

2011

# LASER+ PHOTONICS

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PRECISION IN PERFECTION

## 4 | High-end photographic lenses

The mastery of photographic optics

## 28 | Guide star lasers

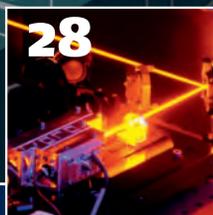
20 W tuned and stable at sodium's D<sub>2</sub> line

## 42 | Ultra-sensitive CMOS sensors

Pushing the low signal envelope of image detection

## 74 | Laser direct structuring

Cost-efficient 3D interconnect devices via LDS



HANSER

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While the achievable absolute peak outputs previously characterized the requirements for a high-power laser diode, the usable optical power (the achievable intensity) is of prime interest today. A new generation of laser diodes allows five to ten times higher intensities.



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## Peripheral vision

**2010 comes to an end** amid enthusiastic market reports out of more or less every corner of the photonics industry. Certainly for most sectors, the volume of orders and the expected turnover for 2010 are approaching or are even forecast to exceed previous record levels. Although we can expect some degree of normalization, the vital signs are still good. As usual, in this issue of Laser+Photonics: Made in Germany, Austria & Switzerland, you will find a selection of the best 2010 Laser+Photonik articles – but in English. Supplementary to these, and for the very first time, there are some brand new contributions. All contributions originate from companies and institutions based within the German-speaking regions Europe. The raison d'être of the magazine is to provide those outside with a glimpse of the industry within.

The themes represented here – optics development, laser technology, imaging technology, optical metrology and materials processing – correspond to the (admittedly, not only German-speaking) European photonics industries' major strengths. Missing from the list is perhaps only LED/OLED technology.

Excluding perhaps materials processing and laser technology, Europe does not necessarily dominate the entirety of any one of these industry sectors. The bulk of industrial optics are manufactured elsewhere, for example, as are industrial LEDs, but Europe does lie well up amongst the leaders in terms of innovation. But is it necessary to command the full width and breadth of a sector, from development through to manufacture and onto integration and application, so that funding and pursuit of that sector still makes sense? What are, for example, the financial repercussions for Europe in letting industrial component manufacture in any one sector drift away to foreign shores?

To know this, one needs to understand the impact of photonics as a key enabler in greater industry. That is, what is the financial leverage exerted by photonics in the peripheral industries, industries where photonics makes a key contribution in manufacture and/or in the final product. A new European Commission study, undertaken in 2010, has attempted to shed some (initial) light on the significances here within the European context, with the results due for publication in 2011.

*Gregory Flinn*

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**N W**

## HIGH END LASER SENSORS

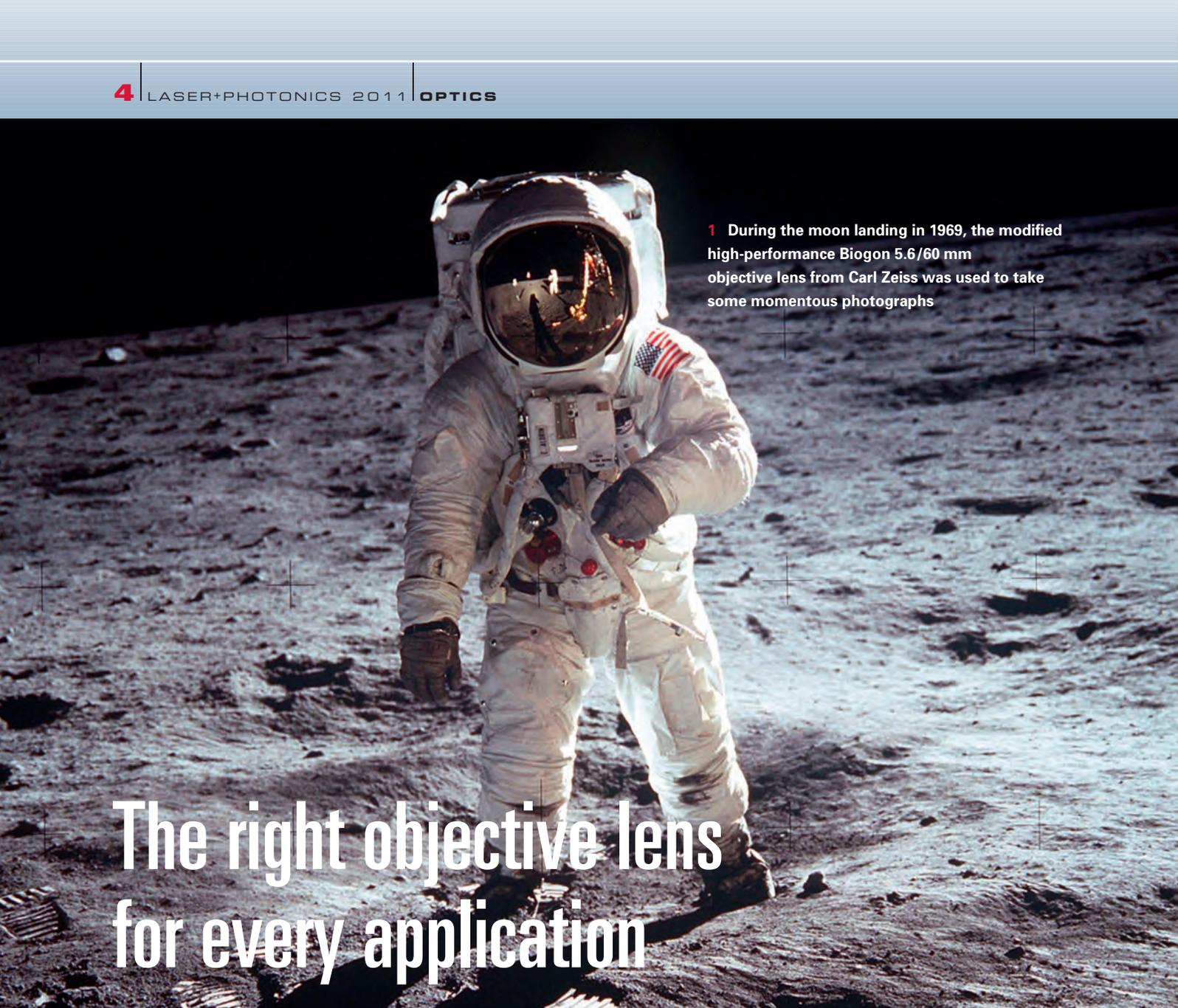
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1 During the moon landing in 1969, the modified high-performance Biogon 5.6/60 mm objective lens from Carl Zeiss was used to take some momentous photographs

# The right objective lens for every application

**CARL ZEISS DEVELOPS SPECIALIZED OPTICS** even for the most demanding of technical applications. Carl Zeiss objective lenses are one of the most important tools used by photographers and film makers and, additionally, play a crucial role in many technical applications – from industry and production to measurement and observation through to space travel. The breadth of applications for photographic objectives is matched only by the differing requirements in terms of materials and function.

