libraries like TensorFlow and Scikit-Learn. This ensures transparency and allows the software to benefit easily from new developments in that field. The system architecture of ZEISS ZEN Intellesis highlights the fact that the software uses a

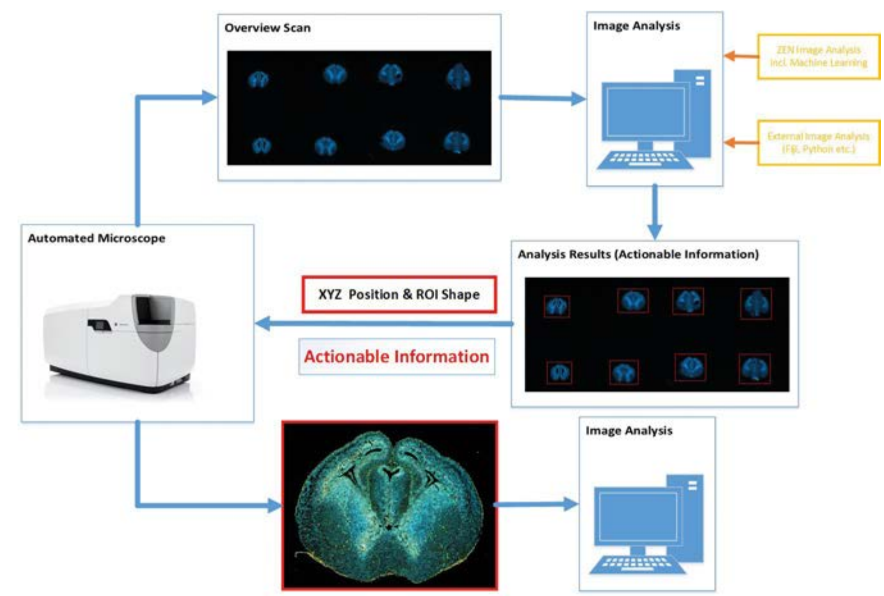

Figure 1: The general concept of Actionable Information – Use Image Analysis and Machine-Learning to guide the next acquisition steps in automated workflows or for the final image analysis

cross-platform segmentation backend written in Python, in combination with the ZEISS ZEN microscopy software. Such Client-Server architectures allow re-use of the segmentation algorithms inside other platforms like the cloud-and-docker container based image and data processing platform, APEER. This was developed as a ZEISS initiative in parallel with Intellesis.

Both libraries are implemented in Python and are therefore platform-independent, which allows the user to deploy the segmentation algorithms not only on desktop machines running on Microsoft Windows but also inside the APEER cloud processing platform. A simple APEER workflow below can use the exact same segmentation service as the Intellesis software module.

APEER – microscopy workflows simplified through easy to use modules

APEER provides a digital common platform to overcome this challenge, such that microscopy users can build and combine pre-defined packages into unique workflows that can be shared with peers, to accelerate research and innovation. As stated above, this includes automatic image segmentation by machine learning but can include almost any type of image analysis or data processing possible – e.g. particle size/shape determination, area counting etc.

In industrial environment, researchers could benefit from APEER automatically performing routine tasks for improved efficiency, gaining flexibility in building pre-defined modules and saving time by using workflows targeted for specific jobs.

Machine Learning – a solution to the segmentation problem

ZEISS ZEN Intellesis is a module for the ZEISS ZEN software platform. It is a data-agnostic guided machine learning system, which can be used alone or in conjunction with other software platforms.

The general workflow of segmenting an image using this tool typically starts with labelling and training a model. The user defines such a model, and then 'trains' the model by labelling regions on an image, set of images or part of a larger, multidimensional data set (2D or 3D).

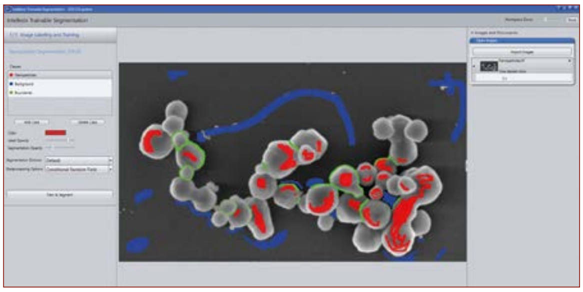

Figure 2: ZEISS ZEN Intellesis training interface - identification of individual nanoparticles. Image acquired using a ZEISS FE-SEM.

To "train" the system a specific feature vector is created for each labelled pixels. The profile (feature vector) for each pixel that has a certain number of properties, generated from several intensity, texture and edge filters or by extracting the features from the layers of a pre-trained network.

A "forest of random decision trees" approach is then used to create a classifier, using these feature vectors, which best recovers the provided training labels.

An interactive and intuitive user interface is used to generate the training regions. This is done by 'painting' the different classes or features of interest onto the image, as shown in Figure 2. After each segmentation operation, the user updates the labelling. This improves the segmentation results that the machine learning has produced, and gives it additional labelled regions to generate an updated classifier. This process (including labelling of multiple image

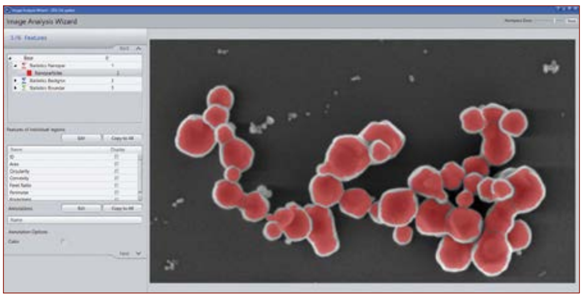

Figure 3: Integration of machine-learning segmentation results in the ZEN measurement framework and the Image Analysis Wizard to transform the segmentation results directly into actionable information. The results can be visualized or exported for further downstream processing steps.

data sets) can be repeated as many times as needed to generate satisfactory results.

Furthermore, it is possible to link such a trained model directly to a ZEISS ZEN Image Analysis Setting. This is a measurement pipeline, which includes a mandatory segmentation step to create objects. The actual feature measurement is the done on the segmented object level; measuring object-specific parameters like size distribution, shape etc.

The software supports even 6D datasets, like tiled images with multiple-channels and Z-stacks taken over time. When segmenting these or any other large data sets the built-in data manager will automatically “chunk” the data into digestible pieces for the machine-learning algorithm, and automatically distribute computation power depending on the available resources.

Conclusions

Image segmentation is an important step for industrial researchers, materials scientists and technicians who want to extract meaningful information from their 2D or 3D micrographs. They can enhance their research, improve productivity of routine tasks and increase their accuracy. Even though both classical threshold-based methods and machine learning algorithms exist, using them effectively and accurately often requires image segmentation expertise. The lack of automated image segmentation can result in operator-biased analysis as well as many hours of manual investigation. In fast moving industrial environments, a robust image segmentation platform that provides repeatability and accuracy of results while saving time, is essential.

ZEISS ZEN Intellesis brings all these advantages to organisations and individuals working on industrial materials and it is fully integrated into the ZEISS ZEN software platform. From performing grain size analysis on metals or ceramics, size distribution of nanoparticles in agglomerates, layer and phase analysis of materials, to porosity and exporting 3D real structures for physics simulations, ZEISS ZEN Intellesis works efficiently on all image formats (both colour and greyscale) and provides a seamless image segmentation. ZEISS ZEN Intellesis is not a standalone application, but is an optional module for the ZEISS ZEN Blue and ZEISS ZEN Core image acquisition and image analysis platforms. It can be fully integrated into these existing and established solutions.

Application Examples

Since ZEISS ZEN Intellesis is a generic tool for image segmentation it can be applied to many different applications and research fields.

Molecular Genetics – Drosophila Brain Sections

One of the biggest possible issues with electron microscope images intended for segmentation is the level of noise. Noise makes classical segmentation extremely challenging, because thresholding alone does not provide accurate results. Figure 4 shows an electron microscope image of a section of the calyx region of a 30-day-old Drosophila. The goal of the experiment was to identify the different structural components of the sample.

Five different groups of features have been classified: vesicles were identified in white, membranes in blue, mitochondria in red, cytoplasm in yellow and intercellular space in green. After image segmentation utilizing ZEISS ZEN Intellesis all five components can be distinguished and quantified, despite the relative high noise and small grey-scale differences within the image. The approach of ZEISS ZEN Intellesis to consider a large number of different features for the segmentation – e.g. texture and neighbourhood (rather than just greyscale differences as for classical thresholding approaches) ensures a more accurate result.

Determination of size distribution of nanoparticles

Nanoparticles research plays a very important role in numerous industrial applications such as pharmaceuticals, biomedical applications, coatings, inks and pigments, energy materials and filtration. To engineer nanoparticles with unique properties, improve synthesis methods and innovate new products, the chemistry, size and shape of individual nanoparticles must be determined. Even though there are bulk analytical techniques (such as sieving or laser scattering) to determine particle size distribution

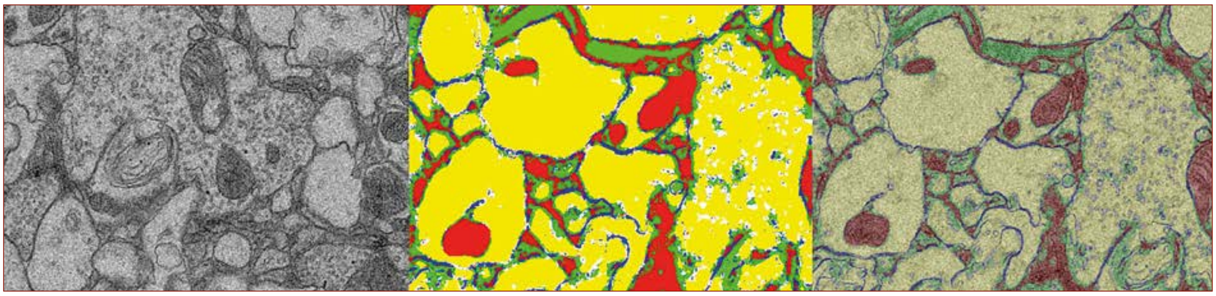

Figure 4: Calyx region of a Drosophila brain. Left: EM image showing mitochondria, synapses and presynaptic vesicles. Middle: Subset of left image showing segmented areas for mitochondria (red), membranes (blue), cytoplasm (yellow), intercellular space (green) and vesicles (white), segmented with ZEISS ZEN Intellesis. Right: Overlay of second image and raw data. Images courtesy of Max Planck Institute for Molecular Genetics, Berlin.

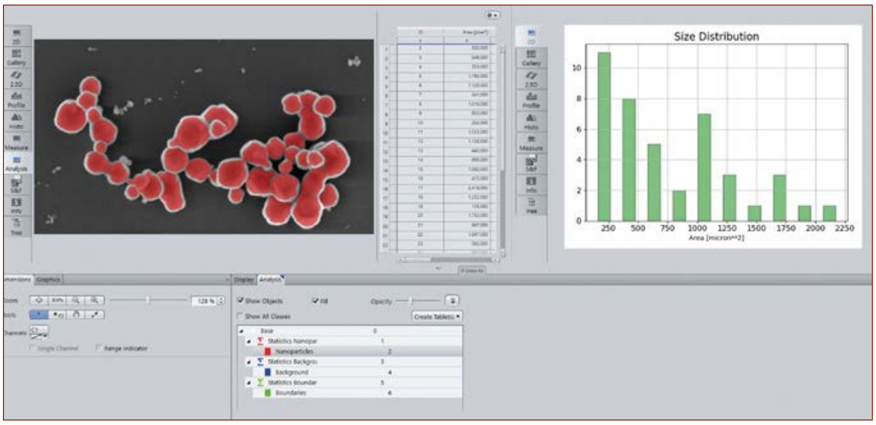

Figure 5: Workflow of nanoparticles size distribution analysis: (left) Image of nanoparticles acquired at 2kV in a ZEISS FE-SEM using the InLens detector, then segmented using ZEISS ZEN Intellesis. (right) Particle area distribution of individually segmented nanoparticles.

(though these methods may be limited by particle size and/or composition), automated analysis of individual nanoparticles in agglomerates still remains a challenge.

Figure 5 shows a section of an example automated workflow used to separate individual nanoparticles in agglomerates and to determine their particle area distribution using machine-learning, integrated into the ZEISS ZEN measurement framework. As shown above, ZEISS ZEN Intellesis was successfully used to identify three different classes: nanoparticles, boundary between nanoparticles and background. To further separate individual nanoparticles and determine the size distribution further binary processing steps were applied and the resulting data table was visualized an open-source python package (https://matplotlib.org/) and displayed inside the ZEISS ZEN software. The complete workflow was automated using the built-in python scripting in ZEISS ZEN.

Grain size determination of metals and ceramics

The properties of most engineering alloys and ceramics are strongly affected by the grain size and morphology. Various standards exist for measurement of grain size by light microscopy or by other methods including electron back-scatter diffraction. There is a fundamental factor common to all methods – differentiation of one grain from its neighbours. For light micrographs, this is facilitated by appropriate etching – either to highlight the grain boundary (typical in steels and nickel alloys) or by colouring each grain differently from its neighbour (e.g. some aluminium alloys). Once individual grains have been identified, measuring their size/shape distribution is trivial.

Figure 6 shows examples of grain boundary detection in metals and ceramics using light and field emission scanning electron microscopy. The metal (Alloy 600) was polished and then electro-etched. The grain boundaries are clearly visible, as are the twinning lines within the grains. However, the twinning lines are lighter than the grain boundaries, and grain boundary detection was straightforward using machine learning. The zirconia sample was more challenging – it was examined in the as-received (unpolished and un-coated) condition in a ZEISS Sigma 300 FE-SEM using secondary electron imaging at 1kV. The grain boundaries are visible, but there are significant variations in contrast across the sample, as well as several pores. Using machine learning in ZEISS ZEN Intellesis, it was possible to directly segment grain boundaries to permit determination of grain size/shape, while simultaneously detecting and measuring pore size/shape/distribution.

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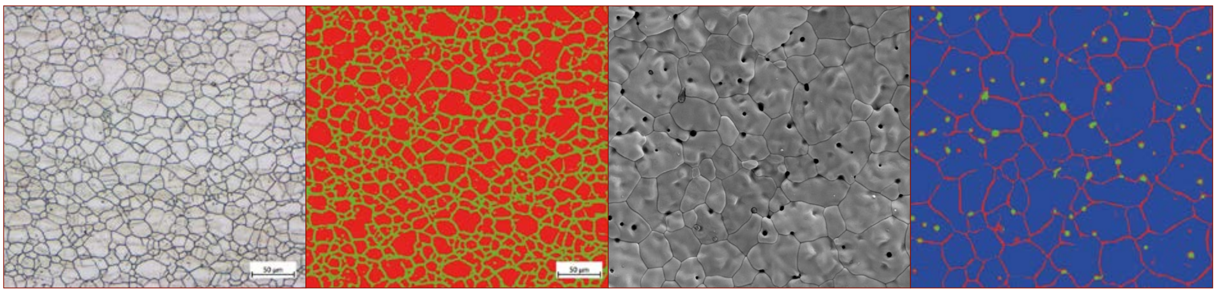

Figure 6: (left) Nickel Alloy 600 after metallographic preparation and electro etching. Brightfield imaging on a ZEISS Axio Imager Z2.m. (half left) ZEISS ZEN Intellesis segmentation of this image, showing grains in red and grain boundaries in green. (half right) Zirconia in the as-received condition, secondary electron imaging at 1kV at 30Pa in a ZEISS Sigma 300 VP. (right) ZEISS ZEN Intellesis segmentation of this image, showing grains in blue, grain boundaries in red, pores in green.

Lasers in the Quantum World

When quantum theories were first formulated a century ago, who would have guessed how much technological developments originating from quantum physics shape the way we live and interact today. Whether we work on a computer, use our mobile phones, or get a diagnosis based on magnetic resonance imaging: the understanding of quantum mechanics is the basis for all these technologies. In photonics, the laser and light-emitting diodes are prime examples, with a current market of more than 12 billion USD for lasers alone. Now, there are new quantum technologies on the horizon, with applications so exciting that researchers and science writers alike are proclaiming a second quantum revolution. Their enthusiasm is shared by governments and companies investing heavily in "quantum 2.0". The amazing gist: The most fragile properties of quantum systems, often perceived as counterintuitive or even spooky, are actually the source of radically new technologies. While the resulting applications are novel, the tools to enable quantum technologies are not. Already Newton acknowledged what is at the heart of modern science and technology: "If I have seen further it is by standing on the shoulders of Giants." This is particularly true for quantum technologies. As an example, the laser, a product of the first quantum revolution, is an enabling technology for quantum technologies. Its application is by

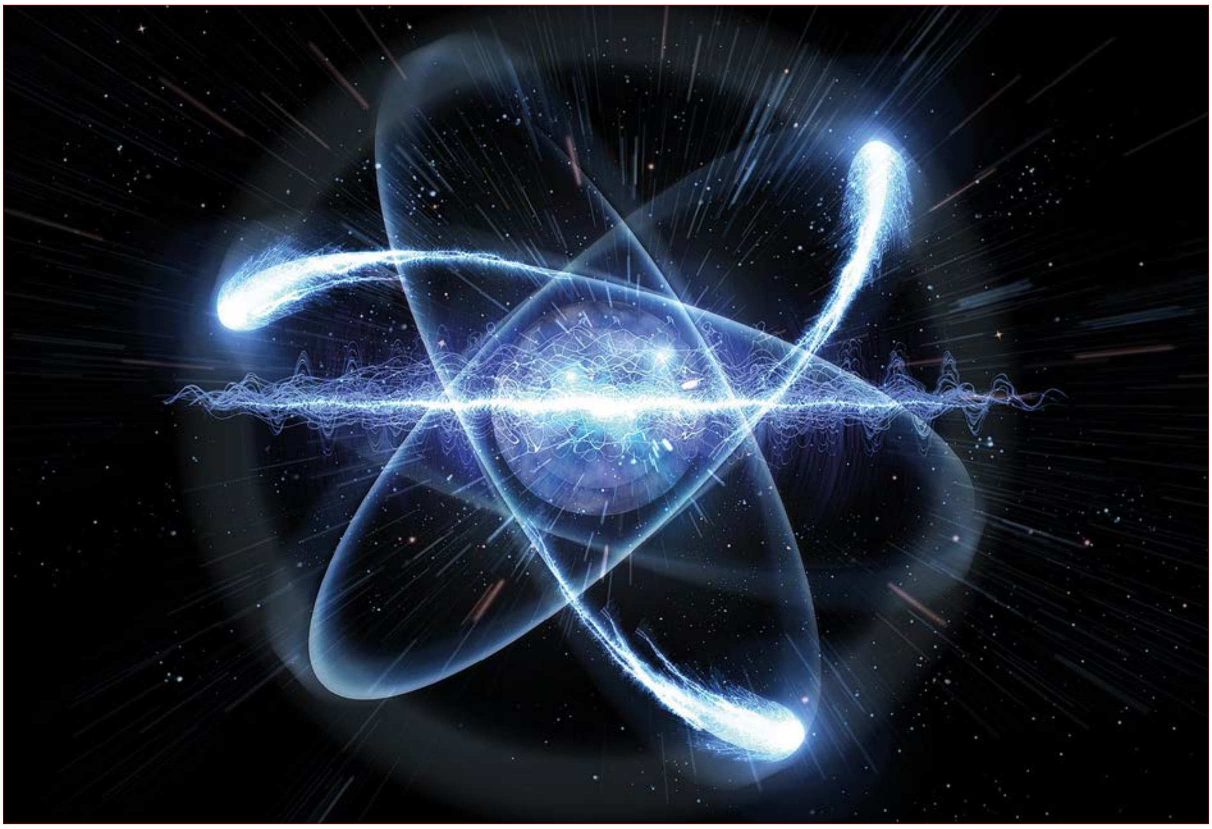

Figure 1: The most striking non-classical properties of quantum systems like single atoms or ions are the basis of radically new technologies. © Ezume Images – stock.adobe.com

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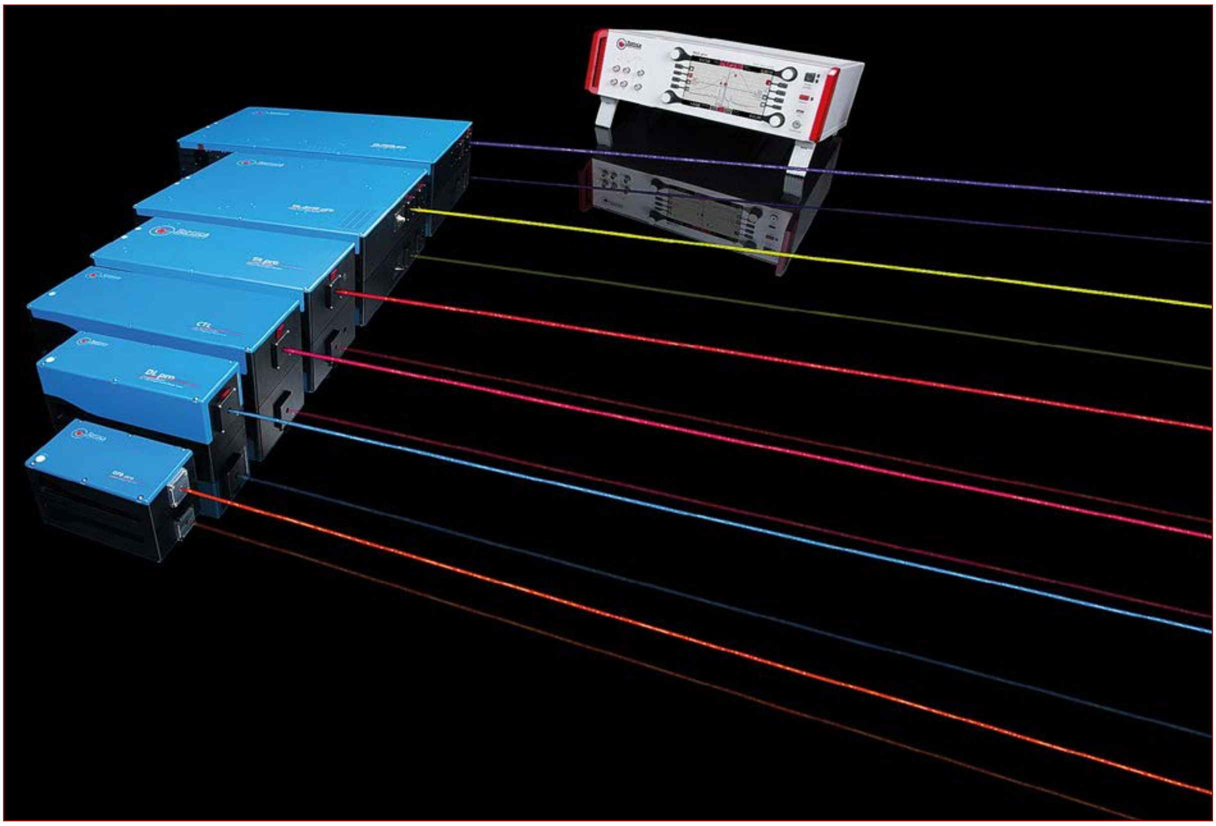

Figure 2: With a large line-up of tunable diode lasers and convenient digital control, TOPTICA Photonics provides a custom solution for basically all quantum technologies requiring lasers.

no means limited to purely optical quantum technologies. Lasers are rather found in the majority of quantum setups. In fact, the laser company TOPTICA Photonics AG, which has its origins in laser cooling and spectroscopy of atomic species, is now the major provider of laser systems for all areas of quantum technologies: quantum communication, quantum computing, quantum simulation and quantum sensing.