JÜRGEN FAHLBUSCH  
NORBERT DIETE

A standard objective lens quickly exhibits its limits when used beyond its design intention, which is why Carl Zeiss provides tailored solutions for the types of application that call for a specialized design. One prominent example of a customized solution was the modification of a Biogon 5.6/60 mm objective lens for Hasselblad (**Figure 1**). This lens was included on the Apollo Moon mission in 1969 – the photographs taken included the world famous picture of the very first footprint in the Sea of Tranquility.

The objective first had to be made suitable for use in the extreme conditions in space and on the Moon. For example, the optical design and the materials chosen needed to be adapted for use in a vacuum as well as be tolerant of the extreme temperature fluctuations. In addition, modifications were made to the objective so that photographs could still be taken even while handling the camera with space suit gloves. Even the first aerial photographs of the large scale destruction of New Orleans caused by Hurricane Katrina in 2005, which moved people across the world so deeply, were also taken with objectives especially developed by Carl Zeiss for this type of application.

### Designed to do the job at hand

Admittedly, specialist optics cannot cover all applications, but each and every objective is made to perform exceptionally well in its intended application. Together with their customers, the expert teams in Oberkochen and Jena develop highly specialized solutions for use in harsh production environments, for example, with exposure to dust and under extreme temperature conditions. »The first step is to produce a feasibility study for the customer and a framework for the likely cost,« explains Jürgen Fahlbusch, Product Manager for Industrial Lenses at Carl Zeiss. Cost is a very important factor when considering specialist objectives, as it can often increase almost exponentially depending on the actual challenge presented to developer and materials. »Some types of optical glass are more expensive than gold,« Fahlbusch continues, »so it is essential to analyze exactly what the objective will be used for and to determine the requisite properties needed by the glass.« Developing a highly specialized objective lens for technical applications can sometimes take several years and often involves close collaboration with the customer throughout.

### Eagle-eyed

Customized lens solutions from Carl Zeiss are particularly in demand in photogrammetry. »This is a very complex but extremely relevant area,« says Norbert Diete, Product Manager for the corresponding aerial photography lenses at Carl Zeiss. »We increasingly encounter aerial photographs in our daily lives – a great example is Google Earth – but many people do not realize how difficult it is to take these types of photographs.« With photogrammetric measurement methods, aerial photography (**Figure 2**) provides organizations with important information on the earth's surface, for example on its composition. Areas of forestry land that are damaged and the effects of a recent hurricane are just two examples. In addition, the exact routing for roads and sewers can be determined to within a few centimeters, and the photographs also provide assistance in the planning of industrial and residential areas.

Measurements are carried out using contiguous and overlapping pictures. By capturing the earth's surface from different perspectives, software can be used to calculate a three-dimensional model. In the past, aerial photographs were taken in 23 x 23 cm<sup>2</sup> negative format, requiring correspondingly bulky camera equipment. Nowadays, photogrammetry is digital. The



**3** Digital camera system (DMC II) from Intergraph with optics from Carl Zeiss



**2** Picture taken with a digital aerial camera (type RMK-D, altitude approximately 1000 m), and enlarged detail of a house

resolution of the objective lenses must be precisely matched to the pixel size of the CCD sensors in order to prevent an »aliasing effect« in the image data.

One of the leading suppliers of aerial cameras is Intergraph Z/I, based in Aalen, Germany. Intergraph's »DMC« (**Figure 3**), »RMK-D« and »DMC II« digital camera systems enable three-dimensional data to be captured with optimum geometric and radiometric precision. This type of data is important for urban and landscape planning, for remote observation of agriculture and forestry, and also forms the basis for data included in geo-information systems.

Carl Zeiss has developed various different objective lenses for Intergraph, all designed to handle the specific requirements associated with operation in aircraft at altitudes of anywhere between several hundred and several thousand meters. Issues include the extreme temperature fluctuations – even when it is warm and summery on the surface of the earth, temperatures at altitude can be as low as -40°C. The objective, which was sitting on the runway in the aircraft just a few minutes earlier, is relatively quickly subject to an ambient temperature difference of 50°C or more, and this for several hours.

Conventional photographic objectives would exhibit a significant loss of performance, but for the calibrated and metric Carl Zeiss aerial photography objectives, these temperature

fluctuations are the norm. They can also withstand severe pressure fluctuations and huge mechanical loads due to vibrations or turbulence. In order to minimize these issues, the experts at Carl Zeiss simulate in advance how the materials will behave at different temperatures and vibrations and adapt the optical design and the construction accordingly.



**4 A telecentric Visionmes objective lens operates even in the harsh conditions of manufacturing**

Besides the highly qualified and experienced development team, Carl Zeiss is also equipped with the proper measurement capability necessary for developing and manufacturing exactly this type of sophisticated optical system. Each objective lens is especially developed and is in many cases unique and unsurpassed in terms of accuracy and performance.

#### Minimally but decidedly different

Next to the large-scale images taken to measure the earth's surface, the detail examined in some production processes is minute in comparison. For example, the complexity of form presented by modern aluminum profiles quickly illustrates the limits of the human eye. At the same time, the allowable tolerance in production is very small – just a fraction of a millimeter can mean that a profile must be rejected, as a window frame thus produced would not hermetically seal. Production of such profiles is complex and susceptible to errors. A minimal drop in temperature, a slight increase in pressure or a tool that is just a little too worn can all result in profile dimensions that fall outside the allowable tolerance. This makes reliable quality assurance absolutely essential for manufacturing.