Most obviously, light sources are at the heart of quantum networks, because photons are the natural carriers of quantum states over large distances. They enable applications like quantum key distribution and the future interconnection of quantum computers. But laser are also essential components in many quantum computers, quantum sensors and optical clocks. In essence, the incredible control over all degrees of freedom of the light emanating from a laser, often at the quantum limit, is a prime tool to initialize, manipulate and read out other quantum systems. Every property of a laser, i.e. its wavelength, linewidth, power, polarization, temporal and spatial beam profile is an important control parameter in quantum technologies.

The list of quantum systems employed in or proposed for quantum technologies is no less varied than the list of quantum applications. This may seem immature compared to e.g. the one-species-does-it-all approach of silicon-based

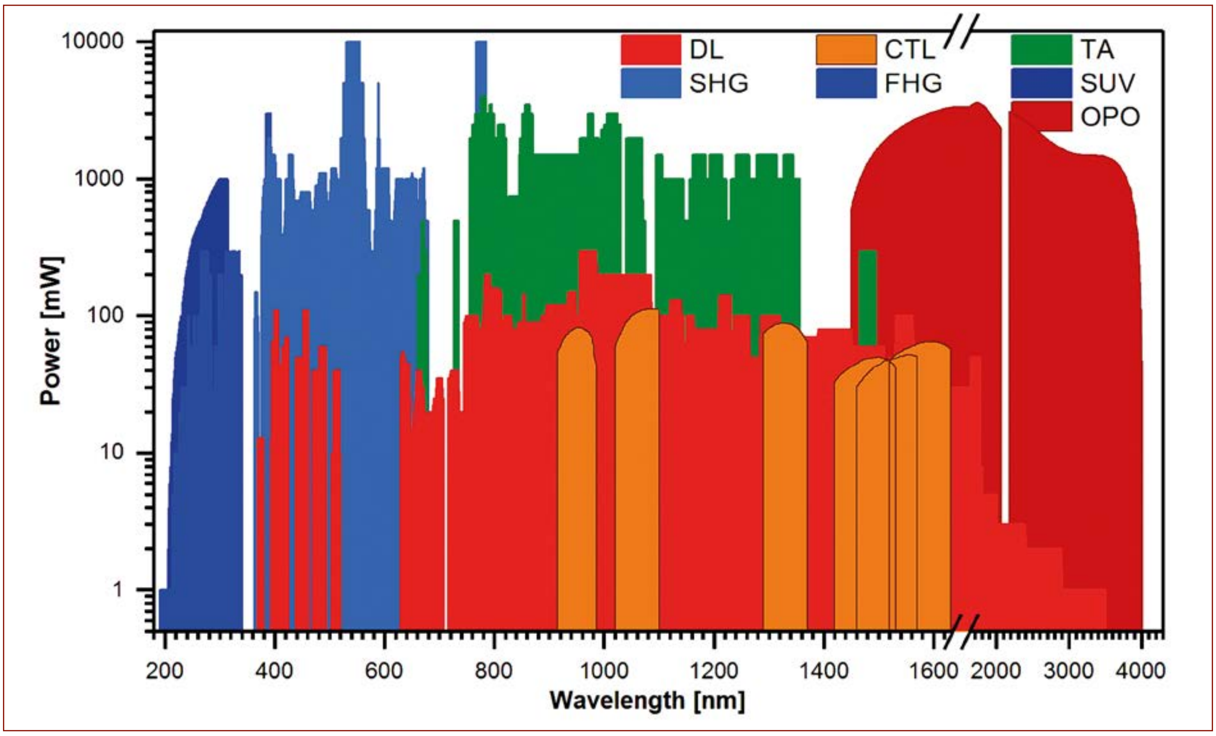

Figure 3: Each quantum system requires lasers with a specific combination of wavelengths and power levels. The broad wavelength coverage from 190 nm to 4 μm provided by TOPTICA's tunable diode lasers combined with reliable and convenient operation therefore enables many spectacular applications of quantum technologies.

classical computer technologies. It reflects, however, the intrinsic interconnections of individual atomic properties like their energy-level structure and the variety of applications. Researchers take advantage of the full diversity provided by nature by employing many different elements of the periodic table, not only in their neutral form, but also as ions, in molecules and embedded in solids. These natural quantum systems are complemented by artificial atoms and other nanostructures like quantum dots. The resonance frequencies of all mentioned systems cover a great part of the electromagnetic spectrum such

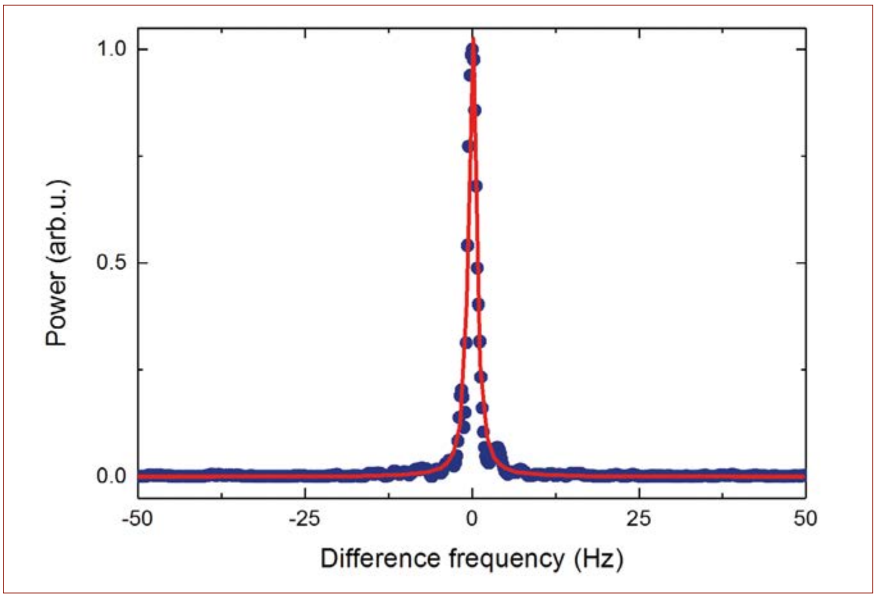

Figure 4: Narrow-linewidth lasers are key for applications like optical clocks. By locking to a high-finesse optical cavity, the linewidth of external cavity diode lasers can be reduced to the 1 Hz level. The graph shows the optical beat signal between two independent, cavity-stabilized TOPTICA diode lasers at 1162 nm.

that lasers at basically all wavelengths are needed (see Figs. 2 and 3).

This colorfulness in its most literal sense is complemented by very well defined transition frequencies in each individual species. This makes atoms and ions with extremely narrow transitions ideal frequency standards. When these transitions are interrogated with lasers in optical clocks, the linewidth of the laser often defines the quality of the clock (see Fig. 4). Frequency combs, like TOPTICA's DFC CORE, are used to compare different optical clocks. At this extreme level of accuracy, control of the environment plays an important role. As an example, light at a so called "magic wavelength" has to be used to trap neutral atoms. Only at this wavelength, the disturbance of the clock transition caused by the optical trap is small enough for the targeted accuracy.

Optical traps are only one example of how laser light is used to manipulate the motion of atoms. It can also be employed to cool atoms as far as to the absolute ground state. This often requires a lot of power while maintaining full control over the spectral properties. High powers are also required when scaling quantum computers based on trapped ions, where each ion carrying a single quantum bit has to be addressed individually. Obviously, these approaches are also very demanding with respect to the pointing and other spatial properties of the employed beams.

The lasers' polarization is another control knob that is used to discriminate even between spectrally degenerate transitions using selection rules. The polarization of a single photon is also a natural degree of freedom for the encoding of a quantum bit in quantum communication. But the timing, frequency or even orbital angular momentum of single photons can likewise be used, each with their specific advantages and disadvantages. Even the phase and amplitude of pulses of light are employed in quantum communication.

Besides the application-determined and physics-driven demand for control of all laser parameters, there are many technological challenges to be met by light sources for quantum technologies. Mode-hop-free tuning, large tuning ranges, reliability, compactness, low power consumption, low cost of ownership and remote control are among the many features that are essential. Diode lasers meet many of these requirements.

The United Nations proclaimed 2015 the International Year of Light, celebrating the importance of light and light-based technologies. Quantum technologies are adding another chapter to the great book of light-based enlightenments. It will be interesting to see how small lasers will remain the giants on whose shoulders future quantum technologies can reliably rest.

Figure 5: Compact and robust laser solutions are crucial for many quantum technologies. TOPTICA combines four field-proven narrow-linewidth tunable diode lasers in one compact 19-inch subrack. Digital laser controllers enable remote control of the laser modules and deep integration with the application's control software, e.g. using a Python software development kit.

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Fabrication and Packaging of Infrared Emitting Devices

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Abstract

Infrared emitting devices are commonly used in several applications and tools. They are used to measure concentrations of different gases via detection of material specific vibrations, which cause absorption of infrared light. Typical measurement systems cannot handle temperatures higher than 85 °C. For medical purposes hermetically packaged infrared devices, which can stand higher temperatures, are inevitable. Here, we describe a fabrication and packaging procedure for infrared emitting devices that is suited for these applications. The influence of the package on the spectrum of infrared emitting devices is shown.

Fabrication and characterization of infrared emitting devices

The infrared emitting devices were made of silicon, silicon-oxide and platinum. Grid structures made of silicon were realized via a combination of an anisotropic and an isotropic etching process. Silicon oxide was used as mask for the etching processes. The anisotropic part of the etching process was increased until a mechanically stable depth of silicon grids was achieved.

To separate the silicon grid-structure from the underlying substrate an isotopic etch process was used. Afterwards a platinum layer was deposited on top of the silicon-oxide, acting as a heat resistor in order to form an infrared emitting heating layer. The electrical contacts were made of AlSi. Several different grid designs were realized and analyzed. Figure 1 shows test-structures after the etching process and one of the infrared emitting devices.

The temperature distribution of the infrared emitting devices was investigated via lock-in thermographic measurements. The grid itself has a significant higher temperature than the surroundings. Figure 1 shows lock-in thermographic images of different grid structures. The yellow parts are the parts with the highest temperature, the blue parts have a comparably low temperature.

Further on, the emitted spectra of unpackaged devices were investigated. The spectra of these devices could be described via a composition of two black-body spectra with different temperatures (data not shown). The difference in temperature suggests one of these black-body spectra to be emitted from the grid-structure and the frame of the infrared emitting device, respectively.

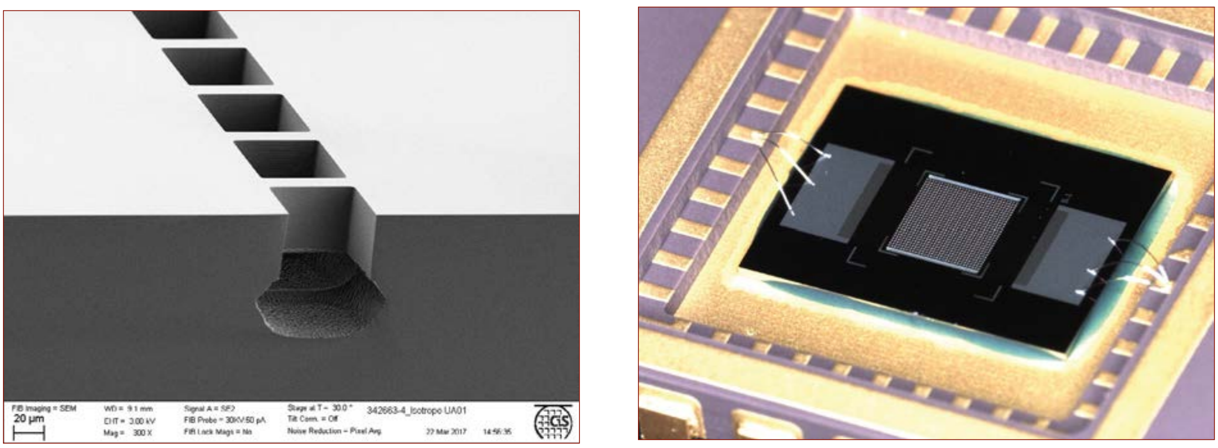

Figure 1: left: REM image of test-structure after the etching process, right: Photographic image of an infrared emitting device.

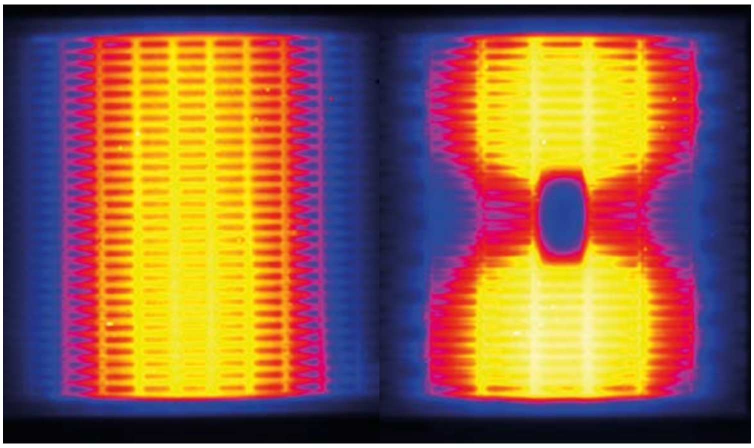

Figure 2: Lock-in thermographic images of different infrared emitting grid structures.

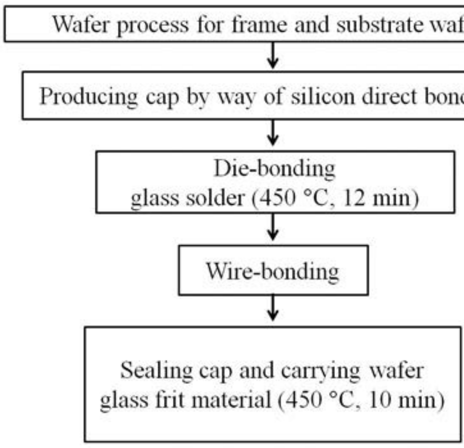

Figure 3: Flowchart of the packaging of infrared emitting devices.

Packaging and characterization of packaged infrared emitting devices

Commercially available devices were hermetically packaged in a silicon structure. This structure uses the cap as an optical window for the emitted light. Packaging of infrared emitters was done according to Figure 3.

Frames were produced via KOH with over-etching. Two frame wafers with a thickness of 400 µm and a cover wafer of 300 µm thickness were direct bonded to create a cap. As material for the cap Si (wafer) with a specific resistivity of 2080-4320 Ωcm was used, because of its high transparency in the infrared spectral region. The internal and the external surfaces of the cap were coated with an antireflective layer system.

Two lines of the glass frit material Ferro FX11-036, for bonding the dies, were dispensed onto a substrate wafer. For the following drying, binder burn out, and glazing process optimized temperature profiles were used. After that, the infrared emitting dies were placed on the glass frit and fired in nitrogen atmosphere at 450 °C. They were contacted with aluminum wire bonds. Afterwards the cap wafer was bonded hermetically on the substrate wafer with glass frit material. Therefore the glass frit paste was screen printed on the cap. After drying, binder burn out and glazing process took place. Afterwards the placing of the caps was realized by pressing them onto the substrate wafer and firing at 450°C.

Further on, the emitted spectra of the packaged devices and the temperatures of the package were investigated. For comparison some of the infrared emitting devices were permeably sealed. The packaged devices show a higher emission than unpackaged devices (data not shown). For the packaged devices the hermetically packaged ones showed a higher emission than the permeably packaged ones.
Investigations of the temperatures of infrared emitting devices in TO-bases in comparison to the silicon package, showed temperatures of 200 °C and 100 °C while using the infrared emitting device with an input power of 1 W and 400 mW, respectively.

Summary

Silicon grid structures could be achieved via combining an anisotropic and isotropic etching process. Packaging of infrared emitting devices can be accomplished with a combination of anodic bonding and glass frit material.

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Blue Wavelength Meets High Power Diode Lasers – Enabling Tool for Copper Processing

Introduction

Over the last decades, Continuous wave (cw) powered laser applications have become established as a versatile tool in modern manufacturing, covering ranges of welding, cladding, surface treatment, hardening, brazing, cutting and many more. The shift from a scientific technology to a common production tool has been pushed by the ongoing research of new laser sources, which have continuously enabled new applications. The major developments in cw laser technology were before the millenium the establishment of CO2-lasers with 10.6 µm wavelength, which however could not be fiber delivered. After the millennium, the fiber laser stated to emerge, as a solution for high brightness lasers which could be fiber delivered and nowadays are substituting CO2-lasers in the majority of applications.

These continuous wave lasers are dominantly working in the range of around 1 µm wavelength. This wavelength is suitable for processing of e.g. steel with over 50 % absorption, but very challenging for materials such as copper and gold, which have an absorption of < 5 % at 1 µm wavelength. In order to still process these high reflective materials, high laser intensity is used for the creation of a vapor channel in the material, which increases the absorption. However, this approach limits copper processing today to a deep penetration process regime, with the inherent risk of sputter occurrence and challenging control of energy deposition.

A wavelength below 500 nm is much more suitable for the processing of copper, since the absorption increases strongly to over 50 %. Some laser sources are already available on the market in this wavelength range, which are based on frequency doubling, resulting in wavelengths of 515 nm and 532 nm of the green spectrum. However, these laser sources rely on a conversion process, in which a crystal is converting only a fraction of the pumped laser wavelength into the target wavelength. The conversion process leads to high power losses, complex cooling requirements and a sophisticated optical set-up.

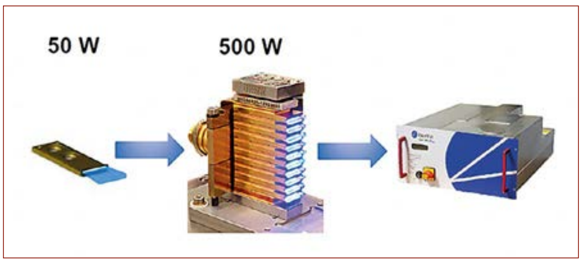
Today, the solution to this technical challenge is addressed with additional urgency due to the close connection to the social challenge of reduction of greenhouse gas. The replacement of combustion engines with electric engines creates a vast demand for reliable processing solutions for copper, which is used in emobility as well as in other renewable energy systems such as wind turbines.

Blue Laser Diode Technology

In order to address this challenge, the company Laserline together with Osram and other partners started the project "BlauLas" [1] in 2016, with the goal to develop the first high power diode laser with a blue wavelength of 450 nm. In contrast to other laser source concepts, the diode laser based on GaN-material enables the direct emission of 450 nm, without further frequency doubling and therefore with higher energy efficiency. With a wavelength of 450 nm, an increase of processing efficiency of the factor 20x is expected for copper material compared to a wavelength around 1 µm.

Based on longterm proven scaling techniques, the company Laserline uses lasers bars by the company Osram to mount, electrically connect and cool the blue laser bars on heat sinks. Each diode bar is actually creating a power level of up to 50 Watts. Using special optics it is possible to combine several mounted diode bars in a stack and even combine two stacks in one laser source.

The success of this approach has been demonstrated



Concept of power scaling with diode bars for the high power blue diode laser ©Laserline

with the presentation of a 700 W high power diode laser, with a 600 µm fiber delivery and a beam quality of approx. 60 mm*mrad [2]. The laser beam delivery to the work piece is achieved with a 600 µm fiber and conventional focusing optic, which is equipped with an adjusted anti reflection coating to the blue wavelength. The actual

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ongoing project has set the goal to develop a blue diode laser with over 1000 W of CW power, opening up new applications also beyond copper processing.

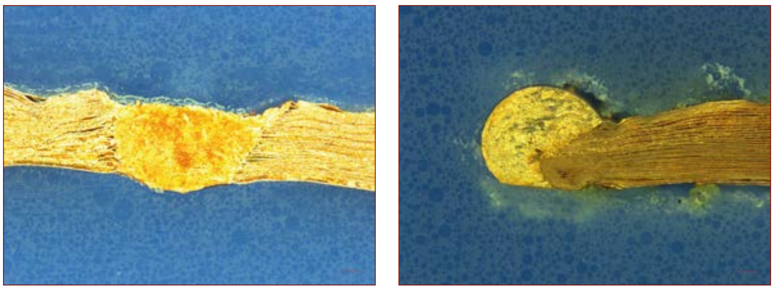
With the application of the wavelength of 450 nm, a melting of copper material in the heat conduction mode is possible for the first time, allowing the precise adjustment of the melt pool geometry also for thin copper materials. The stable energy deposition and heat conduction process regime is especially important for applications, where the high pressure of a keyhole welding mode would lead to a cutting of the material or an undesirable spatter occurrence. This can occur while welding stacked thin copper foils, which may be subject to an uncontrolled gap due to warping of the stacked foils.