In the past, manufacturers had to send a sample section of the profile to the lab at the end of a production run. If a fault was identified, the entire batch had to be reprocessed. The company Ascona from Meckenbeuren, Germany, a leading manufacturer of solutions for optical profile measurement, has developed an imaging system that enables quality control to be

carried out during production itself. The secret lies in the innovative construction of the device. The profile section is positioned horizontally and, rather than being profiled mechanically, it is photographed from the front. This requires a special telecentric objective, such as the Visionmes 300/42 from Carl Zeiss (**Figure 4**) that is designed to withstand the harsh conditions prevalent in production environments, such as extreme temperatures, dirt and vibrations. The production employee simply cuts off a profile section at regular intervals and measures it – no matter how angled the edge, the Carl Zeiss objective provides an almost undistorted reproduction of the profile section, meaning that quality control can be performed quickly to ensure that production is running perfectly. The imaging systems from Ascona allow profile manufacturers to identify deviations of less than a hundredth of a millimeter during production and to correct these as required. This improves efficiency and reduces costs. With an average of four tolerance errors per week and an hourly operating price of several thousand Euros for the aluminum press, substantial savings are made every week.

#### Reliable from start to finish

As downtimes in industrial production are frequently associated with very high costs, reliability is crucial. This aspect equally applies to objectives. For Ascona, this was a decisive factor in their choice of manufacturer. »We cannot simply replace the objective as we can the computer or the camera, because it has to be calibrated with all aspects of the measurement system. If an objective were to fail, we would have a serious problem,« explains Albert Schweser, Director of Ascona, outlining the importance of the optics. From the outset, his main focus was on quality when it came to finding a reliable optical partner and that is exactly the reason Schweser opted to work with Carl Zeiss. His decision has certainly paid off, as the objectives have proved to be the most durable component in the whole system. »A few years ago, there was a flood at one of our customers' premises in the Vorarlberg region of Austria. Our machine stood in over a meter of water. The computer was broken, the camera was broken, the monitor was broken – everything except the objective,« Schweser recalls.

#### Summary

»We provide our customers not just with the uncompromising quality of our products, but above all with our know-how.« This is Jürgen Fahlbusch's description of the Customized Optics philosophy at Carl Zeiss. They produce the right objective lens for every application – whether it is for photographs in space, from an aircraft or in a production environment. ■

**Jürgen Fahlbusch** is the Product Manager for Industrial Lenses at Carl Zeiss in Jena. He is responsible for business development, customer service and technical consulting.

**Norbert Diete** has worked at Carl Zeiss since 1973 and is Product Manager in the Industrial Optics division, including the aerial photography lenses described here. He is responsible for project management and for the direct cooperation with customers.

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# Freeform optics

## THE CHALLENGE FOR FUTURE OPTICAL SYSTEMS.

**In ophthalmology, technologies for manufacturing freeform surfaces with surface tolerances  $<20 \mu\text{m}$  are already in use in serial production. From requiring two sets of eyeglasses for correcting near and far sightedness, eyeglass ophthalmics is now at the point where it can deliver progressive varifocal lenses custom-designed to the needs of the wearer.**



RAMONA EBERHARDT

In the future, the development of new optical imaging and lighting systems will require that all degrees of freedom be used in system design to develop competitive lens equipment. Indeed, the number of patent applications relating to the use of freeform surfaces of enhanced quality ( $<10 \mu\text{m}$ ) has sharply increased in recent years due to the versatility of these lenses.

One constraint imposed on their design by manufacturing technology relates to the feasibility of given surface geometries. The state-of-the-art involves the use of optical components on which the optically active surfaces exhibit aspherical deviation of one degree of freedom; these are known as aspherical

optical elements. It should however be kept in mind that aspherical lenses still possess rotational symmetry.

### Away from symmetry

Modern system design is a precursor to the utilization of all degrees of freedom for the surfaces of lenses or mirrors, such that there no longer be any restrictions on the optically refractive or reflective active surface. By eliminating the requirement of symmetry in system design, innovative lens designs will be possible in the future

– designs that have until now been regarded as unrealistic. Unique optical imaging features, such as the correction of aberrations and compact beam guidance of laser beam sources (Figure 1), will be possible. In many cases, the use of innovative freeform optical components should enable the development of completely new features for a given optical system.

### First specific applications

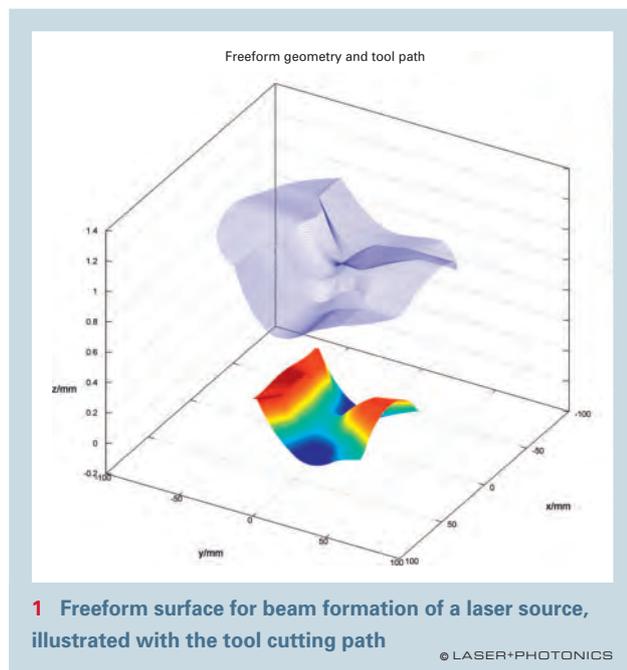
Freeform optics offer the system designer many possibilities, such as the reduction of the number of optical components in a system through the high degree of freedom, thus resulting in an extremely lightweight design. In addition, and for the first time, it is now possible to adapt them to applications involving asymmetric beam guidance, as indicated above.