While applying a butt welding approach with 580 W laser power and 2 m/min feeding speed on stacked copper foils, a weld bead width of more than 0.8 mm can be created with minimal porosity and low undercut. For a fillet weld approach with an irradiation on the edge of the foil stack, the foil endings are molten into a high cross–section area with a complete attachment to the solid foils. In both butt and edge welding the process results in a perfect mechanical joint as well as in a very good electrical conductivity.

With an outlook to more than 1 kW in general and a potential achieve a power increase together with a improvement of the beam quality, Laserline GmbH is convinced that diode lasers are going to be the leading photonic tools in medium to high power material processing already in the near future.

Welding of a copper sheet with 450 nm wavelength ©Laserline

[1] https://www.effilas.de/de/verbuende/blaulas.html
[2] Balck, A. et al., 700 W blue fiber-coupled diode-laser emitting at 450 nm, Proc. SPIE 10514, High-Power Diode Laser Technology XVI, 1051403 (19 February 2018)



Welding of 34 stacked copper foils (each 11 µm) in butt welding (left) and edge welding configuration (right) ©Laserline

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Environmentally Friendly Alternative to Hard Chrome Plating and Thermal Spraying

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Extreme High-Speed Laser Material Deposition EHLA

Today, large components are mostly protected against wear and corrosion by thin, metallic coatings comprising 10 to 250 µm thick layers, mostly applied with hard chrome plating or thermal spraying processes. However, these coating processes' major environmental and technological shortcomings limit their application range. Not only does hard chrome plating consume a great deal of energy, but the used chromium (VI) is also highly damaging to the environment.

As of September 2017, it may therefore only be used upon authorization/approval. This ban presents the industry with enormous challenges. Thermal spraying is facing increasing criticism for the high sound pressure levels generated by some processes and the low powder utilization rates. In addition, hard chrome and thermal spray coatings do not metallurgically bond to the component and can easily flake off. Coating defects require costly and time-consuming repairs. In view of these ecological and economic concerns, there is a great demand from many service providers and end users for alternative coating methods that are automatable, economical and deliver high-quality layers.

Fig. 1: Coating of car brake discs with Extreme High-Speed Laser Material Deposition EHLA. © Fraunhofer ILT, Aachen / Volker Lannert.

Researchers from the Fraunhofer Institute for Laser Technology ILT in Aachen and the Chair of Digital Additive Production (DAP) at RWTH Aachen University developed Extreme High-Speed Laser Material Deposition, known by its German acronym EHLA: a new, highly productive variant of laser material deposition (LMD). As the first of its kind, EHLA addresses both ecological and economical challenges. In many applications, it can be a viable substitute for hard chrome plating and thermal spraying. Fraunhofer ILT and DAP developed the basis for EHLA and established the process in industrial manufacturing in a joint interdisciplinary effort with machine manufacturers and end users.

Coating at up to 500 m/min

In conventional LMD, a laser beam melts the surface of a component creating a melt pool. At the same time a metallic powder is guided into the melt pool. The innovation of EHLA: the powder particles are already melted above, rather than in the melt pool by the targeted interaction of the laser beam and the powder particles. With no time devoted to melting the powder particles in the melt pool, the layer forms much faster, thus greatly increasing the process speed by orders of magnitude from previous levels of between 0.5 and 2 meters per minute to as much as 500 meters per minute. EHLA can also reduce layer thickness: whereas the minimum thickness of layers used to be 500 micrometers, layers as thin as 25 - 250 micrometers can now be achieved cost-effectively. Moreover, the layers are smoother, with roughness reduced to a tenth of typical values for LMD.

Successful transfer to industry

In recent years several companies joined forces in public-private partnerships to establish this technology in industrial manufacturing in a very short time. Manufacturers of powders, laser

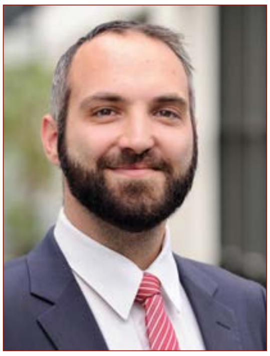
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Fig. 1: EHLA: protection against wear and corrosion, repair and additive manufacturing – all with only one system technology. © Fraunhofer ILT, Aachen, Germany

sources and machine tools, integrators and user groups have created an extensive network of cooperating partners making EHLA available to various markets, i.e. for offshore or mining applications. For example ACunity GmbH, a spin-off from ILT, closely cooperated with the Dutch machine integration company Hornet Laser Cladding B.V. to deliver three large EHLA systems to the Chinese high-tech company Hebei Jingye Additive Manufacturing Technology Co., Ltd.

Triple award-winning process

EHLA's innovative strength stands out and the process has already received several awards: the Joseph von Fraunhofer Prize 2017, the Steel Innovation Award 2018 and the renowned Berthold Leibinger Innovationspreis 2018.

A glimpse into the future

Due to the large deposition rates and the coating qualities achieved, EHLA is becoming increasingly interesting for applications in mass markets. The currently most prominent and promising application is the coating of car brake discs, which is currently being developed in cooperation with German suppliers, OEMs and machine builders. In addition to coating, EHLA also has great potential in the rapidly growing additive manufacturing market, particularly for the modification of the geometry of large components. While coating is a traditional market with enormous revenue, Additive Manufacturing (AM) is thought to have the potential to transform production technology. In combination with Industrie 4.0, AM enables companies to print customized industrial products based directly on digital data in a highly flexible and sustainable way. For this purpose, a prototype machine is currently being built in Aachen, where the workpiece is moved in a highly dynamic manner with up to five times the gravitational acceleration under the EHLA powder nozzle.

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The Importance of Photonics in Additive Manufacturing

Innovation in metal 3D Printing is driven by Photonics

Metal additive manufacturing has become a technique of industrial interest two decades ago, when uniform metal powders were first consolidated into three-dimensional shape (Meiners, 1999). The laser metal fusion (LMF) process of successively melting layers of metal powder into solid metal parts has become the most successful and commonly used technique in a wide range of industrial applications.

At that time, the availability of high power and high brightness laser sources was limited. CO_2 and lamp pumped rod lasers were most commonly used for industrial applications. Although these lasers could deliver kW power levels, brightness and cost put limits to the application in LMF. Hence it was the development of laser devices with continually increasing power and brightness which promoted the technical advancement of metal 3D printing by LMF.

Meanwhile, the development of solid state lasers such as fibre and disk lasers resulted in laser products reaching power levels well in the kW range in conjunction with highest beam quality. Such lasers are bright enough to focus into 30-100 µm sized spots over large working distance optical scanning systems, which makes them ideally suited for LMF 3D printers. Today's systems typically work at laser power levels between 100 W and 1 kW. They produce high quality parts in almost arbitrary shape. The printers provide the manufacturing equipment for applications in a growing range of industrial sectors such as aerospace, energy, tooling and medical industry.

TRUMPF is a world leading manufacturer of high-power industrial lasers, and with the TruDisk, TruFiber and TruDiode, its laser products cover the complete range of laser technology for metal 3D printing.

Multi-laser 3D printers for increased productivity

An increase in processing speed and a reduction of parts cost open up a wider application range in metal 3D printing. Until 2016, conventional 3D printers utilized a single processing laser beam through a scanning system. Today's systems such as the 3D printer TruPrint 5000 by TRUMPF use three laser beams in parallel to achieve build rates almost three times higher.

Because of fully overlapping scan fields, each laser beam can operate at any point in the build volume. The TruPrint 5000 offers highest versatility and productivity irrespective of the many different geometries and sizes of additively manufactured parts.

Such multi-laser systems require sophisticated mechanisms for field calibration and beam positioning. For this purpose, TRUMPF utilizes calibration signals from in-line detectors to achieve exact alignment of the individual beams

Fig. 1: A copper inductor printed by Laser Metal Fusion with a TruDisk 1020 and a TruPrint 1000, both by TRUMPF (Source: TRUMPF)

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over the entire build area with respect to the individual parts' coordinates. As a result, the laser spots always operate at precisely the right location at any time.

Fig. 2: TruPrint 5000: Industrial metal 3D printing using three laser beams (Source: TRUMPF)

Green Disk Laser enables 3D printing of pure copper

Pure copper is a material of interest for its high thermal and electrical conductivity. It finds its applications in induction heating, electronics and cooling. High reflectivity in the infrared makes it difficult to process the material with lasers operating at 1 µm wavelength. While copper alloys with poorer thermo-electrical characteristics can be processed at acceptable speed, pure copper so far could be processed only to yield porosity levels above 1 percent (Colopi, 2018). Such porosity is not acceptable for the demanding technical applications where highest thermal and electrical conductivity are needed in conjunction with very good mechanical and surface properties.

With the TruDisk 1020, TRUMPF is offering a 1 kW continuous wave, fibre delivered frequency-doubled industrial disk laser. This laser is an ideally suited source for the processing of reflective materials (Pricking, 2016). It has been demonstrated in laser welding applications that higher absorption of copper at 515 nm leads to a much more efficient and stable welding process.

In LMF, TRUMPF could demonstrate pure copper part manufacturing with low porosity and high thermal and electrical conductivity close to the value of bulk material at unparalleled build rates.

Within the coming years, future products of the TruPrint series will be utilizing this green laser source for industrial scale manufacturing of high quality parts in pure copper for demanding applications. Such systems will also have benefits in other reflective materials, such as precious metals, with respect to build rate, part quality and process stability.

Conclusion

In summary, out of TRUMPF's competences in the field of photonic technologies, the company introduced a number of photonic innovations into industrial metal 3D printing to increase build rate, to ensure process stability and parts quality, and to extend the range of printed materials.

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Additive Manufacturing: Laser Powder Bed Fusion with VCSEL Heating

In cooperation with the Chair for Technology of Optical Systems TOS of RWTH Aachen University, the Fraunhofer Institute for Laser Technology ILT has developed a new process in which the workpiece in the powder bed is heated with innovative laser diode arrays, the so-called VCSELs. As a result, distortion can be reduced, taller parts generated and new materials used.

Located in Aachen, the Fraunhofer Institute for Laser Technology ILT has gained a lot of expertise in the field of additive manufacturing processes. More than 100 scientists work on a wide variety of AM topics, from increasing efficiency to developing system concepts and processes or even qualifying new materials.

Heating with kW power from above

The team of Fraunhofer ILT and their colleagues from the RWTH TOS Chair utilize a new preheating system for the additive manufacturing process Laser Powder Bed Fusion (LPBF), also known as Selective Laser Melting SLM. With this new system parts can be built with less thermally induced stress and less distortion compared to conventional process technology.

In the LPBF process thin layers of metal powder are melted selectively by a laser to generate a three dimensional component. The combination of locally limited energy input and layer-wise machining enables the generation of fine structures and virtually unlimited geometrical freedom. Internal stresses are caused by temperature gradients in the generated component: In the laser spot, temperatures above the melting point prevail, while the rest of the component cools rapidly. Depending on the geometry and material, this temperature gradient can even lead to cracks in the material. To avoid this, the workpiece is usually heated from below via the substrate plate. However, measurements with an infrared camera reveal a decreasing temperature of the layer currently being processed with increasing build height especially with smaller and taller structures.

An adjustment of the substrate plate temperature may result in the required preheating temperature, but is subject to two major disadvantages: On the one hand, the preheating temperature must not exceed the melting temperature of the material to be heated, so that ultimately the overall height is limited. On the other hand, there is a (partly) undesirable in situ heat treatment.

As part of the Digital Photonic Production DPP research campus, a funding initiative of the German Federal Ministry of Education and Research (BMBF), the experts from Fraunhofer ILT and RWTH TOS Chair are working together with their partner Philips Photonics to develop solutions for this task. In the joint project DPP Nano, they have developed a set-up in which the component is heated from above.

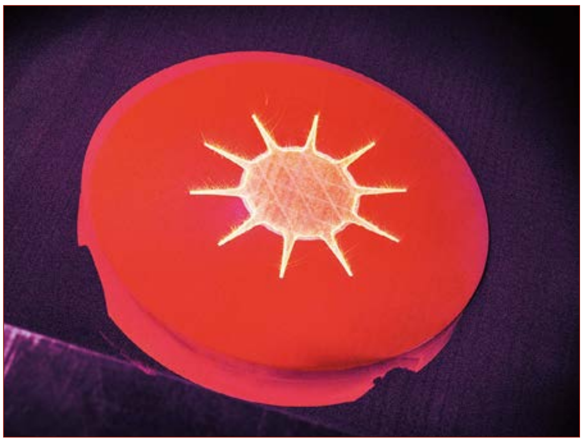

Fig. 1: With up to 2.5 kW, the working plane is preheated independently of the overall height.
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Fig. 2: Exposure with simultaneous VCSEL preheating.
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Dr. Jochen Stollenwerk

For this purpose, an array of six vertical-cavity surface-emitting laser bars (VCSEL) with 400 W each is installed in the process chamber. With infrared radiation at 808 nm, this array heats the workpiece from the top to several hundred degrees Celsius during the building process. The bars can be controlled individually so that sequences of different patterns are possible. The process is monitored with an infrared camera to ensure a homogeneous temperature in the layer currently being processed.

In the course of a number of investigations, the Aachen engineers have constructed parts made of Inconel® 718 and $TiAl6V_4$ and demonstrated significantly reduced distortion. The components were both heated up to 500 °C.

The preheating with VCSEL reduces the thermal gradients and thus also the stresses, allowing taller components to be manufactured. But even more interesting are the possibilities that arise for materials that are difficult to be processed. Soon, components made of high-temperature titanium aluminides or nickel-based super alloys are to be produced. For this, the workpiece will be heated to over 900 °C.

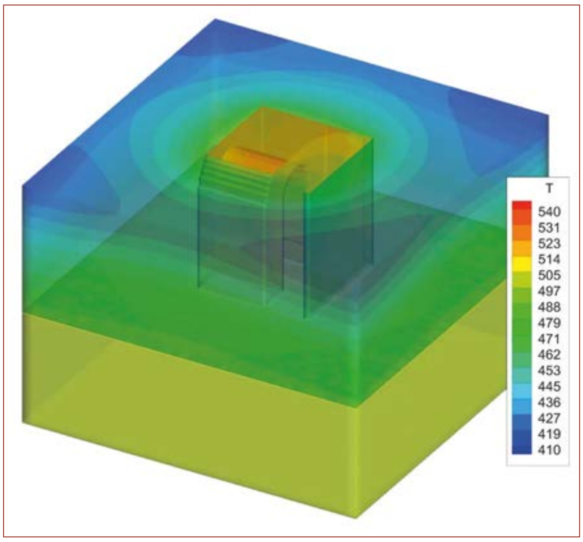

Fig.4: Simulation of the temperature distribution in a preheated LPBF process. © Fraunhofer ILT, Aachen, Germany.

Such parts are commonly used, for example, in the hot gas section of turbochargers or turbines. In addition to turbomachinery, the process also opens up new prospects for other industrial sectors where thermally induced stresses in additive manufacturing processes have to be reduced.

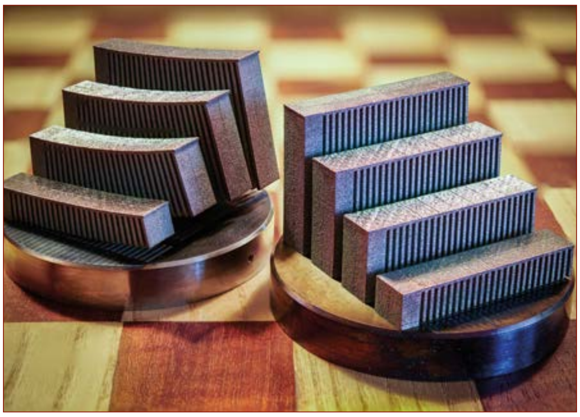

Fig.3: The component preheated with VCSEL (right) has significantly less distortion than the component not preheated during the exposure process. © Fraunhofer ILT, Aachen, Germany / Volker Lannert.

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Wafer-based Mass Production of High-precision Glass Optics for Diode Laser Applications

Micro-optics for the markets of tomorrow

For many years, laser systems and photonics have served as a key technology and driver of innovation in a large number of industries and markets. The beam shaping required by this technology – essentially the art of controlling and shaping laser light – has caused the market for optics to soar to its current volume of half a trillion dollars. Laser illumination in particular, which was previously limited to sophisticated applications such as optical lithography or to small niche markets such as measurement technology, has made inroads into the high-volume automotive industry and consumer electronics markets, where it is vigorously expanding into new dimensions.

The series production of optical components for consumer applications began with diode lasers for CD/DVD and Blu-ray players. Now, micro-optics are needed in over one billion smartphones every year for facial recognition and gesture controls, for example. The next big increase in the demand for micro-optics is set to come from their use in innovative technologies like additive manufacturing (3D printing). The same is also true for the automotive industry, where beam shaping is now used for more than just headlights. Modern head-up displays, LIDAR systems and 3D sensors are improving driver visibility and safety while unlocking new possibilities for tomorrow's autonomous vehicles, meaning that these technologies will also serve as important high-volume micro-optics markets in the future.

These high-precision, and in many cases safety-related, applications are accompanied by rigorous demands for the stability and performance of the micro-optics they use. Due to cost considerations, optics made of polymers had previously been the first choice for imaging applications, despite the fact that micro-optics made from glass have proven to deliver better optical properties and greater long-term stability. Specifically, the known degradation mechanism of haze, caused by the absorption of ultraviolet light, leads to transmission decline and can reduce the functionality of polymer-based optics in harsh ambient atmospheres, such as those found in the automotive industry. Gloss and birefringence also inhibit precise optical control in industrial and consumer applications, which in turn has a negative impact on the design and production options for the optical assemblies: As is the case with naturally illuminated objects in photography, degradation of the laser illumination reduces the resolution and functionality of the devices.

Production technology for large quantities

Therefore, in order to make the use of glass – a high-quality optical material that was previously the more costly option – feasible for high-volume, cost-driven consumer applications (with demand ranging from 10 to 100 million pieces), LIMO has developed a production technology for cylindrical lenses that allows high-precision polished micro-optics to be manufactured from glass, at the cost of polymer.
LIMO produces the lenses on wafers, which allows several

Figure 1: Wafer with micro-optics made from glass

thousand lenses to be fabricated from high-grade glass in a single step. When mass-producing complex glass optics, manufacturers face the challenge of processing large wafer areas with a consistently high level of precision. In the glass molding process that has typically been used up to now, glass lenses are processed at high temperatures. However, in order to produce lenses of high optical quality, the glass must be heated and cooled slowly. Considerable precision must be used in adjusting the cooling process, in order to prevent changes to the refractive index of the materials.

Thanks to a "cold" working process at room temperature, combined with higher grinding and polishing rates, LIMO has now successfully increased the wafer size

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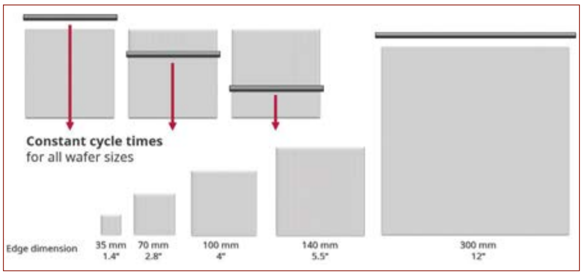

Figure 2: Simultaneous processing of glass substrates with cylindrical optical elements

for the micro-optics without any decrease in quality, while simultaneously reducing the cycle time per wafer.

In five steps, it was possible to increase the original 35 mm (1.4") edge length of a polished glass wafer, which can be structured in a simultaneous grinding process, to up to 300 mm (12"). Since the wafer area scales quadratically with the edge length, with only a negligible increase in processing time, LIMO was able to lower the production costs per mm² with each wafer generation. The newest generation of 300 mm x 300 mm (12" x 12") lens arrays has an effective processed wafer area of 90,000 mm². If the latest stealth dicing techniques are used, more than one million high-grade 1-mm² micro-optics can be produced on just twelve wafers.

What's more: Because nearly all of the tools and machines used for the production process are made in-house by LIMO, the company also enjoys maximum flexibility when it comes to the geometries and design of the lenses. Both sides of a wafer can be structured in any desired shape. This enables a wide range of possible combinations, from fast-axis and slow-axis collimators (FACs/SACs) for single emitter diodes or LIDAR applications and homogenizers for lithography to beam transformation systems (BTS).

The processing time for the wafers is virtually independent of the material selected. This means that LIMO has the ability to process not only special glass types with a high index, but also other optical materials such as silicon, germanium, fused silica or calcium fluoride – with the same level of productivity.

Glass is the better plastic

Although glass optics offer better thermal stability, higher optical quality and greater durability than optics made from polymers, plastic optics were, for cost-related reasons, the preferred choice of the past for applications involving large quantities. Thanks to its high processing speed for fabrication, the production technology from LIMO now combines the performance benefits of ground and polished glass optics with the cost advantage of plastic lenses. This technology puts an entirely new cost structure within reach for applications with extremely high volumes, while redefining the use of cylindrical glass lenses in consumer and mass applications.

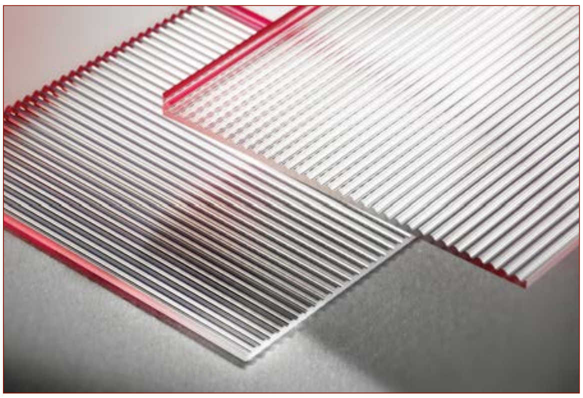

Figure 3: LIMO has succeeded in making the process for manufacturing laser optics that provide the demanded quality suitable for high-volume production

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Optical MEMS-Scanner: Design, General Drives and Applications

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Introduction

Micromechanically produced elements for beam deflection (micro mirrors, scanners) currently have a multitude of applications: image and film projection in the consumer sector, augmented or virtual reality (AR/VR), data transmission (telecommunications), gesture and object recognition, autonomous driving (LIDAR) or the machining of surfaces and the cutting of materials in the field of high-power lasers are just a few of them. Each of these applications requires proprietary mirror designs with special designs, geometries (Bild Lidar Scanner Deckel) and drive principles, as well as an adapted electronic, optical and software-based system environment. Small size, low energy consumption, large optical scan angles up to 180 ° and very good black values, which are often lacking in other displays, characterize this type of image and pattern projection.

LIDAR camera systems for spatial environmental monitoring

Precise detection of distances to objects for near-field 3D imaging is a prerequisite for modern industrial applications such as robotics or gesture recognition. Thereby, the accurate analysis of the movement of persons, machines or the recognition of gestures in real time is crucial for a versatile human machine interface tools or as a means of coordination in robotics.

The prototype presented here is a short-range LIDAR system in which a 2D micro mirror with a diameter of about 1 mm is resonant, or based on Lissajous projection. The slow axis of the 2D MEMS scanner with a frequency of 525 Hz is horizontal and covers a total optical scanning angle of 40°, while the fast vertical axis with a frequency of 16.4kHz also covers a scanning angle of 40°. At a distance of 2 m, the MEMS scanner thus enables the illumination of a plane of approx. 1.5 x 1.5 m^2.

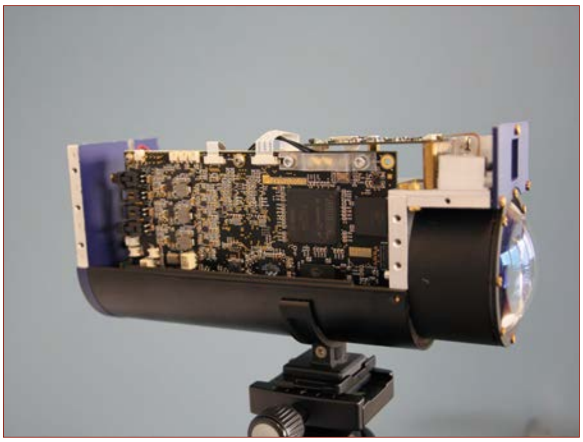
The light source is a laser modulated at a frequency of 60 MHz (sampling rate). The digitally modulated laser beam is directed through a deflection mirror at an angle of 22.5 ° to the 2D MEMS scanner. The mirror is vacuum-shredded at wafer level with a sloping glass lid. The vacuum is used to reduce the air attenuation and thus to generate larger scan amplitudes, the sloping cover deflects the parasitic light reflection from the image field.

The range of coverage in this case is 0.1 - 8 m with a relative accuracy of 5 - 10 mm. The range can be varied or increased for other applications. Detection takes place in real time with the aid of an avalanche photodiode (single pixel). The xy resolution is 450 pixels x 450 pixels, the refresh rate 6 fps, the sampling rate 60 MHz. The interface currently used is UDP Ethernet.

Based on the 2D MEMS scanners of the Fraunhofer ISIT, a high-resolution prototype of a 3D camera is thus available, which uses the phase difference between modulated laser light and its reflected echo as a reference for distance measurement. Thus, both representations of the light amplitudes and the phase differences are possible [1].

New technologies: Piezoelectric and electromagnetic drives

Through innovative manufacturing technologies, the ISIT has developed MEMS scanners with piezoelectric and electromagnetic drives. In the piezoelectric actuator, flat springs are provided as parts of the mirror suspension with a piezoelectric layer consisting of PZT, AlN or AlScN. By applying a pulsed voltage with amplitudes in the range of 15 V-20 V a contraction in the piezo-material is caused. This leads to



3D camera with FPGA-based electronics.

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Scanning mirrors with different aperture diameters ranging from 0,5 mm - 20 mm with WLP optical glass windows.

a bending of the spring and thus via the mirror suspension to a periodic tilting of the mirror. Piezoelectric ceramics are usually quite brittle and have low fracture strength. In order to obtain a robust, reliable drive design with adequate service life, stress distribution in the suspensions was optimized using FEM and calculations. A manufacturing process patented by ISIT results in biaxial scanners with high torque and low power consumption with optional quasi-static or resonant control with frequencies above 1 kHz to about 45 kHz and optical scanning angles above 100° [2].

Optical Wafer level package with tilted glass windows for shifting the parasitic reflex out of the projection plane.

In the electromagnetic drive, ferromagnetic structures consisting of an ALD agglomerated NeFeB powder are introduced into the frame suspension by an ISIT patented process [3]. If electric pulses are now applied to electromagnetic coils below the frame, it is set in tilting mode along its torsion suspension. If this oscillation frequency is within the range of the resonance of the mirror in the frame, then the circular mirror likewise performs tilting oscillations. The oscillation amplitude of the frame is several orders of magnitude below that of the mirror. Even larger, compact mirrors with diameters in the cm range can be controlled in this way.

Like the electrostatic elements, these mirror modules can be provided with optical and anti-reflective vacuum capping with tilted windows (Bils WLP oblique cover). The mirrors themselves are coated with dichroic filters in applications with high laser powers > 300 W.

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Investigating Ceramic Coatings with Terahertz Radiation

Dr.-Ing. Ole Peters
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Terahertz technology

Terahertz time-domain spectroscopy (THz-TDS) is a newcomer to the field of nondestructive testing (NDT). THz radiation can penetrate a variety of non-metal materials, including ceramics, semiconductors, fiber composites and polymer foams and offers the solution to NDT problems unthought of before. Because the THz signal gives time-resolved information, it can be used to measure layer thicknesses and to detect defects between layers or between a coating layers and a substrate. THz-TDS is a contactless method, and allows for simultaneous measurement of the coating thickness and spectrum. With a scanning device, depth-resolved imaging of specimens is possible.

The schematic drawing (Fig. 1) shows the measurement principle of the THz-TDS system for layer thickness measurement. The THz incident pulses are reflected on the interfaces due to changes of layer refractive indices. The polarity of the THz reflection pulses can vary depending on the sign of the reflectivity. The THz signals behave very similar to ultrasonic pulse echo signals and give time resolved information. The time required for the THz pulse to propagate through the coating and to be reflected back to the receiver gives information about the thickness of those layers.

Menlo Systems

Menlo Systems, a company based in Germany, is an early pioneer in the field of THz-TDS. Their systems use laser-driven photoconductive antennas (PCAs) to emit and detect terahertz radiation. The femtosecond lasers are equipped with Menlo's proprietary figure 9® technology for ultra-stable and reliable laser mode-locking, an attribute that is a crucial requirement for harsh environments like those usually encountered within industrial production sites. The telecom wavelength employed also enables compact, flexible and stable delivery of the optical pulses via optical fiber to the various parts of the spectrometer, ensuring eye-safe operation.

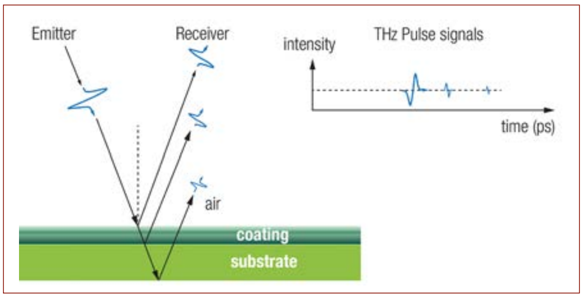

Fig. 1: Schematic of the THz pulse-echo method illustrating their reflectivity at interfaces. The reflectivity depends on the refractive indices of the layers.

Application example: ceramic coatings

Menlo Systems and Prof. Wu Datong from the Munich University of Applied Sciences recently demonstrated the capability of THz-TDS for ceramic coatings of gas turbine blades. The turbines are continually improved for higher efficiency, which can be reached by raising the temperature of the gas, increasing the wear of the turbine parts. Since this results in lower component life, to withstand the high temperatures the turbine blades are coated with a thermal barrier coating (TBC). This acts as a thermal shield keeping a lower temperature at the base material and is a barrier to oxidation of the base material. The thickness of the TBC ranges from 100 µm to millimeters, and is strongly dependent on the coating process, which is hard to control. Thus, it is important to measure the coating thickness, the porosity and the thermal conductivity to know the properties of a turbine blade including its lifetime.

For this demonstration, a nickel-based super alloy sample coated with a layered TBC, Inconel 738 (IN 738), was examined (for a picture see the top of Fig. 2). The sample was provided by Siemens AG. There is a metallic bond coating of 100 and 230 µm, covered by yttria-stabilized zirconia, which was added on top by electron beam physical vapor deposition. The thickness of each added layer is given for part. The temporal THz signals in Fig. 3 show the surface and interface reflections at step 1 and step 4. The difference between the first peak (reference), and the

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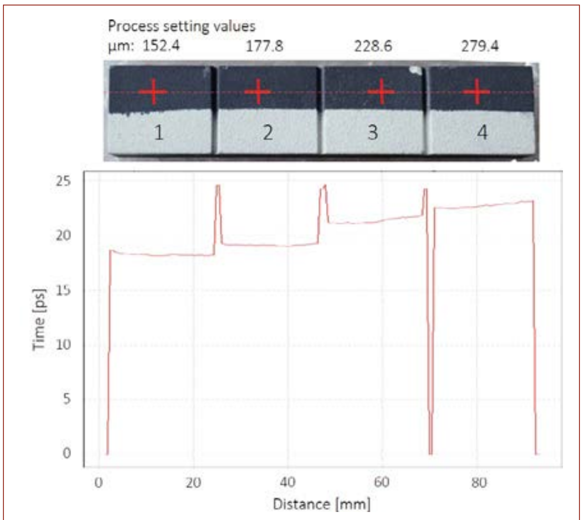

Fig. 2 Top: Photo of zirconia coated IN 738 sample (89 mm x 19 mm x 9 mm). Upper half is additionally sprayed with graphite. Bottom: time delay profile over the indicated dashed line of the top picture

echo peak provide information to extract the thickness. In Fig. 2 below the photograph, the time delay between the first and the second reflection is plotted. For plasma sprayed ceramic coatings the refractive index of ranges from 4.5 to 5. With these values, the thicknesses are estimated to be 152.1 - 169.0 µm, 181.2 – 201.3 µm,

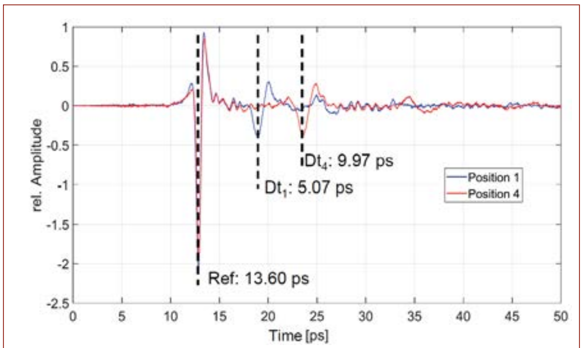

Fig. 3. Temporal THz signal (left) and the corresponding spectrum of the zirconia coating on IN 738 (right).

Fig. 4: Menlo System's TeraSmart, a compact THz-TDS

258.3 – 287.0 µm and 299.1 – 332.3 µm for step 1, 2, 3 and 4, respectively. When doing an exact calibration of the refractive index with a known sample, the accuracy would be strongly increased.

Creating solutions

Realizing automated test systems requires the necessary components to be industry-ready, especially the terahertz generation and detection unit. Menlo Systems recently made a major step in this direction, by releasing the new product TeraSmart, a compact all optical fiber-based THz-TDS (see Fig. 4). The product integrates the latest achievements in THz-TDS into an easy-to-use turnkey solution. The design is modular with industry-proven components, based on our OEM laser platform ELMO and enabling a flexible configuration of the system. This way, the TeraSmart meets the needs for integration into industrial measurement systems.

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Optical Transceivers for 5G Mobile X-haul Applications

Data traffic in mobile and fixed access networks is constantly increasing. With the transition from the legacy 2G and 3G to LTE, LTE-Advanced, and later towards 5G services, mobile data rates have grown from 200kbps to several Gbit/s, and even 10Gbit/s facilitated by emerging radio access technologies such as massive MIMO (multiple input multiple output). At the same time the number of devices as well as the number of antennas and base stations is growing rapidly. These developments impose stringent requirements on the optical network connecting the cell sites, especially in dense urban areas, where fiber links are also at a premium for most operators. The current trend goes towards separating the baseband unit (BBU) from the antenna itself. The signal processing for multiple antennas (or remote radio heads - RRHs) is performed in the former, while the radio frequency processing takes place in the latter. This leads to two sections in the network, where the optical interconnection is essential: the backhaul and the fronthaul network. Nowadays, in the mobile backhaul section, Ethernet protocol data are mostly transmitted between the mobile core network and the BBUs, with current data rates around 1Gbit/s. Over the mobile fronthaul section, the BBU is connected to the radio heads mostly using the Common Public Radio Interface (CPRI) protocol that has stricter timing requirements than the standard Ethernet. For 5G networks, different functional splits of the processing in the BBU and the radio heads are being discussed. For instance, the new eCPRI specification has been recently released, which enables the use of Ethernet transport with data compression and other enhancements needed to meet the increased requirements of 5G. However, the data rates between the BBU and the radio heads are still required to be two to three times higher when moving from 4G to 5G technology. To scale the mobile network, sufficiently cost-effective optical front- and backhaul technology needs to be considered.

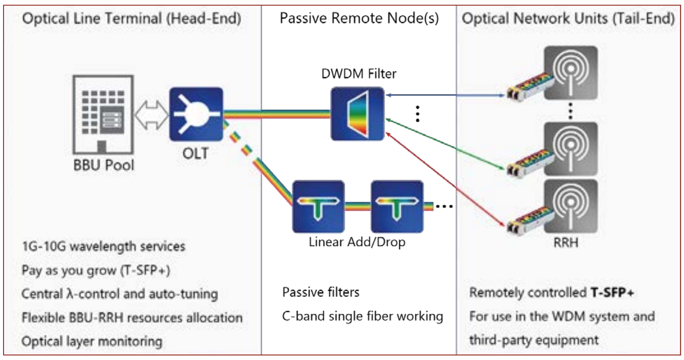


Figure 1: Mobile fronthaul enabled by passive WDM technology

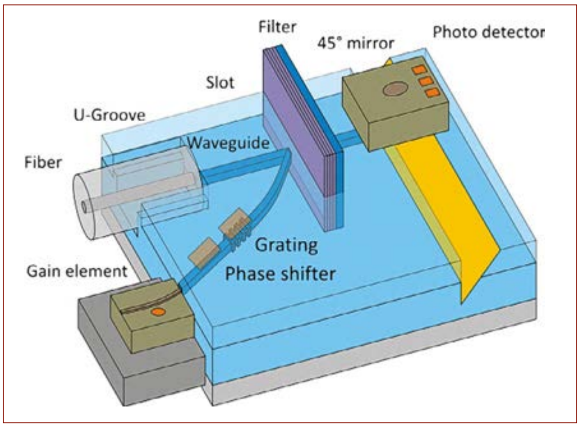
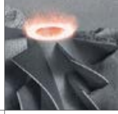


Figure 2: Illustration of Technology Platform PolyPhotonics Berlin

To meet the aforementioned requirements, we are developing a passive metro wavelength division multiplexing (WDM) technology in the BMBF project PolyPhotonics [1]. This technology allows to flexibly provision the optical fronthaul link between the RRH at the antenna tower and the BBU at the central office (CO), as illustrated in Fig. 1. By multiplexing both upstream and downstream signals independently on different wavelength grids, only a single trunk fiber is needed for deployment in the field, which can significantly save the fiber resource in the dense urban area. Moreover, tunable wavelength-agnostic tail-end transceivers (in a SFP+ form factor) facilitate an auto-configuration of the optical layer and substantially reduce inventory sparing and operational efforts. A centralized wavelength locker is applied in the head end, which is able to set and control the tail-end wavelength autonomously according to the connected port at the remote node. Such an implementation will



Jim Zou
ADVA

Mirko Lawin
ADVA

also reduce the cost and complexity of the tunable tail-end transceiver, as a dedicated wavelength locker is no longer needed.

Leveraging the PolyPhotonics Technology Platform which provides a toolbox of hybrid-optical building blocks, the project has designed and fabricated a low-cost tunable optical transceiver chip made of polymer. This chip features passive elements such as the mirror, thin film filter, and micro-optics, as well as active elements such as photodiodes and the laser gain element. The latter components are connected to the waveguide chip, as illustrated in Fig. 2. ADVA is further developing the SFP+ module using such a polymer-based photonic chip and implementing an out-of-band communication channel between the

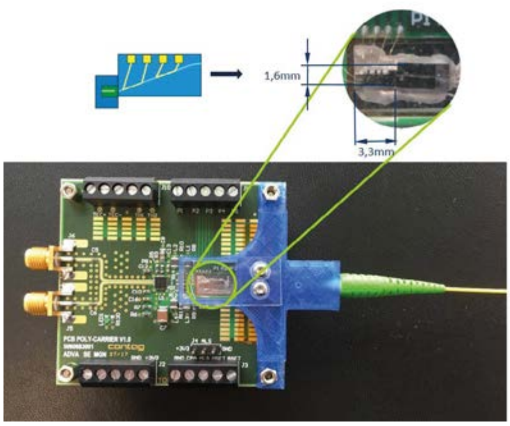


Figure 3: Assembly prototype of polymer-based tunable transmitter

centralized wavelength locker and the tail-end side, such that each tail-end SFP+ is able to adaptively tune its transmission wavelength to fit the connected filter port. As a first step, the transmitter chip has been assembled on the electrical sub-mount with a touch protection made by 3D printer, as shown in Fig. 3. The inset magnifies the chip layout and the wire bonding in detail, where the core polymer chip features a size of only 1.6 mm by 3.3 mm (an additional polymer waveguide alongside is needed for fiber coupling). In the current prototype, a pilot tone tagging the laser wavelength can be superimposed on the high-speed data payload by directly dithering the laser bias, helping the centralized wavelength locker identify and track different tail-end transceivers.

In the meantime, ADVA is investigating the application of the tunable optical transceiver for mobile X-haul applications in EU-funded Horizon 2020 projects, such as 5G-XHaul [2] and 5G-PICTURE [3], where we validate the feasibility and functionality of our proposed passive WDM fronthaul solution using wavelength-agnostic transceivers. ADVA has been contributing the outcomes of these projects to the newly-consented ITU-T Recommendation G.698.4 (ex-“G.metro”) since the beginning of the standards development.

We believe that the passive WDM technology is a very promising solution for 5 G front- and backhaul networks and can be flexibly adopted for a multitude of wireline and wireless applications. A centralized wavelength locker at the head end enables autonomous wavelength assignment and control of the tunable tail-end transceiver. This enhanced efficiency will be the key to reducing the overall cost and complexity.

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Photonic Solutions for Medicine and Environment

Prof. Dr. Ute Neugebauer, Dr. Dana Cialla-May, apl. Prof. Dr. Wolfgang Fritzsche und Prof. Dr. Jürgen Popp

Infectious diseases are one of the primary causes of death in the world. Today, the widespread and often unnecessary use of antibiotics is contributing to the global spread of resistant pathogens. As a result, minor infections can become deadly. Other urging challenges in health care emerge from the increasing average age of individuals. Diseases such as cardiovascular disease, cancer and diabetes become more prevalent. To prevent a post-antibiotic era and to tackle challenges of an aging society, modern medicine requires groundbreaking innovations.

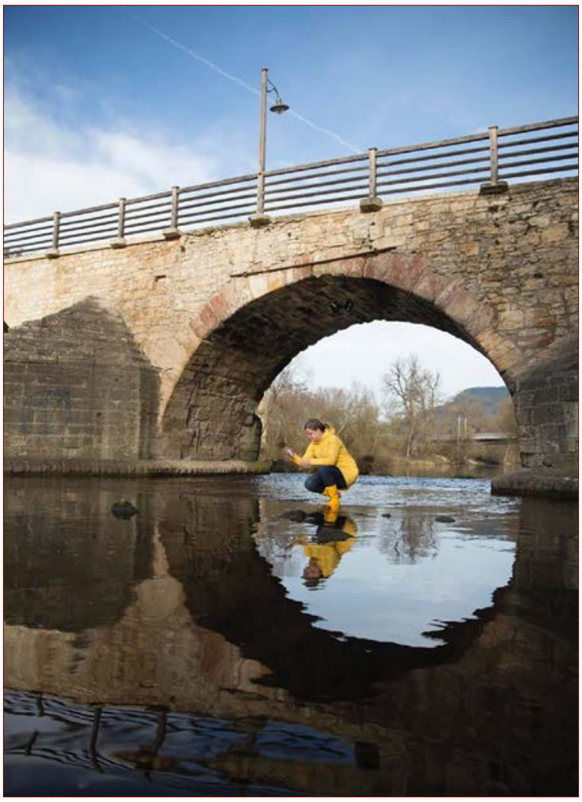
Optical and photonic technologies have proven potential to provide fast, sensitive, specific and accurate solutions for medical and environmental issues. Photonics can help to understand the causes of diseases, allow early diagnosis and, based on this, bring about targeted and effective treatment. This improves the patient's quality of life, the quality of health care and substantially reduces the overall costs.

To establish future technological solutions and commercial methods that cover currently unmet medical and analytical needs, Leibniz IPHT uniquely combines (bio)photonic research with technological expertise in fiber-optics, microfluidics, micro and nanotechnology as well as quantum and system technology. The photonic techniques range from vibrational (micro)spectroscopy, multimodal imaging (combining Raman, fluorescence, optical coherence tomography, etc.) and (super-resolution) microscopy to fiber-optical (micro)spectroscopy, holography, hyperspectral imaging and plasmonics.