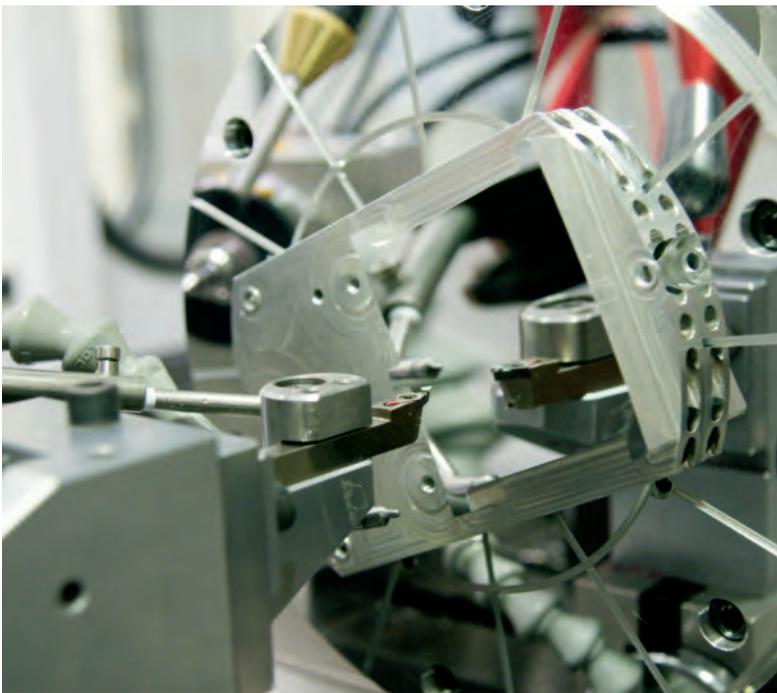
Initial design concepts derive from glasses delivering virtual or augmented reality data, generally termed head-mounted devices (HMDs), where beam guidance resulting from the geometry of the head is directed in-line with the latter using freeform optical elements.

The automotive industry represents another market. Important traffic, speed and routing information, as well as warning

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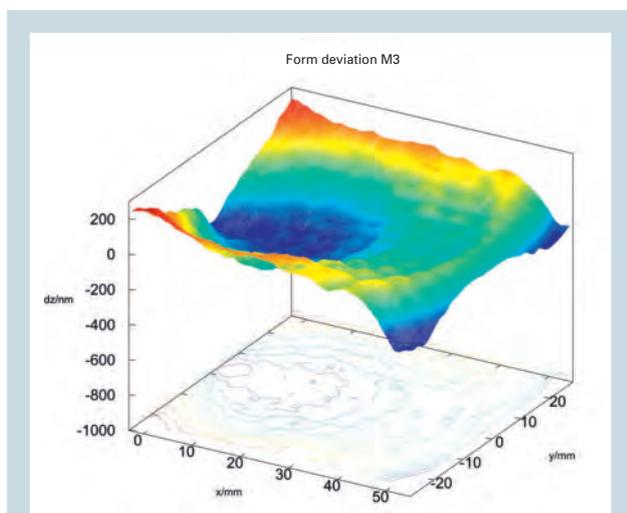




messages, can now be projected onto the windscreen, within the visual field of the driver. These so-called head-up displays (HUDs) are based on large-surface freeform mirrors that are manufactured to exacting standards of geometric precision and surface finish in a replication process suitable for mass production.

### Manufacturing processes

The degree of accuracy, materials, the quantity required and the associated costs all determine which of several processes can be used to manufacture freeform components. At the Fraunhofer IOF, for instance, optical surfaces made from metallic non-ferrous materials and plastics are cut with diamond tools (**Figure 2**). For deviations from a given rotational symmetry of the order of a few 100  $\mu\text{m}$  and up to several millimeters, the optical surfaces are produced on a conventional ultra-precise



**3** False color representation of tactually identified form deviation of the freeform mirror after correction using reference elements

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### **2** Diamond turning of an off-axis mirror with reference points designed to assist measurement and placement in the optical path of an IR telescope for observing the Earth (DLR-FK: 50EE0804)

turning machine, with an additional stroke introduced into the movement of the machining tool. Control of the diamond is synchronized with the angular position of what will later be the freeform surface. Forward and reverse movements are either performed by the massive feed-in axis itself (slow tool servo), or else an additional redundant kinematic is used, the so-called fast tool servo, as used for high-spatial frequency machining. If none of the design surfaces exhibit rotational symmetry, freeform surfaces can also be produced by shaping or milling. What both methods have in common is that the upper surface is processed by the diamond tool in a grid pattern of rows or columns. Whereas in the case of milling the tool is driven in order to achieve the required cutting speed, surface removal in shaping/milling is achieved solely via the relative movement between the tool and the lens that is being processed. The advantage of this technique is the possibility of shaping supplementary structures – that is, adding further optical functionality – onto the freeform surface.

For mass production of freeform surfaces, it is conceivable that a master tool could be molded in plastic using processes such as hot pressing or injection molding. Equally,  $\text{UV}$  reaction molding is a proven solution for replicating high-precision lenses in plastic. Freeform lenses can be manufactured from various forms of optical glass by means of glass pressing. This process uses ground freeform molds made from extremely hard materials.

The additional degrees of freedom of the optical surfaces impose new challenges on quality inspection of the geometry and on assembly of mirrors and lenses into systems. A surface without rotational symmetry must be precisely dimensioned in six degrees of freedom and positioned exactly in the optical path. A very promising approach would appear to be that developed by the Fraunhofer IOF Jena, using reference elements that simplify characterization of the surface (**Figure 3**) and that are also applicable during the assembly process.

The challenge for the German optics industry is to develop a basis for describing complete and efficient manufacturing process sequences for brittle (glass, crystals, et cetera) and ductile (metals, polymers) freeform components and systems. Work on this is currently ongoing and in collaboration with research institutes. These activities are supported by the Federal Ministry for Education and Research's (BMBF) high-tech strategy  $\text{Freeform Optics}$  funding program, under the auspices of  $\text{Optical Technologies}$  ([www.bmbf.de/de/3591.php](http://www.bmbf.de/de/3591.php)).