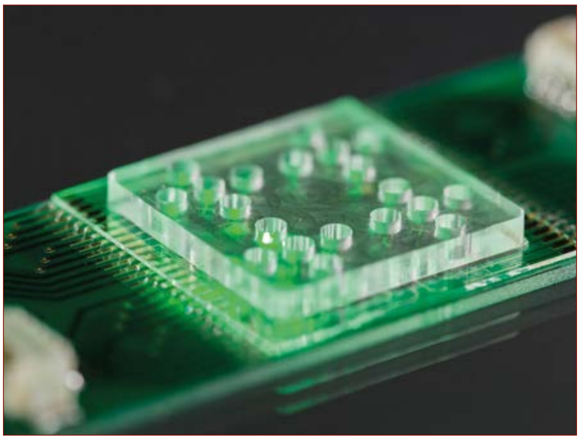
Tracking down Antibiotic Resistance

Common infectious diseases such as urinary tract infection but also life-threatening sepsis are mostly caused by bacterial pathogens. A timely identification of the specific pathogen and its resistance pattern allows a personalised therapy with an effective antibiotic. Administering the correct drug saves lives and prevents spreading of antibiotic resistances. In BMBF-funded projects, Leibniz IPHT researchers in collaboration with partners from the Jena University Hospital developed a photonic lab-on-a-chip (RamanBioAssay™) for fast and accurate infection diagnostics. The system combines Raman spectroscopy with a microfluidic chip to detect bacterial pathogens and their antibiotic resistance in approximately three hours.[1] Thereby, the technology is many times faster than current standard biochemical and molecular-biological diagnostic methods based on cultivation steps. Just a few drops of a patient sample, e.g. urine of a patient with urinary tract infection, are sufficient for the measurement. Elaborate preparation methods prior to the measurement are not needed, as electrical fields capture the bacteria from the sample in a specific region of the chip. The pathogens are identified based on their specific Raman spectrum and its comparison with databases. In addition to the qualitative result, i.e. whether the strain is resistant or sensitive, the scientists obtain quantitative information. This enables doctors to estimate the minimum concentration of the antibiotic required to inhibit bacterial growth.[2]

Together with the company Biophotonics Diagnostics GmbH, the researchers in Jena work on the further development of the RamanBioAssay™. The objective is an open instrument platform that complements microbiological pathogen diagnostics in hospitals. Another perspective is the integration of the assay into a miniaturised, closed cartridge system for mobile application e.g. at the general practitioner.



Water samples from river Saale are examined towards trace contaminants using SERS. © Sven Döring, Leibniz-IPHT



A custom-made microfluidic chip is at the heart of the RamanBioAssay(TM).
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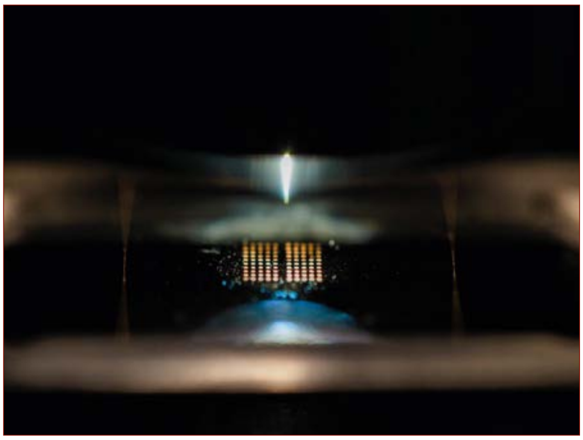

Pathogens and resistance genes in surface waters can by detected using a plasmonic micro-array and hyperspectral imaging.
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Systems for on-site Environmental Analytics

Besides its great potential to revolutionize infection diagnostics, photonics can complement existing technologies in environmental analytics. Recent challenges emerge from the increasing number of antibiotic resistant bacteria and the presence of drugs in surface waters, which pose a potential hazard to ecosystems and our health. For example, the allergenic antibiotic Sulfamethoxazol is often administered to treat urinary tract infections and can be found in rivers all over the world. A robust and cost-efficient point-of-care analytic is needed to detect and monitor these contaminants.

Leibniz IPHT is researching highly sensitive and specific photonic solutions and combine them with microfluidics and fiber-optical technologies. Customized substrates for surface-enhanced Raman spectroscopy (SERS) integrated in microfluidic chips allow to detect even traces of contaminants in water and food.[3,4] The application potential of SERS lies primarily in the field of on-site analytics, where several hundreds of samples can be analysed with minimal effort. In a fiber-optical approach, UV absorption spectroscopy within anti-resonant hollow-core fibers can monitor low concentrations of drugs in water.[5,6] In the framework of the EU joint projects “TRACE” and “WaterCHIP”, a chip-based method employing localized surface plasmon resonance (LSPR) and hyperspectral imaging is used to quickly and reliably detect pathogens and resistance genes in waterbodies.[7]

The future will be bright

For an effective translation of photonic technologies into real-life applications, it is not only necessary to gather researchers, technology developers, engineers and users at one table. The establishment of tailor-made infrastructures that cover the whole innovation chain – from fundamental research to licensing – is indispensable, too. By setting up a targeted translation process, the future of photonic technologies in medicine and environment will be bright.

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Optoelectonic Innovation Drives the Next Generation of Intelligent Vehicles

Every year, vehicle manufacturers release new concept cars representing the most sophisticated technology available for commercial use. The vehicles in question deploy state-of-the-art materials and solutions, featuring the latest technologies to ensure the safety and comfort of both the driver and its passengers. The use of visible and invisible light is helping to advance the efficiency of driver assistance systems, automotive driving to information transmission, infotainment and even interior lighting to change the way we experience driving. Osram Opto Semiconductors works closely together with leading manufactures and is one of the major innovation drivers in the areas of lighting, sensor technology and visualization.

Light contributes to driving safety

Today, we can find a wide range of solutions based on visible light in automotives: from intelligent headlights, where new multi-pixel LED technology is shaking up the industry, to efficient interior lighting or head-up displays.

In addition to much discussed topics such as adaptive driving beam (ADB) or adaptive front lighting systems (AFS), there are numerous applications that contribute to improving automotive safety – these include solutions such as adaptive cruise control, pre-crash sensing, automatic emergency braking, pedestrian protection, active NIR night vision, driver monitoring, occupancy detection and many more.

The invisible safety

Many safety-related automotive systems are based on invisible light from infrared LEDs (IREDs). Depending on the wavelength, these light sources are used in different applications. A main application field for IREDs with a wavelength of 850 nanometres (nm) are, for example, infrared lighting units for camera systems that monitor the outside environment of a car. These systems include night vision systems and forward collision detection systems such as pre-crash sensing and pedestrian protection solutions that work with camera images. Flooding the scene in front of the vehicle with infrared light enables the vehicle environment to be reliably detected even in the dark. Unlike laser-based assistance systems which work with pulsed light, the above-mentioned systems tend to use permanent light sources. In the last years, there have been major improvements in the efficiency, brightness, a decreased size and lower system costs for such IRED solutions, helping to accelerate the implementation of these safety systems into the automotive market.

IREDs with a wavelength of 850 nm are predominantly used for exterior applications. The reason lies in human perception of infrared light at a wavelength range lower than 900 nm: It appears as red glow to the human eye. While this is not problematic in exterior systems, it would be disturbing for interior applications. In these areas of applications infrared light with 940 nm is used, as this spectral range is no longer perceived as red glow. A typical application for IREDs with 940 nm is driver monitoring: a

For driver monitoring the IREDs illuminate the driver precisely so that a camera can capture the drivers' status (drowsiness, distraction) and pass this information to the system.

Joachim Reill,
Senior Director
Application Engineering
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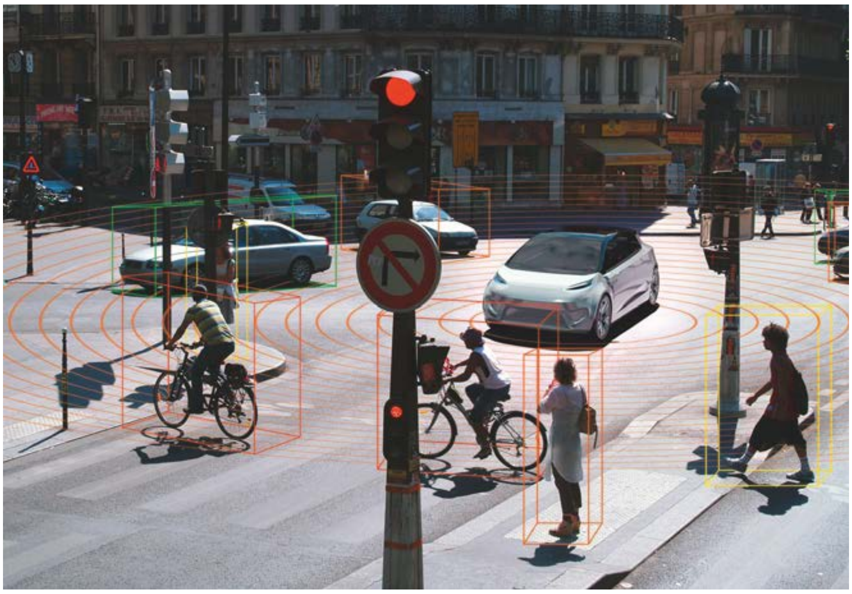
Semiconductors

camera system with infrared lighting monitors the driver's face and line of vision. The system can direct drivers' attention back to the traffic when they are not looking directly at the road. It can also detect when drivers are tired and alert them – a well-recognized improvement for road safety. Passenger occupation detection systems can also improve safety by adjusting the deployment of the airbag according to the passengers' position, while gesture recognition improves the easy of operating car systems, hence reducing the time the driver takes his eyes off the street.



Osram's lasers are found in LiDAR technologies from a wide variety of companies. They are helping speed the widespread adoption of autonomous and semi-autonomous vehicles.

In addition to efficiency and performance, the development progress for the latest generation of 940 nm IRED components, such as the Oslon Black family, includes advancements in high optical pulse outputs and a wide range of integrated lens options. These allow system designers to select the right IRED for virtually any application without having to install secondary optics.

Paving the way to (semi-)autonomous driving

Another automotive technology using invisible light is called LiDAR (Light Detection And Ranging). LiDAR works on the principle of radar but uses light pulses emitted by an infrared laser diode. The latest developments have seen various multi-beam LiDAR systems, which generate an accurate, three-dimensional image of the vehicles' surroundings. This information is used to initiate the appropriate driving manoeuvres.

Biometrics enter the automotive industry

Applications in mobile and consumer technology have triggered a spurt in the development progress for biometrics technology. The automotive industry could be the next to see a surge in uptake as the latest concept car "Snap" by Rinspeed has demonstrated at CES and the Geneva Motor Show 2018. Biometrics technology – from fingerprint scanning to facial recognition or iris-scan – is largely considered to offer a high degree of security and is extremely user-friendly. Automotive manufacturers are considering the use of these systems for car access, driver recognition or access to in-car data systems.

Ultimately, the true 'car of the future' can't be predicted to 100 percent accuracy. However, based on the emerging technologies available and currently being tested, a steadily clearer image of what to expect is emerging – and light based technology will play an important role to ensure driving safety and comfort.

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Freeform Optical Systems for Future Markets

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Fraunhofer IOF

Optical freeform systems enable next-generation applications of modern optics, offering advantages of excellent optical performance and extremely compact design. Due to the complex technology involved, the production of appropriate solutions was previously impossible or too expensive. The initiative ƒo+ [freeform optics plus], however, has further developed the technology to market maturity [1]. For the advancement of the freeform technology, the team has received the »Research in Collaborative« science award 2018 of the »Stifterverband für die Deutsche Wissenschaft«. Among other things, the jury praises the economic impact as well as the novelty of the scientific-methodological approach and the progress in knowledge.

The freeform approach

By definition, freeform surfaces can be defined as surfaces with an arbitrary number of geometrical degrees of freedom. A freeform thus describes an area in three-dimensional space, which deviates from classical, highly symmetrical surface forms and has either very little or no symmetry properties.

The optionally shapeable surface profiles of freeforms offer new opportunities to optical designs, so that freeform elements lead to a new class of optical systems that e.g., contain off-axis elements, exhibit multiple focal lengths, enable reusable propagation, consist of highly folded optical pathways, and are ultra-compact at the same time. They allow a wider field of view and higher resolution and are able to better control aberrations, especially of higher order. The possibility of correcting aberrations results in an elimination of time-consuming post-processing of the data by appropriate software tools.

A holistic technology platform

Within the Innovative Regional Growth Core project ƒo+, eight leading Thuringian Photonics companies and two prestigious research institutes have teamed up to develop and market innovative freeform optical systems based on the new developed technological platform (Figure 1). Each collaborate; i.a. Jena-Optronik GmbH, JENOPTIK Optical Systems GmbH, asphericon GmbH, and the Institute of Applied Physics of the Friedrich-Schiller-Universität Jena, contribute their expertise so that the manifold capabilities of the group cover the entire process chain – from design to production of components and system integration.

Due to their characteristics, freeform optics offer a wide range of applications in areas, such as green energy, illumination, aerospace, and biomedical sensors: for example, as infrared optics for rescue teams, as special optics for space telescopes or as driver assistance systems. New application scenarios are feasible in Earth observation and weather monitoring, in environmental technology, and in the public safety sectors.

The freeform optical developments

The ƒo+ partners developed a high-resolution freeform telescope for Earth observation containing freeform metal mirrors produced by combined manufacturing of ultra-precise turning and magneto rheological finishing [2]. The »snap-together« approach for the system integration of the mirrors reduces the alignment degrees of freedom for such an optical freeform system drastically [3], while the manufacturing of the mirror substrates consisting of more than one optical surface is of particular importance [4,5]. Coated substrates have to be post-polished for improving the spectral range [6] and a sophisticated approach in structuring metal optics is essential to use in spectrometer systems [7]. Due to the high requirements on spaceborne optical systems with respect to thermal stability, certain thermal effects need to be precompensated [8]. The finally developed design of the system ensures an increase in the field of vision by 13.4° and a modulation transfer function of MTF > 60 % at 100 lp/mm in contrast to conventional

Figure 1: Technology platform »freeform optics«.

telescopes with aspheric optics. The distortion of the telescope is about 2.9%.

Recently, the Fraunhofer IOF has succeeded in exploiting its scientific findings regarding opto-mechanical designing, ultra-precise manufacturing, coating, and developing methods for the efficient assembly and adjustment of freeform optical systems in order to support global space missions of remarkable success.

For the International Space Station ISS, an all-metal »Earth Sensing Imaging Spectrometer« called DESIS [9,10] has been developed in close cooperation with the German Aerospace Center (DLR) und the National Aeronautics and Space Administration (NASA). The DESIS hyperspectral Earth observation instrument (Figure 2) was mounted to the exterior of the ISS on August 27, 2018 operating with highest performance of any hyperspectral Earth observation instrument in space [11]. Figure 3 shows its very first image [12].

Figure 2: Complete optical system of DESIS consisting of a Three-Mirror Anastigmat telescope with a focal length of 320 mm, and a corresponding Offner type grating spectrometer for observing the ecosystem of the Earth's surface. © Fraunhofer IOF

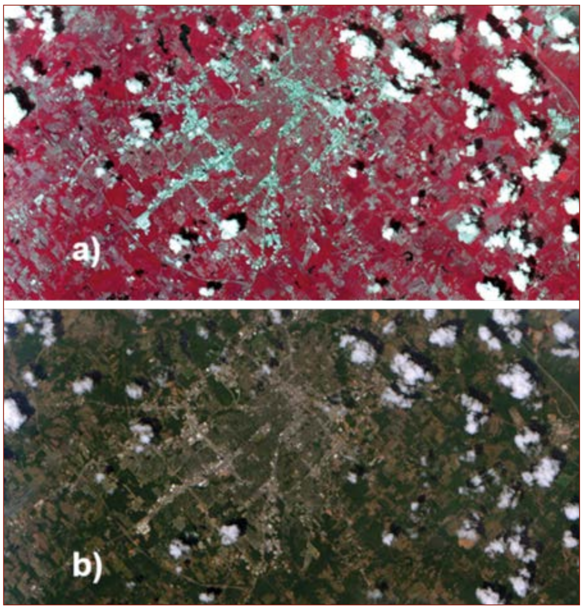

Figure 3: First image from DESIS with a hyperspectral optics consisting of 235 spectral channels in the wavelength range from 400 nm to 1 μm and a resolution of 30 m at the bottom; a) Tyler NIR-VIS and b) Tyler VIS. © DLR

Challenging application of freeforms in the IR spectral range concerns night vision technology in cars; here, conventional technology would require a large number of cameras to record all the angles. Freeform optics, however, enable the construction of cameras that combine different focal lengths and functions in a compact housing. The fo^+ demonstrator based on a Germanium monolith provided the world's first recording of an IR thermal image, with MTF axial > 50% FOV > 30% at 20 lp/mm, with a brilliant resolution, high contrast ratio, and a significantly higher mechanical stability. A further considerably downsizing enabled the optomechanical design in chalcogenide glass IG4 (Ge10As40Se50) [13].

In August 2018, an extended team started into a second research period. Next step is extending the platform to address broader applications in future markets like automotive, laser materials processing, and machine vision. The team focuses on concepts for higher accuracies (VIS), nm- or even sub-nm scale, integration of multiple technologies, continuous implementation of measurement technology along the platform, and small to high volume production.

Funding grant no. 03WKCK1 and 03WKCX1 by the BMBF as well as collaboration with the DLR is gratefully acknowledged.

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[13] R. Eberhardt, Photonics in Germany, 50-51 (2017)

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Integrable Solutions for the Growth Market of Digital Laser Material Processing

Laser light can drill, join, cut, ablate, or even refine surfaces - and it can do all that to virtually any material with unparalleled precision. The potential applications of laser light are seemingly endless. Because of this, laser material processing has become an all-rounder in production processes worldwide and continues to boast impressive growth figures year after year.

The market for laser material processing, which has been growing steadily for years, is leading to a continuously rising demand for Jenoptik´s optical systems. These beam-shaping optical assemblies are the key element in laser production systems, directing the efficient light with extreme precision and accuracy.

With a focus on trends and future applications, Jenoptik is your expert partner for optical systems for laser beam shaping and guidance. One priority area is the digitization of optical systems for production and machine data capture during material processing. These new systems are able to use this data and apply the results intelligently, enabling both automation and error correction.

In order to create its innovative products, Jenoptik combines technology from the optics, electronics, sensor, and software industries, facilitating industry-compatible, cost-effective, and user-friendly solutions – for smart integrable systems within a new group called "Connected Optics".

Optical Solutions Enabling Digital Services

As an established OEM partner in the photonics sector, Jenoptik digitizes and integrates customer-specific optical systems. And with the market launch of a motorized beam expander, the company is also broadening its focus to include the digitization of standard products for laser production systems. The motorized expander is based on beam expanders that are traditionally produced in-house and are primarily responsible for critical industry parameters in standard integrated systems: time, quality, and ease of handling.

The motorized beam expander 1–8x is an example of efficient digitized laser material processing. When integrated in a laser system, the motorized beam expander can - in contrast to its manually adjustable counterparts - adapt the beam to achieve the optimal laser spot size at the press of a button and can be adjusted even during ongoing production processes using the machine controls. The collimation of the laser can also be adapted in the same way in a targeted manner – this is necessary if thermal effects caused by laser power lead to tolerance deviations.

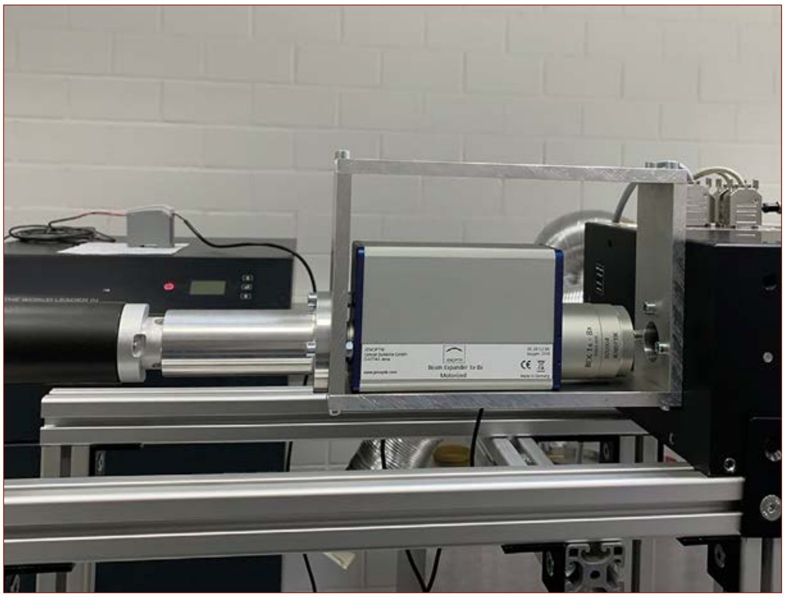
An other advantage is that the production data can be utilized for future processing jobs. Different configurations can be saved and assigned to products that have already been produced. It's possible to achieve a constant, reproducible processing result every time without incurring high costs, which is a huge advantage when different products are manufactured on the same system. This provides users with additional flexibility.

Motorized Beam Expander 1x – 8x

Steffen Reinl
Product Manager
for Connected Optics
JENOPTIK
Optical Systems GmbH

Integration via a web server is of particular interest to providers that offer their customers remote maintenance services. Machine data, such as temperature, can be monitored from any location, thus enabling predictive maintenance. If a fault occurs, the user can intervene in the production process promptly and avoid costly production errors.

Digital features like this - automated magnification and focusing of the laser beam, storage of configuration data, use of sensors, and integration into the network - help achieve quicker setup times, increased efficiency, greater flexibility, and, of course, reproducible production results.



Application picture BEX-M 1x-8x at prozessfabrik BERGER, www.prozessfabrik-berger.de

The motorized beam expander 1–8x has been specifically designed to work with Jenoptik's own F-theta lenses but can also be used in other beam guidance systems. Among other applications, the expander has been integrated in machines used to produce microstructures, equipment to cut, mark, and label different materials, and systems for 3D sintering as well as welding. Thanks to field bus interfaces such as EtherCAT and Profibus, it can be integrated into practically any control system.

High-Precision Optical Solutions Made by Jenoptik

The Jenoptik Group is globally operating in three photonics-based divisions: Light & Optics, Light & Production, and Light & Safety.

Jenoptik provides a broad portfolio of technologies combined with deep experience of more than 25 years in the fields of optics, laser technology, digital imaging, opto-electronics and sensors. Our customers are leading machine and equipment suppliers working in areas such as semiconductor equipment, laser material processing, healthcare & life science, industrial automation, automotive & mobility and safety, as well as in research institutes.

Jenoptik's Light & Optics division is a global OEM supplier of solutions and products based on photonics technologies. The division is a development and production partner, focuses on advancing cutting-edge technologies to improve our customers' system performance and ultimately realize product outcomes that reach new heights enabled by our highly-integrated photonic solutions. The systems, modules and components based on photonics technologies help our customers overcome their future challenges.

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vicotar® Blue Vision

Compact, Robust, Lightweight – Telecentric Measurement Lenses for the Blue Spectral Range

Dr. Jürgen Geffe
Vision & Control

In industrial image processing, optical imaging is expected to provide high image sharpness with the greatest possible depth of focus. However, these are two parameters that in part exclude each other and often require compromises. Stopping down the lens to achieve the necessary depth of focus has the effect that the image becomes increasingly blurred due to diffraction. For example, for a specific lens with an aperture of 0.05 (corresponding to aperture value 10), a diffraction disk of 8 µm radius is created under red light (650 nm). If, on the other hand, blue light with a wavelength of 450 nm is used, the disc is reduced to 5.5 µm - a significant gain. In addition, the LEDs available today with a wavelength of 450 nm (Deep Blue) show an extraordinarily high degree of efficiency. If possible, work should therefore be carried out with monochrome blue light.

Vision & Control lighting systems are designed for these short wavelengths of 450 nm and offer good illumination even under difficult conditions due to their large power reserve (both in continuous light and flash mode).

The opinion is often expressed that monochromatic working enables the use of simple, colourless lenses. However, this is only true to a limited extent. An LED is not completely monochromatic, but has a half-width of about 20 to 30 nm. This appears to be very minor, but nevertheless produces a dispersion that is often not negligible. This causes both a lateral colour error (the magnification changes with the wavelength) and a longitudinal colour error (focal shift, the focus shifts). In the case of a non-corrected lens with an image scale of 0,2 and an object field of 15 mm diameter, colour fringes of more than 10 µm were measured at the edge of the image if the wavelength was changed by 20 nm. The outer pixels are washed out by this amount, which leads to considerable blurring. The additional longitudinal colour error also leads to blurring in the center of the image. This means that even when monochrome light is used, colour correction of the lens cannot be avoided.

Colour corrections in the range of the entire visible light are connected with high effort. In most cases, the correction is realized for two wavelengths within the respective spectrum and certain zone errors are allowed in between. At the edges of the corrected spectrum, the error usually increases steeply again - and this is precisely the favourable range between 450 and 480 nm.

In this context, the idea was obvious to develop a series of lenses that would do justice to this circumstance

Lenses of the TO30 and TO18 series from Vision & Control (source: Vision & Control)

Lens type	Reproduction scale	Operating Distance [mm]	Sensorsize	Distorsion [%]	Overall lenght [mm]	Max. diameter [mm]
T018/4,1-100-V-B	0,23	100	1/4“	0,4	57	30
T018/6,0-95-V-B	0,33	95	1/3“	0,2	63	30
T018/9,0-85-V-B	0,50	85	1/1,8“	0,1	75	30
T018/11,0-80-V-B	0,62	80	2/3“	0,1	83	30
T030/4,3-100-V-B	0,15	100	1/4“	0,8	92	42
T030/6,0-100-V-B	0,20	100	1/3“	0,9	98	42
T030/9,1-85-V-B	0,31	85	1/1,8“	0,6	106	42
T030/11,1-80-V-B	0,37	80	2/3“	0,6	111	42

and have a colour correction in the blue spectrum. Initially, two series of telecentric lenses with an object field diameter of 18 or 30 mm were developed. The reproduction scale of the individual lens types was selected so that the usual sensor sizes are used to the full. Thus, the diagonals of the image field are 4.1 mm (1/4"), 6.1 mm (1/3"), 9 mm (1/1.8") and 11 mm for 2/3".

The emphasis of the colour correction was put on approx. 470 nm. Thus, in the range from 450 nm to 490 nm, only very small longitudinal chromatic aberrations of 10 µm occur, which are below the detection limit.

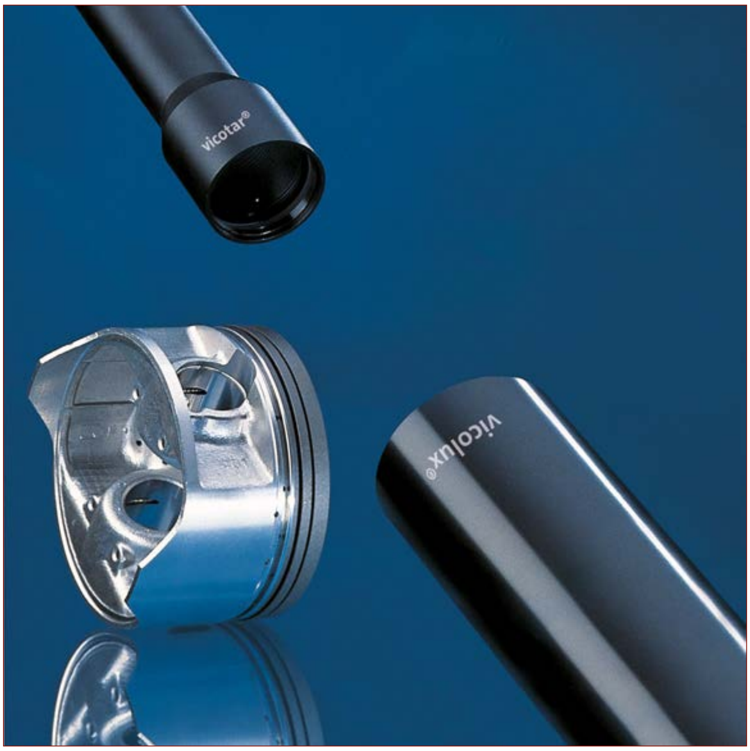
Particular emphasis was placed on low distortion (well below 1%) and compact design. For example, the vicotar® T018/4,1-100-V-B lens is barely longer than a conventional entocentric lens. The wall thickness of the tubes is not thicker than required for stability (harsh industrial conditions) and continues Vision&Control's typical slim design.

Since the lenses have been specially optimized for the blue range, they can only be used to a limited extent for red and IR. It is therefore planned to develop an analogue lens series for the IR range.

The lenses have an adjustable aperture. For use under particularly harsh conditions, a vibration-resistant version is available with a fixed aperture and rugged lenses. With their small dimensions and low weight, these lenses are ideal for use in robotics. The lenses are diffraction limited for aperture values from aperture 8 to 11 (type dependent) and therefore very suitable for 5MP sensors.

The lenses of the T018 series have a tube diameter of 28 mm (aperture ring 30 mm) and can be locked to this size. Corresponding lens holders are available.

The T030 series has a diameter of 42 mm in the front part, the rear part is identical to the T018 series, so the same holders can be used.



vicotar® lens and vicolux® telecentric light in application (source: Vision & Control)

About Vision & Control

For more than 25 years, Vision & Control has been developing, producing and marketing a coordinated component system for industrial image processing - from intelligent cameras and multi-camera systems to high-performance LED illumination and precision optics. With this competency in product development and many years of experience in consulting and support regarding the use of image processing, Vision & Control provides a unique pool of expertise - from research and development to production, education and training.

VISION & CONTROL

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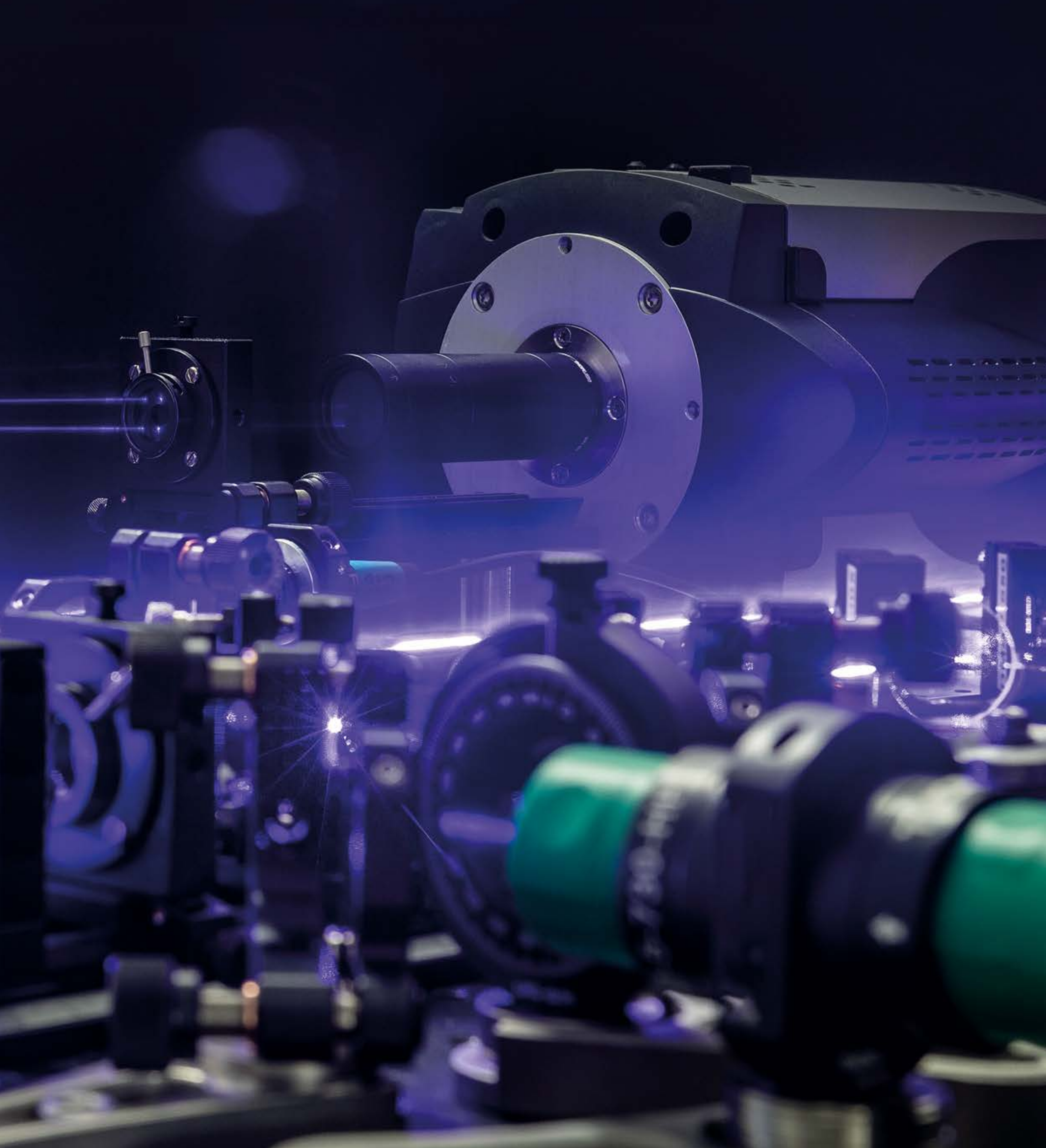
Results and Services from Research Institutions



Fraunhofer Institute for Applied Optics and Precision Engineering IOF – Photonics made in Jena

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena conducts applied research in the field of photonics and develops innovative optical systems to control light - from the generation and manipulation to its application. The services offered by the Institute covers the entire photonic process chain from opto-mechanical and opto-electronic system design to manufacturing of custom-specific solutions and prototypes.

Current focuses of our research activities include freeform technologies, micro- and nanotechnologies, fiber laser systems and optical technologies for safe human-machine interaction and quantum technologies. The institute is active in its business fields optical components and systems, precision engineering components and systems, functional optical surfaces and layers, photonic sensors and measuring systems, and lasers.

The core competences of the institute include design and simulation, micro- and nanostructuring, system integration, additive manufacturing, quantum technology, fiber technology, joining and AVT, coating technologies and functionalization, ultra-precision machining and surface polishing, free-form technologies, integrated photonics, active optics and actuators, laser development and frequency conversion, laser material processing as well as measuring methods and characterization.

The outstanding technical equipment in its unique range is an essential basis of the successful research and development work. From ultra-precise diamond tools and a state-of-the-art electron-beam lithography system to comprehensive measurement technology such as a computer topograph, the Fraunhofer IOF has excellently equipped laboratories, a large clean room, an excellent mechanical workshop and a comprehensive test field for test and demonstration purposes.

The next development stage of photonics is characterized by integrated system solutions. The increasing merge with the semiconductor technology not only leads to a further development of the photonic products, but above all to an intelligent networking and system integration of the

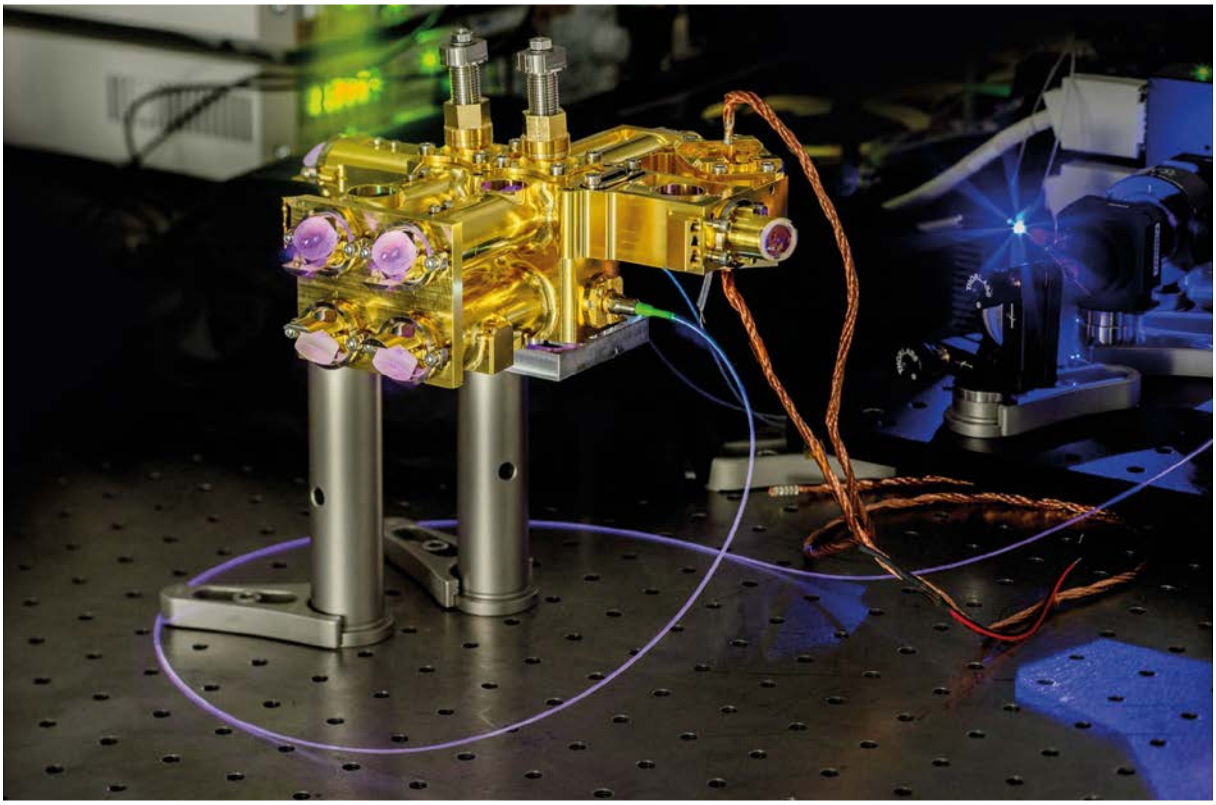


Fig. 1: Satellite-based source for entangled photons. ©Fraunhofer IOF

Fig. 2: 3 D- Sensor for realtime 3D tracking for human machine interaction. ©Fraunhofer IOF

individual components to a problem-solving whole. As an international research institution, the Fraunhofer IOF cooperates with partners in North America, Australia, Asia and European Union countries.

Network of Excellence.

In close cooperation with its partners, the Fraunhofer Institute for Applied Optics and Precision Engineering IOF develops new optical solutions for the markets production, information, health, mobility as well as aerospace. The high level of networking, in particular with partners from Thuringia, Bavaria and Baden-Württemberg, contributes significantly to regional development. As a joint service center for photonics, the Friedrich Schiller University Jena and the Fraunhofer IOF are establishing efficient ways of transferring knowledge and technology. Meanwhile, the close cooperation with the Institute for Applied Physics (IAP) of the FSU Jena ensures the scientific preparation and the education of young scientists.

Another example for Fraunhofer IOFs effort in contributing to the education of outstanding young scientists is the coordination of the national network of excellence “Max Planck School of Photonics”. The Max Planck School of Photonics uniquely connects the best scientists in German photonics research with the most talented junior researchers across disciplines, institutions and regions. As a national, closely networked graduate school with an integrated master program, it adopts the best international young scientists with a master's and bachelor's degree and integrates them actively and sustainably into the German research system.

Empowering Research. Enabling Innovation.

As part of the “3Dsensation” research alliance, the Fraunhofer IOF and its partners face the challenge of giving machines the power of visual recording and interpretation of complex scenes through 3D technology. The Innovation Alliance 3Dsensation pursues the goal of fundamentally changing the interaction between man and machine. The handling of humans with machines and all technical systems should be made more natural and more intuitive, safer and more efficient. The prerequisite for this is the complete adaptation of human-machine interaction to the needs and experiences of humans. The aim of the consortium is the interdisciplinary merging of optics / photonics, IT / software technology and electronics competencies in the fields of design, neuroscience, cognitive science and ergonomics.

Being part of the Thuringian Innovation Center for Quantum Optics and Sensor Technology (InQuoSens) as well as coordinating the Fraunhofer lead project QUILT (Quantum Methods for Advanced Imaging Solutions) makes the Fraunhofer IOF an important partner for researching quantum technologies. InQuoSens and QUILT both unite technology platforms, excellent scientific expertise and contribute to make quantum technologies an interdisciplinary field of excellence in the Fraunhofer-Gesellschaft.

Within its close link to the Fraunhofer “Leistungszentrum Photonik” (High performance center of photonic) - which is a joint initiative of the Fraunhofer IOF, the Friedrich Schiller University Jena, the Leibniz Institutes HKI and IPHT as well as the Helmholtz Institute Jena - new solutions with light for important future fields and their implementation and application in science, business and society are promoted.

Fig. 3: Assembly of a space telescope with free-form optical components. ©Fraunhofer IOF

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Fraunhofer Institute for Laser Technology ILT

Source: Fraunhofer ILT

ILT – this abbreviation has stood for combined know-how in the sector of laser technology for more than 30 years. 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 500 employees and more than 19,500 m² net floor space, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

The four technology areas of the Fraunhofer ILT cover a wide spectrum of topics within laser technology. In the technology area "Lasers and Optics" we develop tailor-made beam sources as well as optical components and systems. The spectrum reaches from freeform optics over diode and solid-state lasers all the way to fiber and ultrashort pulse lasers. In addition to the development, manufacture and integration of components and systems, we also address optics design, modeling and packaging. In the technology area "Laser Material Processing" we solve tasks involving cutting, ablating, drilling, cleaning, welding, soldering, marking as well as surface treatment and micromanufacturing. Process development and systems engineering stands in the foreground, which includes machine and control engineering, process and beam monitoring as well as modeling and simulation. Along with partners from life sciences, ILT's experts in the technology field "Medical Technology and Biophotonics" open up new laser applications in bioanalytics, laser microscopy, clinical diagnostics, laser therapy, biofunctionalization and biofabrication. The development and manufacture of implants, microsurgical and microfluidics systems and components also count among the core activities here. In the technology area "Laser Measurement Technology and EUV Technology" we develop processes and systems for our customers which conduct inline measurement of physical and chemical parameters in a process line. In addition to production measurement technology and material analysis, environment and safety as well as recycling and raw materials lie in the focus of our contract research. With EUV technology, we are entering the submicron world of semiconductors and biology.

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 in a long-term cooperation contract with the institute in the sector of research and development. As an additional benefit, the companies can use the technical infrastructure and exchange information with experts of the Fraunhofer ILT. Around 20 companies already use these advantages. Alongside established laser manufacturers and innovative laser users, new founders, laser manufacturing engineering and laser metrology find appropriate surroundings to implement their ideas industrially.

The Fraunhofer ILT is part of the Fraunhofer-Gesellschaft, with 72 institutes, more than 25,000 employees and an annual research budget of 2.3 billion euros.