### Summary

Other uses for freeform optics include lighting applications involving complex distributions of light and luminance. Mastery of freeform optics will in principle facilitate new approaches in the field of applied optics, as well as revolutionizing consumer optics and many optics applications in production processes and measurement technology. ■

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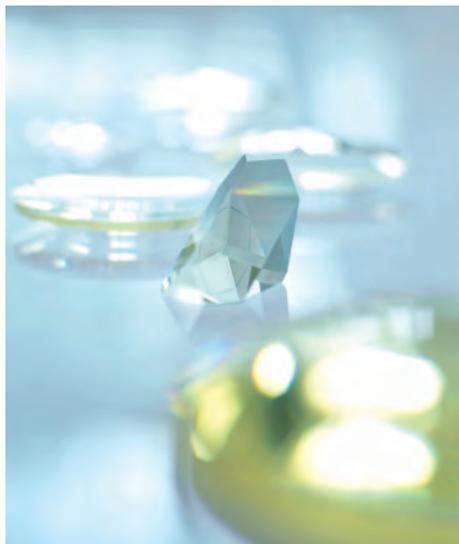
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### All aspects of optical expertise under one roof

FISBA unites all required disciplines and expert knowledge under one roof. Lens designers and engineers, backed by specialists in physics and coating technology, develop, analyze and optimize optical systems and components for the entire spectral range from UV to NIR — integrated and sustainable.

### New technologies for affordable glass optics

FISBA employs and develops leading technologies to provide outstanding results for

every production stage, from prototypes to complex optics in large-scale production. Uncompromising quality control vouches for flawless products that render incoming goods inspection superfluous, saving valuable time and increasing process stability.

Newest technologies are implemented not only to offer customers the best optic solutions for their application but at a reasonable price as well. FISBA employs precision glass molding for the production of glass optics with arbitrary forms in larger lots at a fair price, opening up totally new possibilities in the customer's system development and assembly optimization.

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- Aspheres

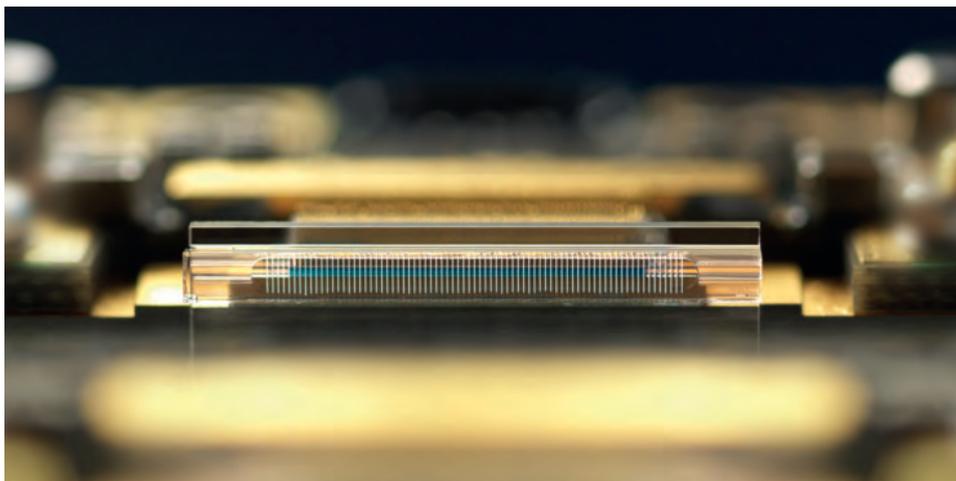
#### Optical Systems

- Lens systems
- Objectives
- Laser Modules
- Laser Optics
- Collimators
- Illumination

#### Optical Microsystems

### Application Fields

- Biophotonics
- Bildverarbeitung und Sensorik
- Industrielle Fertigung
- Sicherheit und Verteidigung
- Weltraum und Astronomie





LAYERTEC, established in 1990 as a spin off from the Friedrich-Schiller-Universität Jena, produces high quality optical components for laser applications in the wavelength range from the VUV (157nm) to the NIR (~4µm).

The company combines a precision optics facility and a variety of coating techniques (magnetron sputtering, thermal and e-beam evaporation).

The precision optics facility of LAYERTEC produces plane and spherically curved mirror substrates, lenses and prisms of fused silica, optical glasses like BK7 and some crystalline materials, e.g. calcium fluoride. Fused silica and calcium fluoride can be offered with rms-roughnesses as low as 0.15nm.

Components for the UV are coated by evaporation techniques. Coatings for the VIS and NIR are mostly produced by magnetron sputtering. This special coating process yields amorphous layers with a very high packing density resulting in lowest straylight losses and a high thermal and climatical stability of the optical parameters. Furthermore, the coatings are optimized for high laser damage thresholds.

LAYERTEC has developed magnetron sputtering for optical coatings from a laboratory technique to a very efficient industrial process.

#### The main products of LAYERTEC are

- High – power - coatings for the NIR (e.g. for Nd:YAG-, Ho:YAG- and Er:YAG-lasers)
- Femtosecond laser mirrors with exactly determined phase properties (low GDD or negative GDD and R>99.9%)
- Steep edge filters, e.g. HR 1030nm >99.9% + R(980nm)<1% with high laser damage thresholds
- Low loss laser mirrors (R>99.99 in the VIS and NIR)
- Coatings on laser- and nonlinear optical crystals
- Metallic mirrors and coatings (Au, Ag, Al, Cr)
- Coatings for all excimer laser wavelengths including 157nm

Besides the development of efficient coating plants LAYERTEC has preserved its capabilities for flexible production and the development of prototypes and OEM components.



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#### Polytec GmbH

For over 40 years Polytec develops and manufactures high-quality measurement systems for the analysis of vibration, length, speed and surface topography. The applications range from microsystem technology to large scale mechanical engineering for the automotive sector and aerospace industry, medical technology, biomedical sciences, etc. These Polytec products are well known around the world as the gold standard in non-contact, laser-based measurement of vibration, speed and length. Advanced product development remains a core strategic activity at Polytec with

new electro-optical systems designed for analytical process measurement, NVH analysis and factory automation.

Besides laser technology, Polytec manufactures optical spectrometer systems and components for various applications in process analytics covering the whole range from OEM products to turn key solutions.

The third focus of the Polytec business is the distribution and service for opto-electronic components and modules as well as complete measurement systems for various applications. Polytec focuses on machine vision, lasers and laser systems, fiber optic sensing, optical telecommunication, optical radiation measurement, spectroscopy, semiconductor and photovoltaics, metrology as well as on electro-optical test systems.

Polytec has staffed offices throughout Europe, North America and Asia to provide customers with the best local sales, service and support in the industry.



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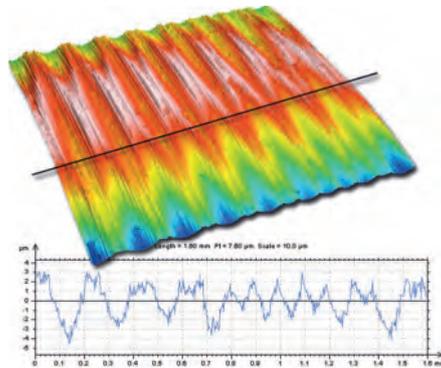
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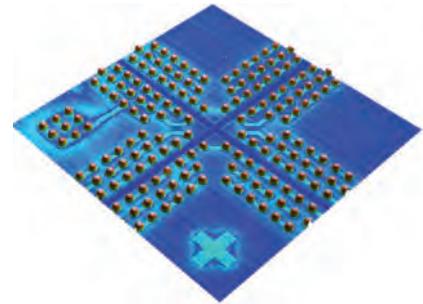
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## Fast and precise 3D Surface Metrology Solutions for Laboratory and Production

NanoFocus develops, manufactures and distributes high-resolution optical 3D metrology systems and corresponding software solutions for laboratory and production environments. The flexible systems permit fast, simple, and non-contact measurements of 3D topography with resolution in the nanometer range. These reliable instruments are designed for surface roughness analysis according to DIN EN ISO, structure- or micro-geometry, as well as layer thickness measurements of technical surfaces.



The components used for the NanoFocus metrology systems go through strict selection and validation processes to guarantee highest quality standards, stability and low-maintenance. The product range comprises 3 differ-

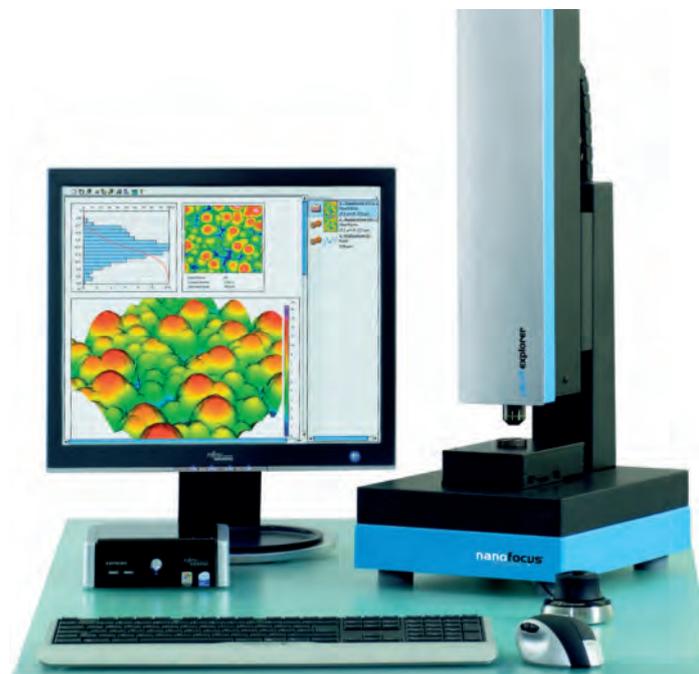


ent lines: the  $\mu$ surf confocal microscopes, the  $\mu$ scan laser profilometers, and the  $\mu$ print high-speed inline metrology systems. The powerful  $\mu$ soft software tools provide a variety of analysis options as well as automated measurement and evaluation processes. Analysis can be performed using the ISO 4287/4288 traditional 2D parameters as well as new 3D parameters, in accordance with ISO 25178. The combination of robust hardware and versatile software provide users with a universal tool to reliably quantify engineered surfaces. With the automation software, measurements can be processed at a high throughput rate with highest efficiency and without user influence.

The NanoFocus technologies offer various advantages for the characterization of technical surfaces in the micro and nanometer ranges. Contrary to a SEM (x,y) for example, NanoFocus' confocal technology offers the data in true 3-dimensional coordinates (x,y,z). Only with this quantitative data an exact analysis of 3D surface parameters can be performed, delivering a larger range of information about the surface texture. Additionally, this technology does not require preparation of the measurement

sample. Already after a few seconds, meaningful data is provided for further analysis.

More than 700 NanoFocus metrology systems are in operation worldwide. NanoFocus customers include well-known companies from all major industries, such as automotive, photovoltaic and electronics industries, the medical sector, forensics and mechanical engineering, as well as renowned universities and research institutes.



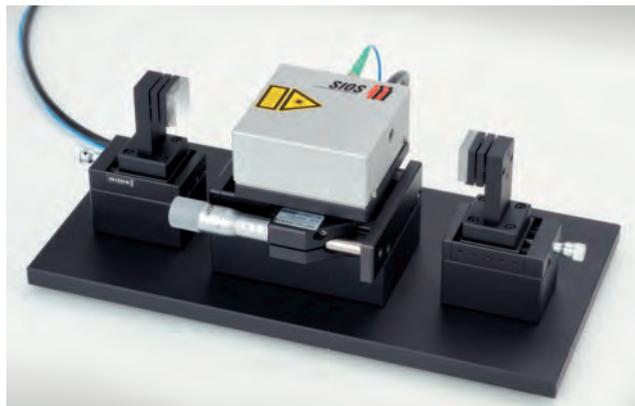


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beam from the laser light source is transmitted to the sensor head by a fiberoptic cable. The miniature interferometer converts distance changes of the parallel mirrors along the beam axis into optical interference signals that are transmitted to an optoelectronic signal processing/power supply unit for processing and output.

Instrument operation and display of measurement results are controlled either through a separate keypad/display unit or an USB connected PC running optional software.