Fraunhofer
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SAVE THE DATE!
LASER APPLICATIONS OF TOMORROW
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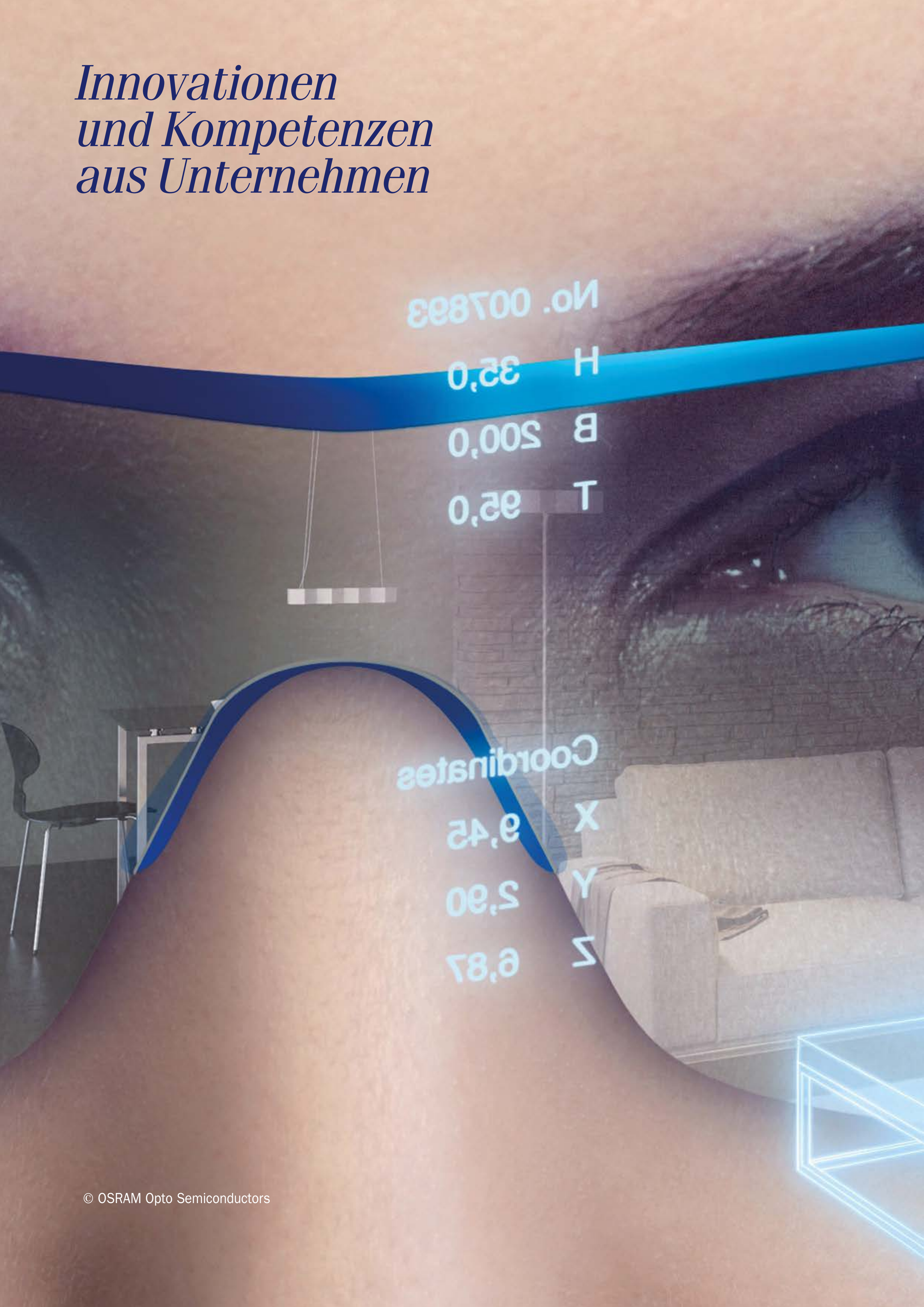
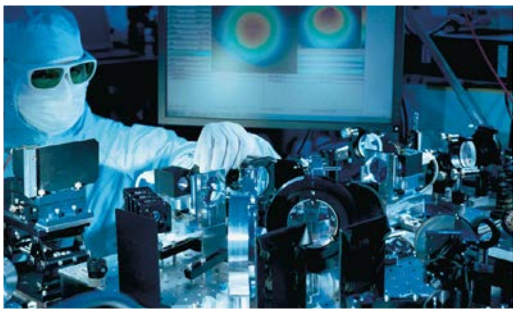
Innovationen und Kompetenzen aus Unternehmen



Innovations and Competencies in Industry

BERLINER GLAS – OEM optical solutions from concept to volume production

BERLINER GLAS
BERLINER GLAS GROUP



Berliner Glas is one of the world's leading providers of optical key components, assemblies and systems, high-quality refined technical glass as well as glass touch assemblies.

With decades of experience in the development and production of optical systems and manufacturing technology we integrate optics, mechanical systems and electronics to provide innovative system solutions for our customers and make a significant contribution to their value chain.

Our solutions are used throughout the world in selected market segments of the light-using industries – the semiconductor industry, medical technology, laser and space technology, metrology and the display industry.

From concept to volume production

We focus on our customers as a reliable, competent long-term partner, along the entire process chain – from concept to volume production.

With more than 1,400 qualified and experienced employees the Berliner Glas Group develops and produces optical system solutions at five locations in Germany, Switzerland and China.

The complete spectrum encompasses:

Engineering

- System engineering
- Optical design
- Mechanical design
- Electronics system design and development
- Coating design
- Customer-specific metrology

Key components

- Cylindrical lenses with lengths of up to 2,000 mm
- Spherical/aspherical lenses and plano optics
- Coatings
- Electrostatic and vacuum chucks
- High-precision structural parts

Assemblies & Systems

- Optical assemblies and systems
- Opto-mechanical assemblies and systems
- Electro-optical systems
- Lens systems
- Measuring systems
- Cameras

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Thin Disk Laser Technology in Downtown Stuttgart

Image 1: Thin Disk Modules by D+G with our new TDM 3 in the middle, allowing pump powers up to 3 kW; perfect for research groups to build their own laser; disk laser modules in various power classes are offered: the TDM 0.05, TDM 1.0, TDM 2.0, TDM 10 and TDM 30 allow for maximum pump powers of 50 W, 1 kW, 2 kW, 10kW and 30 kW, respectively.

Ultrafast thin disk regenerative amplifiers from D+G have recently gained in output powers: they are now available with >400 W in fundamental mode at pulse durations in the pico- and femtosecond regime. Due to effective and homogenous cooling, the thin disk geometry allows for high beam quality (M2 < 1.3) even at these output powers.

When utilizing moderate forms of chirped pulse amplification (CPA) picosecond pulse energies of >150 mJ are easily available. However, even without CPA, femtosecond pulse energies of several mJ can be obtained due to the good energy-scaling capabilities of the thin disk gain medium.

Image 2: VaryDisk laserhead from D+G with SHG module and electronic compartment; a strongly modular design allows easy upgrades and adaption to customers specifications.

D+G offers modifications of its VaryDisk Series in order to provide specialized thin disk laser systems upon customers demand. A highly industrial control system allows for an easy integration in manufacturing environments.

One of the most recent – unique – laser operating modes is the so called “mixed pulse train” with ns- and fs-pulses mixed in one single train of pulses. On the workpiece “mixed pulse trains” can combine the advantages from both time domains by use of only one single laser source.

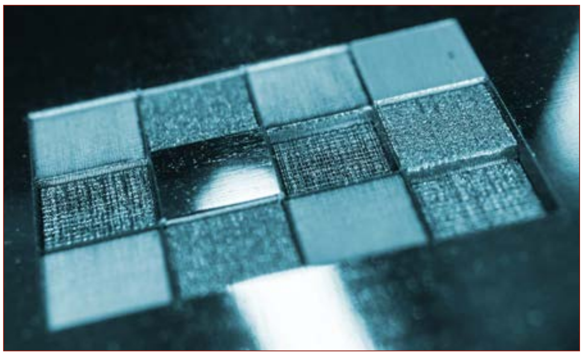

Image 3: Application example for “mixed pulse trains”: matt areas were ablated with 100x – 1000x 400 fs pulses, reflective areas where smoothened with 20x 12 ns pulses.

Disk laser technology is beneficial for medical applications, micro- and macro machining in the industry, as well as research fields like: optical parametric chirped-pulse amplification, extreme ultraviolet generation, and attosecond physics.

Please contact D+G for further information:

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From Outer Space to the Everyday
Making Satellites See Even Better with HOD 500

With HOD 500, Heraeus is filling a gap in the optical materials market. Diffusers made of ultrapure opaque synthetic quartz glass possess a combination of properties that were previously impossible to find. HOD 500 is chemically and mechanically stable like transparent quartz glass allowing it to be processed by standard machining techniques. It scatters light at angles up to approximately 50° making it a nearly perfect diffusor while at the same time exhibiting no absorption outside the OH absorption bands. Irregularly shaped gas inclusions in the HOD 500 scatter light ensuring homogenization. HOD 500 can be used in UV, VIS, NIR and IR applications. An optional treatment is available to harden against UV radiation to enhance functional lifetime making it ideal for permanent UV exposure. HOD 500 is further benefited by having closed porosity on the surface allowing for easy cleaning with water, solvents and ultrasound.

Challenging space application

Optical measuring devices for all applications with diffusers made of HOD 500 are stable for extended lifetime under the most challenging conditions. HOD 500 has been selected for satellite spectrometers to measure atmospheric composition with a full functional performance for the duration of the planned mission of more than 20 years in space. Heraeus has shown that the right fused silica will function long-term even under the harsh conditions of outer space as evidenced by the fused silica prisms from Heraeus in the laser reflectors that landed on the moon with Apollo 11 in 1969. These are still in use to this day for determining the distance between the earth and its satellite.

Down to Earth applications

HOD 500 diffusers are finding scientific applications back on earth too. Whether characterizing and measuring particulate matter in cities or in ambient air surrounding volcanoes HOD 500 is proving itself as an ideal diffuser material. In photometry diffusers increase a detector's sensitivity for a greater spatial angle. They are used to reduce the light coming from a strong source, such as a laser, to measure performance. In optical metrology, diffusers made of HOD 500 are suited for cladding for integrating spheres. HOD 500 diffusors the size of a nickel are adequate for calibration. Diffusors made of HOD 500 can also be used for setting a camera's white balance and while the lighting industry relies on plastic films to homogenize LED light, diffusers made of fused silica are used in specialty light sources.

The technology group Heraeus has specialized in producing and processing natural and synthetic fused silica for far more than 100 years. Heraeus has used its extensive knowledge and experience to create HOD 500, the first volume-scattering material made of synthetic fused silica for optical applications. Read more about the material at: https://bit.ly/2PJW8WJ

Heraeus

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Your Expert for Light Measurement Solutions

Instrument Systems
KONICA MINOLTA Group

With the development of high-level light measurement technology, Instrument Systems enables innovative product development. Our measuring instruments are indispensable for LED and lamp manufacturers, producers of entertainment electronics, in the automotive and aviation industries as well as in research and development. For many years we have been actively involved in standardization organizations such as DIN and CIE, and we cooperate with the leading metrology institutes. As a subsidiary of Konica Minolta we have a strong global network at our disposal, and at the same time benefit from the flexibility of a successful medium-sized enterprise.

The spectrometer – crucial element of a good measurement system

All our measurement solutions are based on our widely recognized CAS 140 series of spectroradiometers which have already established themselves as reference systems. The newly developed CAS 140D combines high accuracy with a robust design and simple operation. The centerpiece is a Crossed-Czerny-Turner spectrograph incorporating a high-end, back-illuminated CCD detector. The spectrometer design thus effectively reduces stray light, resulting in a significantly improved dynamic range and measurement accuracy. Whether for measurement of the solar spectrum or an energy-saving lamp, our spectroradiometers determine all spectral quantities such as color coordinates, color temperature and even color rendering index can be determined over a wide spectral range from UV to IR.

Production control of LED modules

LEDs and OLEDs are very test-intensive products. Our solutions for the determination of luminous flux, luminous intensity, color coordinates and spatial radiation properties are ideal for measurements in the laboratory and fast tests in production.

Optical characterization of solid-state lighting

New standards require comprehensive optical characterization of solid-state lighting products. Instrument Systems provides powerful and compact goniophotometers for development and production, as well as large and small integrating spheres with diameters of up to 2 m.

Display testing

For testing displays we offer high-precision imaging photometers and colorimeters, as well as goniometric measurement systems. All parameters, e.g. luminance, homogeneity, contrast and color, are determined with a high degree of precision.

Light channel technology for automotive lighting

Our Optronik Line provides turnkey solutions and photometric laboratory equipment for automotive exterior, traffic and aerospace applications.

We bring quality to light.

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Web www.instrumentsystems.com

Laserline – The Benchmark in the World of Diode Lasers

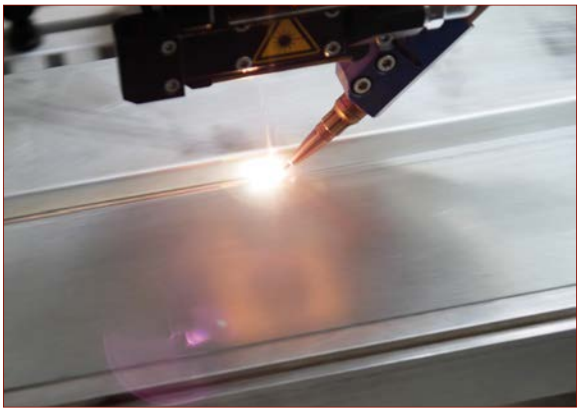
Laserline is one of the pioneers in diode laser technology, and played a significant role in achieving a breakthrough with this laser type. Founded in 1997, the company grew within only a few years to becoming an international leading developer and manufacturer of diode lasers for industrial applications. As of today, about 5,000 Laserline diode lasers have been delivered worldwide. Laserline currently employs 350 people and has international subsidiaries on the American continent (USA, Brazil) and in Asia (Japan, China, South Korea) as well as sales partners in Europe (France, Italy, Great Britain) and in the Asia-Pacific region (India, Taiwan, Australia). The German company is focused

Production of Laserline diode lasers

on sustained growth, and by setting up its headquarters on company premises in Mülheim-Kärlich close to Koblenz, it sets the spatial conditions for future expansion in terms of development and production.

Laserline diode lasers can be found in a wide variety of different sectors and application areas. Typical application areas are classical forms of metal processing, as in welding, brazing, hardening or softening, as well as realization or repair of coatings. Furthermore, Laserline diode lasers have been established for plastic welding and in newer production processes like additive manufacturing (metal 3D print) or welding of fiber composites. Users can be found mainly in the automotive industry, engineering, as well as tool and mold-making. In aerospace and heavy industry, Laserline diode lasers are also in use.

The power range of Laserline diode lasers reaches well into the multi-kilowatt area. As today's standard, lasers with up to 25 kW power are available; in test runs, 60 kW has already been realized. The exceptionally high wall-plug effi-



Brazing process with triple-spot module

ciency of almost 50 percent is groundbreaking. For applications with high demands for focusability, diode lasers with a beam converter have been developed that offer beam qualities from 8 to 4 mm • mrad. Laserline diode lasers are both durable and low-maintenance, and are characterized by a compact and mobile design.

This is possible because of the innovative Laserline diode cooling technique which makes flexible application scenarios possible. Furthermore, Laserline offers diode lasers as 19-inch rack-mount and customized laser designs. At its own application lab, industry specific solutions are developed, possibly realized as prototypes, and tested comprehensively. Additional components like processing optics, scanners, beam switches and monitoring systems round out the company's portfolio. Training, service and maintenance contracts are offered to operators. In the case of malfunction, a 24/7 service hotline and teleservice with remote diagnosis are available.

laserline

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Metal Optics – Ultra-precision Machining Centers – Machine Components

Tailor-made ultra-precision machine building and manufacturing of metallic optical components are the strong core business of LT Ultra. With more than 20 years of experience in ultra precision machining today the company is a competence center for multi-axis diamond machining.

The scope of metal optics ranges from injection molds for small lenses to automotive lights, from barcode readers for logistic facilities to components for spectral analysis applications or components for particle accelerators – all over the world LT Ultra products and solutions secure the commercial success of our clients.

Our machine portfolio provides entire UP machines as well as key components like ultra-precision rotation stages and linear stages or interferometers. LT Ultra is a pioneer in integration of future-proof periphery and automation into our machines. Such as automatic tool-changers and tool-setting or in-situ measurement devices that allow producing and measuring of the work piece in one setting. Your benefits are unique precision, time saving and security of investment. Get your machine solution tailored specifically to your requirements. The unparalleled manufacturing depth guarantees highest reliability and contemporary pricing.

As a privately owned company, LT Ultra cooperates with its customers on a long-term relationship. Our experienced experts provide intensive consulting and a close cooperation from the beginning.

ULTRA-PRECISION MACHINES

LT Ultra has a continuous portfolio from UP-turning and milling machines, to large embossing roller turning machines

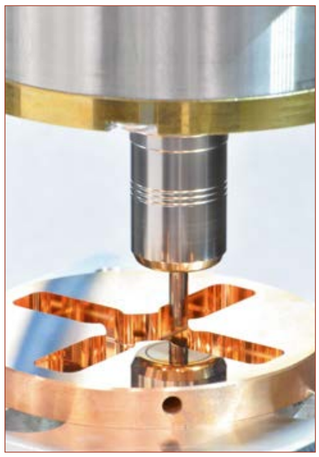
- UP-turning, -milling, -planing, -grinding, -micro structuring, -engraving
- Extreme contour accuracy and surface quality
- Bearing systems free of stick-slip for increments <<10nm
- Range of standard machines
- Customized machines or even built from scratch according to your needs
- Accessories that range from different spindles to fast tool axes or from automatic tool changers to in-situ measurement devices

UP milling machine MMC 900H with full automatic tool changer, online process surveillance and temperature control system

METAL OPTICS

LT Ultra produces metal optics on self-developed machines

- Full range from flat mirrors to free-form surfaces, molds or structured surfaces
- Highest precision of parts regarding contours, roughness, surface quality
- Outstanding price-performance-ratio
- From single part to mass production
- Fast delivery



Metal optic of a particle accelerator made of copper

LT ULTRA
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Omicron-Laserage Laserprodukte GmbH

Flexible Lasers and LED Light Sources for Industry and Science

Omicron develops and produces innovative laser systems and LED light sources and is one of the leading manufacturers for demanding applications in biotechnology, microscopy, microlithography, medicine and many more.

Multi Wavelength Solutions


Single Mode Diode Lasers

Innovative Products

LuxX+® / PhoxX+® :
Ultra Compact and High Speed

The lasers of the LuxX+ and PhoxX+ series are compact single mode diode lasers. With fast, direct digital modulation capability of >250MHz and analogue power modulation >3 MHz as well as fast electronic shutter function with full modulation depth >500 kHz, the LuxX+ lasers have got unique modulation speeds. The PhoxX+ lasers offer full ON/OFF (infinite modulation depths) >180MHz digital modulation bandwidth. The lasers can be modulated with >25MHz analogue intensity modulation. The LuxX+ and PhoxX+ lasers are available in more than 30 different wavelengths in the range of 375nm to 1550nm with an output power of up to 500mW. Various input signals like differential modulation signals allow easy integration into existing or future customer’s designs.

QuixX PS® Ultrafast Picosecond Pulsed Diode Lasers

With the innovative laser series “QuixX PS” Omicron for the first time presents universal diode lasers, which can be pulsed in the picosecond range, as well as being operated in “continuous wave” (CW) and modulated mode. The compact laser modules with completely integrated driver electronics, high precision temperature regulation and beam shaping optics can emit ultrashort pulses down to 50 picoseconds and analogue modulated CW emission. Diodes with up to 500mW optical output power and wavelengths between 375 and 2300nm can be used in the “QuixX PS” systems. The light output can be either free-space or fibre-coupled. CW operation is possible with up to 1MHz analogue modulation and an electronic shutter function which can switch the emission on and off at a bandwidth of more than 200kHz. In pulsed mode the repetition rate can either be triggered by an external synchronization signal, or it can be generated by the internal, programmable frequency generator with up to 100MHz.

Flexible Multi Wavelength Solutions – LightHUB, LightHUB+, LedHUB

The LightHUB® compact laser beam combiners meet today´s needs in biotech and microscopic applications, they combine up to six wavelengths of diode and DPSS lasers. The combiners are able to steadily combine the laser beams of up to six diode or DPSS lasers into a co-linear beam, which can then be used in free-space or fibre coupled applications. The new LightHUB+ laser light engine is a flexible plug and play version, which gives the end-user the possibility to upgrade the laser lines in the field. It offers a single-mode PM fibre output, 6 individual analogue and digital modulation inputs. For all LightHUB and LightHUB+ models, the customer can choose from over 30 different wavelengths in the range of 355 to 2090nm.

The Omicron LedHUB® is a high-power LED light source for biotech, industrial and analytical applications. With up to 6 different wavelengths between 340 and 940nm it can be used in applications like widefield microscopy, optogenetics, chemical analysis, forensics and many more. The modular principle of the LedHUB® provides the possibility to start with only one or two wavelengths initially and user-upgradeability by further wavelengths at a later stage. The capability of fast switching between the wavelengths and high-speed analogue modulation of the intensity is a key feature for demanding applications.

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OSRAM Opto Semiconductors:
Creating technical innovations with passion and know-how

Osram Opto Semiconductors is the semiconductor division of high-tech company Osram. Driven by the conviction that technology helps to improve our lives, OSRAM Opto Semiconductors develops and produces outstanding optical semiconductor technology.

The product portfolio includes high-tech applications based on semiconductor technology such as LEDs, infrared or laser lighting as well as sensors. The solutions are used in highly diverse applications ranging from virtual reality or autonomous driving to mobile devices and Human Centric Lighting. The company with headquarters in Southern German Regensburg and more than 12,700 employees worldwide is a market leader in many applications fields and the global number 1 in automotive lighting.

Clever minds and passionate inventors

Osram Opto Semiconductors prides itself on being home to many of the brightest minds and most passionate developers in the optoelectronics market. It is this enthusiasm and ambition of our skilled employees in combination with the company's many decades of technical know-how and thousands of patented technologies that leads to Osram Opto Semiconductors' success in continuously providing ground-breaking innovations –

- from precise optical sensors for vital-sign monitoring to impressive stage lighting with LED and laser illumination,
- high-end infrared products in mobile devices for curious minds to long-lasting projection applications for brilliant ideas,

- biometrical identification to the complete range of automotive lighting and sensor technology,
- to first ideas to mass-market solutions and the business success of our clients and partners.

We pursue research with clear goals in mind – for example, where do materials reach their limits and how can optimization potentials be derived? The proximity between research and production ensures an extremely high significance of the research results. Close cooperations with universities and industry partners add to this productive environment. This way we enable research at a depth that cannot be found anywhere else in Europe.

This is why Osram Opto Semiconductors is one of the market leaders in the field of optical semiconductors and one of the major innovation drivers in the areas of lighting, sensor technology and visualization.

We see light based solutions as a spectrum of infinite possibilities, this is what drives us every day.

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OWIS GmbH – Precision in Perfection

The OWIS GmbH is a worldwide leading manufacturer of state-of-the-art precision components for the optical beam handling and of micro and nano-hybrid positioning systems. OWIS® products are applied in fields like information and communication technology, biotechnology and medicine, semiconductor and image processing industry as well as mechanical engineering.