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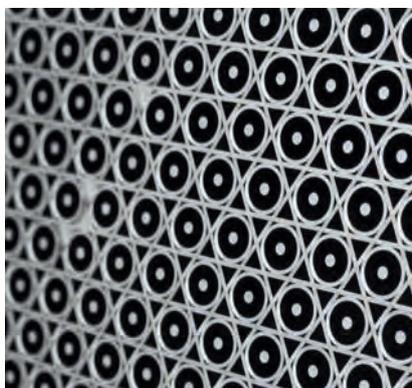
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**Black chromium coating.** Optics Balzers has made use of the black chromium properties, to date applied predominantly in solar collectors and sunglasses, to develop a coating for use in medical devices and other applications. The ›Cr-Black‹ black chromium coating is an optically black coating distinguished by its high absorption capacity and its minimized reflection in the VIS range. Its color hue can be tailored to customers' specific requirements, for example to produce a black chromium part with a blue component. The coating's high environmental



**Patterned and pre-cut CrBlack coating**

stability and durability, high adhesion on glass and metal in conjunction with its high application temperature of up to 250°C make it suitable for a wide variety of uses. Thanks to the high reduction of scattered light and its ROHS-conformity, the CrBlack coating is ideally suited for applications in lens systems of medical devices. The ›CoatingPlus‹ capabilities of Optics Balzers also enable CrBlack to be patterned for demanding applications. The whole-surface or patterned coating can be easily cleaned following additional process steps.

[www.opticsbalzers.com](http://www.opticsbalzers.com)

## Precision molded

**Optics.** Docter Optics has recently introduced an industrially precision molded asphere with contour tolerances allowing applications in imaging systems and which, says the manufacturer, have already proven themselves in practice. Optical components produced in the conventional way (ground and polished),



can therefore be replaced with precision molded components in certain applications, considerably reducing the OEM cost of medium class optics and high volume products. Using the precision-fast-molding process, Docter Optics produces freeform lenses, light pipes, aspheres and arrays with a precision down to 3 µm PV, contingent on geometry. Depending on the field of application, such pressed optical components enable more compact optical systems. In addition, this technology allows the bearing surface or alignment marks to be pressed in, as a single component. In its Optical Systems business section, Docter Optics also develops and manufactures complete optical and optomechanical assemblies for OEMs, thereby offering the full range of services in the value-added chain.

[www.docteroptics.com](http://www.docteroptics.com)

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absorption, high performance coatings especially for use in laser systems for the solar cell industry. They include the *f*-theta lenses with a focal length of



330 mm and that are available in versions for 355, 532 and 1064 nm. Sill supplies appropriate telescopes for laser beam diameter adjustment. Various expansion factors of 1.0 to 20x are available for 355, 532 and 1064 nm. Any standard laser can be adapted to the *f*-theta optics used.

[www.silloptics.de](http://www.silloptics.de)

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## All in one

### Characterization of assembled optics.

Trioptics presents their new ›OptiCentric 3D‹ as a solution for the complete optomechanical characterization of assembled optical systems, measuring lens centering, air spacing, and center thickness inside of assembled optical systems with a single instrument. This new approach integrates different lens analysis technologies, combining the ›OptiCentric‹ centering error measurement technology with a low coherence interferometer called ›OptiSurf‹, which measures the air gaps between lens surfaces and the center thickness of lenses within the optical system. The cross-interaction of both measurement systems enables a fast alignment of the lens system, thus increasing overall measurement accuracy. It provides detailed manufacturing quality information, being able to measure centering errors of less than 0.1 µm as well as air spacing and center thicknesses of less than 1 µm. The software has a two-level user interface for complex analysis routines in the R&D phase and an intuitive and user-friendly display for operators at the production site.

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# Large area scan macroscope

## LOOKING BACK AT THE HISTORY OF THE EARTH'S CLIMATE.

**A large area scan microscope developed by Schäfter + Kirchhoff enables scientists at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven to analyze ice cores rapidly and in great detail. This application stands out from conventional inspection tasks, in particular because of the current relevance of global warming issues. This innovative development uses Linos inspec.x L series lenses from Qioptiq.**

GEORG ZEITLHACK  
THOMAS SCHÄFFLER

**A** history of the Earth's climate is stored in the ice of the polar glaciers. Gases and aerosols trapped over several hundred thousand years can be evaluated in ice cores drilled from polar glaciers. The deepest ice core drilling made to date in the Antarctic descends 3260 meters and spans a period of more than 700 000 years. These ice cores yield detailed data about the environmental and climatic conditions that then prevailed. The information gained is of particular importance in the current climate-related debates, and helps climate behavior to be inferred regarding the role that modern industrial society plays in global warming.

### Tracing ice formation

The formation of ice on a glacier's surface is a complex process, influenced by such factors as quantity of precipitation, temperature, wind force and the presence of trace elements. Glacial snow is compacted by subsequent layers of fresh snow on the glacial surface into an air-permeable firn, and with time this firn is gradually transformed into layers of ice lying ever further below the surface. As the upper layers of the glacier are air permeable, a temporal discrepancy can occur between the bubbles of trapped gases and trapped aerosols that can extend anywhere from 100 to 10 000 years. Glaciologists of the Alfred Wegener

Institute analyze the microstructure of the ice cores to trace the process of ice formation and glean information concerning the development of the gas-containing air bubbles. The objective is to model these processes and reconstruct the past.

### Fast image acquisition from ice samples

Samples of a manageable size are taken from the valuable ice cores for image acquisition. The samples must be scanned as quickly as possible otherwise sublimation changes the porous ice surface, which in turn leads to distortion of the information gained from the images. To enable this rapid image acquisition, Schäfter + Kirchhoff have developed a scan microscope that can scan a large surface with high resolution. **Figure 1** shows the microscope in use.