Founded in 1980, OWIS® recognized in time the market demand for special opto-mechanical parts, a segment where only few suppliers were present. In particular, there were almost no enterprises ready to produce customized solutions in very small lots. From the very beginning, OWIS® have concentrated on this market segment and have ever since continued to specialize themselves. Furthermore, OWIS® belong to the first companies having system components set up on profile rails in their stocks. The fact that this system is still very popular in all laboratories worldwide and that it is still regularly used, confirms its high acceptance.

Today, OWIS® has about 50 employees and is present in many countries worldwide through agencies or own employees. In Germany, Austria, Denmark and in the Benelux Countries distribution is made by the own sales force. Individual solutions are also worked upon with the customers on-site. Customers from universities, laboratories and industry enterprises appreciate OWIS® because of their high level of competence and reliability as well as the exemplary quality and compatibility of their products. For OWIS® , quality and precision "Made in Germany" have top priority, not at last ensured by the certification in accordance with DIN EN ISO 9001.

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Fully Automated Thin Film Metrology System SENDURO®MEMS for Precise Measurement of Film Thickness & Refractive Index

SENTECH Instruments develops, manufactures, and globally sells innovative capital equipment centred on thin films in semiconductor and microsystems technology, photovoltaics, nanotechnology, and materials research. SENTECH offers tools for plasma etching, PECVD, and atomic layer deposition.

SENTECH also focusses on developing and selling high quality optical instruments, especially spectroscopic ellipsometers and reflectometers. Our tools are perfectly suited for research and development and for industrial use.

The **SENDURO® MEMS** is a fully automated thin film metrology system for precise and reliable measurement of film thickness and refractive index of a large variety of materials like silicon oxide, silicon nitride, amorphous silicon, photoresists, and layer stacks of these materials on silicon wafers, silicon-on insulator substrates, silicon membranes, and much more typical used in MEMS and sensor production.

The base platform of **SENDURO® MEMS** can be equipped with reflectometer for the measurement of film thickness, with spectroscopic ellipsometer for the measurement of film thickness and refractive index or optionally with both units.

The reflectometer is working in the spectral range of 400 nm to 1000 nm. The size of the measurement spot is 80 µm. Our spectroscopic ellipsometers are operated in the spectral range of 300 nm to 1000 nm wavelength and featuring most accurate “Step Scan Analyzer”-measurement mode. Ellipsometer configurations are available with measurement spot size of 200 µm x 600 µm, or 100 µm x 100 µm.

Wafer mapping of 100 mm, 150 mm & 200 mm wafers

The **SENDURO® MEMS** is equipped with a robot for automated wafer loading using wafer cassettes (100 mm, 150 mm and 200 mm wafers), a pre-aligner for a defined orientation of each wafer and a x-y mapping table for moving the wafer to the desired locations. A fast and high precision device is integrated for wafer height and tilt alignment before each measurement.

The wafer pre-aligner, the microspot optics, and SENTECH mapping software combined with pattern recognition allow measurements on patterned wafers.

The **SENDURO® MEMS** can be optionally equipped with edge grip end-effector to fulfil the high demands of wafer backside handling in MEMS manufacturing. The edge grip end-effector touches the wafer only at the 5 mm edge exclusion.

The **SENDURO® MEMS** is operated by the SENTECH **SpectraRay/4** software. The recipe mode features fully automated measurements of wafers. After selecting the recipe, the whole measurement sequence is performed automatically. The wafer is loaded, centered and orientated by a pre-aligner, and transferred to the vacuum chuck of the mapping table thereby maintaining the correct orientation.

SENTECH

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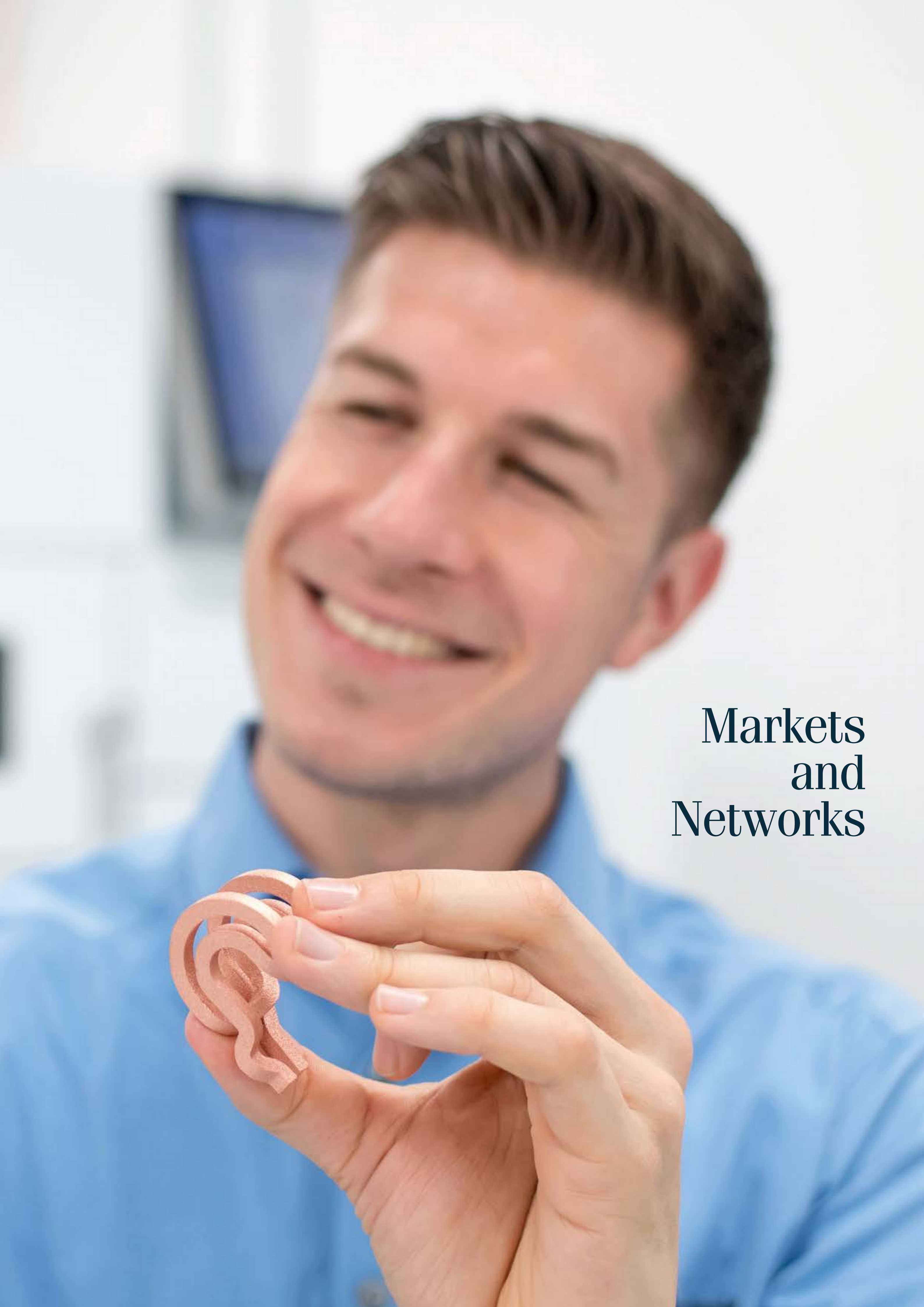
Märkte und Netzwerke



Markets and Networks

German Society of Applied Optics Deutsche Gesellschaft für angewandte Optik e. V. (DGaO)

DGaO
Deutsche Gesellschaft für angewandte Optik
The German Branch of the European Optical Society

Good Scientific Practice in the Age of Data Globalization

The internet has revolutionized our societies. Specifically the ways of communication and mutual interaction have changed dramatically during the past decades. We are all experiencing the impact of these changes on our daily lives. Numerous technological breakthroughs are due to the tremendous potential to collect, transmit and process data. Unfortunately, not all of the changes which come along with the ubiquity of data are to the best of our communities. Especially the internet provides an ideal platform for "information warfare". Ill-founded statements easily seem to override careful argumentation. In this situation, scientists should give good examples of clear reasoning and insist on distinguishing assumptions based on paradigms or world views from evidence based statements. On the other hand, scientists have to reject political efforts to introduce such assumptions into the scientific work. However, even in science and technology it has e.g. become popular to hype specific results in order to receive the "deserved" attention. Good scientific practice with its commitment to honesty (and, yes even modesty) concerning results and authorship is in danger not only on such occasions. This poses a threat to our society since it contributes to the erosion of an open and rational discourse. It is thus one of the most important tasks of established scientific societies like the German Society for Applied Optics (DGaO) to help science and technology maintain a down to earth attitude by stimulating critical discussion. The DGaO is committed to provide a platform for fact-bound critical scientific discussions with specific focus on bridging the gap between industry and universities.

Interface between science and industry

Since its foundation in 1923, the German Society of Applied Optics (DGaO) is devoted to stimulating the interdisciplinary exchange between applied research and industry in optics and photonics. With an annual turnover approaching 40 billion Euros and significant growth rates, optical technologies are one of the most important technological areas for the German economy. Being of outstanding importance as enabling technology for the next generation of globally linked industrial production optical solutions will further gain importance. At the same time digitalization is also becoming more and more part in integrated optical solutions, e.g. for digital image processing or wavefront sensing. In this context, training and education as well as the provision of highly trained scientists and workers is becoming increasingly challenging. DGaO is thus specifically focusing on alluring and supporting young students at the graduate and undergraduate level as well as on establishing a national and international network for the benefit of its members and the future development of optical technologies in general.

Key role to establish applied and close-to-industry research in Europe

As the third biggest "Branch" of the European Optical Society (EOS), DGaO supports and influences optical technologies and science on a European level. Based on a strong optics and photonics industry in Germany as a result of a long tradition of research and education in those fields in our country, DGaO plays a key role in establishing applied and close-to-industry research in optics in the European context.

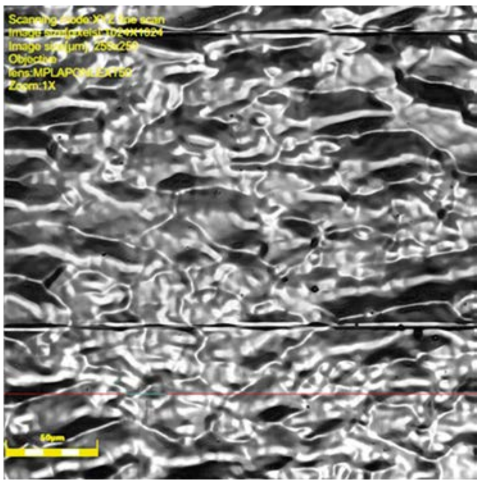


Figure 1: Photograph of arrayed cylindrical microlenses (FISBA beam twister) for optimized beam shaping of high power laser diode bars (courtesy E. Langenbach, FISBA AG, St. Gallen, Schweiz)

Mission to maintain a high level of optics education and advanced training

Education and advanced training in the field of optical engineering and optical technologies become more and more important especially in a European context due to a steadily increasing shortage of qualified employees in this field. DGaO considers itself partner and intermediary between educational institutions and institutions for further training on one side and the needs of the optical industry on the other side. The preservation of the traditionally high level of optics education and advanced training opportunities is a great concern and an important mission of DGaO.

Transfer of technology and new topics from science to industry

Optics and Photonics in Germany clearly exhibit numerous best practice examples for the successful transfer of new technologies into innovative products and applications in relatively short time. DGaO is devoted to further improve this by connecting people from science and industry. Some examples of innovative technologies and approaches may demonstrate this close link between science and industry:

- Innovative freeform, diffractive and even holographic optical elements enable compact systems and have become standard elements in modern applications, from illumination optics, integrated optical sensors to EUV lithography optics.
- Solid state light sources and organic LEDs have not only revolutionized lighting and display applications. Their characteristics rather help to further optimize optical instruments e.g. for imaging, sensing, metrology and quality control.
- Laser sources with optimized output power, ultra-short pulse length or specifically optimized spectra can be used as unique tools for production, metrology, biomedicine, sensing as well as optical manipulation and innovative imaging.
- In combination with the tremendous potential of digital image recording and data processing, these new light sources trigger innovations throughout the industrial and consumer market.

"Young DGaO" and Young Scientist Award

The DGaO is furthermore devoted to the promotion of students, young scientists and professionals by supporting career planning, continuing technical professional training and networking. Initiated by a group of young members, the "Young DGaO" has been founded recently with the goal to develop activities and programs which are of specific interest to students or young professionals. One of the first activities will be the organization of a "summer school on topics of applied optics" which will take place in September 2019. Details will be published on the homepage of the DGaO at (www.dgao.de).

Figure 2: Assembly/Integration/Application of optical elements (reflectors, lenses and light guides) for street lighting (courtesy: M. Wagner; T.Q. Khanh, TU Darmstadt)

The DGaO also cordially invites nominations for the DGaO Young Scientist Award which is traditionally awarded at the Annual Meeting of the DGaO. (see also www.dgao.de).

Annual Meetings

The Annual Meeting of the DGaO has a longstanding tradition and is the most suitable forum to address the topics mentioned above to the corresponding audience, providing an ideal platform for critical scientific discussions. Being frequented by several hundreds of scientists and engineers, this Annual Meeting typically takes place in spring in the week after Pentecost. The meeting is accompanied by a trade-show, where companies and organizations are invited to present their products or services.

120th Annual Meeting of the DGaO in Darmstadt

In 2019 the Annual Meeting of the DGaO will take place in Darmstadt from June 11th -15th, emphasizing topics such as

- Optical Metrology
- Optics Design
- Materials and Processing Technologies for Precision Optics
- Physiological Optics
- Digital Image Processing (Systems and Applications)
- Biophotonics
- Lighting Technology (Optical Systems, Displays and Light Sources)

Numerous short oral presentations (12 minutes) and poster presentations will be given to stimulate fruitful scientific discussions.

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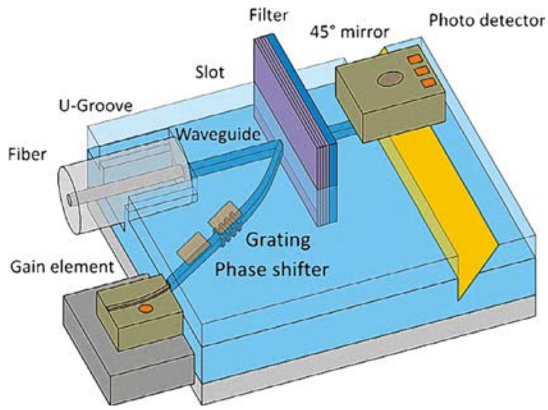
The Photonics Cluster in the German Capital Region Berlin Brandenburg

The capital region Berlin-Brandenburg became one of the globally leading sites for photonics through its diverse range of competencies, the various companies and research institutions. The innovative cluster core consists of over 400 technology companies and 36 research institutions with already more than 16,000 high qualified personnel e.g. in different application fields like digitization, medical technology, aerospace, communication or automation. One of the lighthouse initiatives within the Photonics Cluster is the PolyPhotonics Technology Platform.



The PolyPhotonics Technology Platform
© Fraunhofer HHI

PolyPhotonics Berlin

The growing core "PolyPhotonics Berlin" is part of the "Regional Enterprise Initiative" of the German Federal Ministry of Research. The consortium develops the value chain for the creation of a new technology platform. The Fraunhofer Heinrich Hertz Institute HHI coordinates the project.

Eleven regional enterprises and three research institutes pool their expertise in PolyPhotonics Berlin. For the first time, the network partners will be able to implement comprehensive solutions using optical components made of plastic, which are globally not yet available in this form. The participants in this initiative want to create innovative materials and procedures for the production and assembly of photonic multiple-use components.

The PolyPhotonics Technology Platform provides a toolbox of hybrid-optical building blocks. Using suitable technologies, members of the initiative put these basic building blocks together to form flexible modules for integration into compact functional components of very flexible build (hybrid integration). At the core of the platform is a chip with optical waveguides, which are made of plastic. This chip may feature further passive elements such as optical fibers, thin film filters and micro-optics as well as active elements such as photodiodes or laser chips. In micro technological procedures, the latter components are connected to the waveguide chip. In the group's laboratories, the components are tested and become market-ready.

Crispin Zawadzki, PolyPhotonics Berlin, Deputy Head of Hybrid PICs Group. Mail: crispin.zawadzki@hhi.fraunhofer.de
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The unique aspect is the use of polymer as material for waveguide boards. This board is needed as component for the socket outlet of the future. This outlet must be ready when data arrive via fiber optic cable.

Your first contact for cooperations with the German Capital Region

Berlin Partner for Business and Technology offers business and technology promotion for companies, investors and research institutes in Berlin. Together with the network OpTecBB e.V. and the Brandenburg business development agency WFBB they form the Photonics Cluster Berlin Brandenburg Management which helps companies launch, innovate, expand and secure their economic future.

THE GERMAN CAPITAL REGION
excellence in photonics

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LASER World of PHOTONICS: Preview on the World's Leading Trade Show in Lasers and Photonics

More than 1,300 exhibitors from around 45 countries present their innovations from June 24 to 27, 2019 on the fairgrounds in Munich. Also awaiting the 33,000 visitors is a trend setting congress boasting seven individual conferences and more than 5,000 experts from around the world. In a nutshell: Munich is awaiting an event of superlatives that will provide deep insights into the future of photonics.

The trade show offers a complete market overview – from optoelectronics to lasers in production and imaging. One of the topics will also be biophotonics. It is now enabling ever more accurate medical diagnoses. The LASER World of PHOTONICS 2019 brings together key players from the fields of analytics, diagnostics and bio-technological research. Many of the exhibitors are developing optical systems and components not for one application area alone but are also active in the aerospace industry, are at the cutting edge of progress in the semiconductor and electronics field, or are contributing to quality assurance in the food industry with new imaging techniques.

A platform for young talents

Growth dynamics is a reason why photonics provides a very good environment for founders. The market has more than doubled in ten years. With the Start-Up Area the LASER World of PHOTONICS, young talents receive a platform in the middle of the trade show. Additionally, the Makeathon again provides young engineers and students a platform for demonstrating their expertise in the photonics arena.

LASER World of PHOTONICS Awards: Prizes for viable solutions

Two awards at once are being handed out at this year's LASER World of PHOTONICS, the world's leading trade fair, taking place in Munich from June 24 to 27: The Innovation Award, being conferred for the first time, honors the best product premieres by exhibitors, while the Start-Up Award, now being presented for the third time, is directed at young entrepreneurs offering innovative solutions. The awards are worth 5,000 euros apiece and are being bestowed in collaboration with British publishing house Europa Science.

Supporting program: taylor-made events for photonics professionals

The supporting program of the world's leading photonics trade fair in Munich combines up-to-date expertise with valuable external inspiration. Diverse events and initiatives

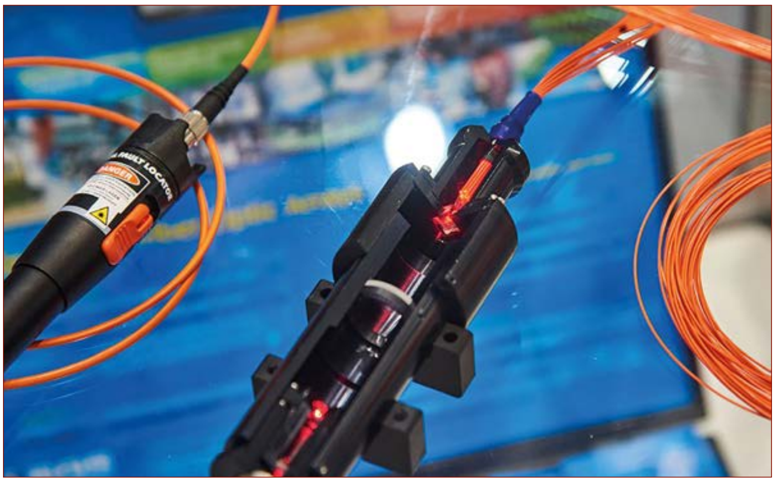

Figure 1: At LASER World of PHOTONICS, visitors see the innovations of more than 1,300 international exhibitors.

Figure 2: The show offers a knowledge-rich supporting program

gather the industry's key players, renowned scientists and visitors, for example:

- The "International Laser Marketplace" informs about markets and applications of laser technology.
- The application panels are dedicated to current application sectors for lasers and photonics.
- The special show Photons in Production offers a comprehensive insight into modern production.
- The Guided Tours are organized by top experts focusing on topics like „guidance and shaping of high power laser radiation"

Figure 3: The LASER World of PHOTONICS presents the whole value chain of lasers and photonics

Figure 4: Highly international: Companies from 45 countries come together at the world's premier platform for the photonics industry.

World of Photonics Congess with well-known speakers

This time, Europe's leading congress counts seven conferences: The newcomer is the OSA conference "Imaging and Applied Optics". In addition, the "European Conference on Lasers and Electro-Optics and the European Quantum Electronics Conference" (CLEO® / Europe – EQEC) will again be shining the spotlight on basic research in the laser technology and quantum optics fields. Prof. Anton Zeilinger will be also address quantum technologies - offering insights into the work of his group at the Vienna Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences in a keynote speech. The opening keynote for the congress on the first day of the trade show will be by Prof. Dr. Karsten Danzmann. He is Director of the Institute for Gravitational Physics at the University of Hanover and Director of the Albert Einstein Institute.

The international LASER World of PHOTONICS network

The LASER World of PHOTONICS has developed an international trade fair network: The LASER World of PHOTONICS CHINA (next event: March 20 to 22, 2019, Shanghai) and the LASER World of PHOTONICS INDIA (next event: October 17 to 19, 2019, Mumbai) are leading regional trade fairs for laser and optical technologies and are staged annually in China (Shanghai) and in India (alternating between Bengaluru, Mumbai, Bangalore and New Delhi). With these trade fairs in Munich, China and India, Messe München is the world's leading trade fair organizer for lasers and photonics.

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