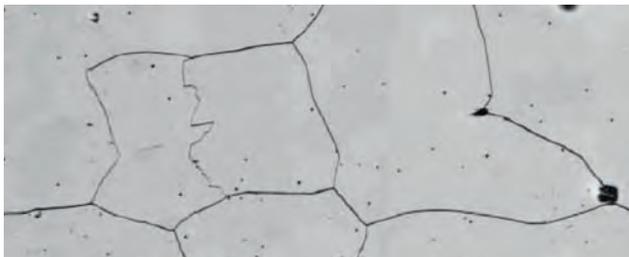
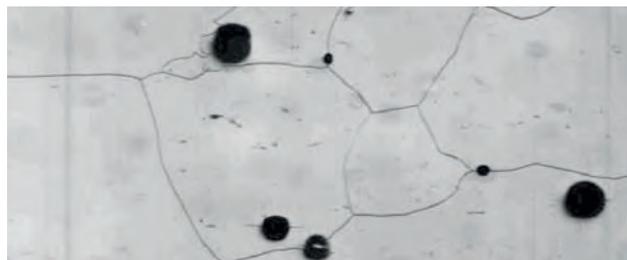
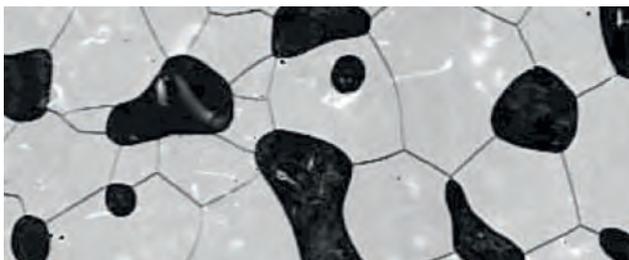
Schäfter + Kirchhoff specializes in developing image acquisition systems for challenging applications, and often implement line scan cameras they develop themselves for this purpose. Line scan cameras are most often employed when the surface to be analyzed is large and yet the smallest details are essential. To obtain a two-dimensional image, the object under study is guided past the camera at a



**1** The scan microscope system from Schäfter+Kirchhoff in action

### CONTACT

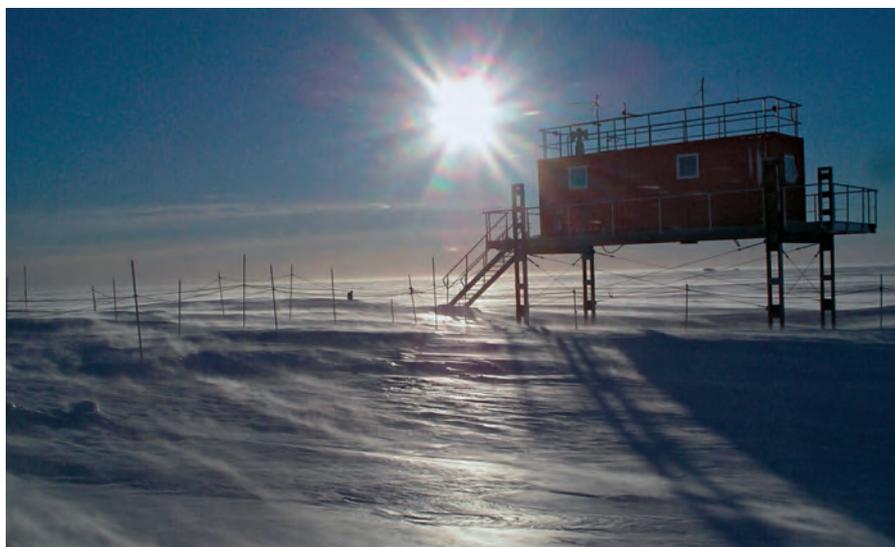
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**2** Scan of an ice core taken from 60 m depth in the Antarctic (above left), where grain boundaries and gas bubbles are clearly visible. At a depth of 615 m (above), gas bubbles are fewer and smaller, while at a depth of 1035 m depth (left) almost all trapped gas has been converted to air hydrates

### 3 Geophysical observatory at the Neumayer Station of the Alfred Wegener Institute just before a snowstorm

(Image: Alfred Wegener Institute for Polar and Marine Research)



precisely defined speed and the image is assembled line by line. The sensor in the Schäfter + Kirchhoff scan macroscope has 8192 pixels and achieves a resolution of  $5\ \mu\text{m}$  over a measuring field width of 41 mm. Thanks to the high line rate of the sensor, it takes just 2.8 seconds to measure a  $41 \times 100\ \text{mm}^2$  area.

#### Stringent requirements for the optics

The need for such high resolution places enormous demands on the optics. A feature size of  $5\ \mu\text{m}$  corresponds to a resolution of 100 lp/mm. With the required magnification of 1.4, this is very close to the theoretical diffraction limit. Moreover, the image data must fill out a sensor that is 57 mm long – compare that to the image diagonal of a standard 35 mm camera, which is just 43.3 mm. The lenses in the ›Linios inspec.x L‹ series from Qioptiq were developed for just this type of application: extremely high resolution with long line sensors. In the scan macroscope, the ›inspec.x L 5.6/105 0.76 x‹ is mounted backwards to give the required magnification of 1.4. **Figure 2** shows the results of scanning ice cores from various depths.

#### Extreme conditions

Not only the optical imaging quality, but the resilience of the entire setup is also important for this application. After all, the scanning of ice cores has to be carried out at a frosty  $30^\circ\text{C}$

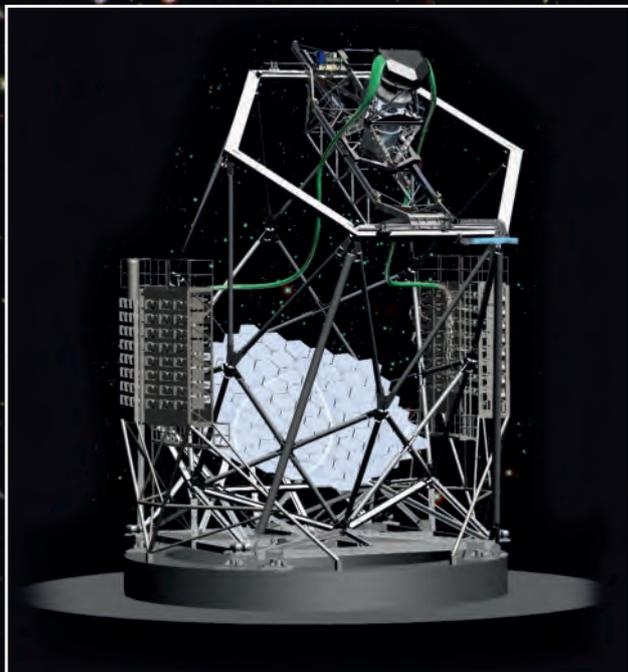
below freezing (**Figure 3**) in order to avoid changes that might occur to the sample before and during image acquisition. At Qioptiq, climate testing of lenses at temperatures down to  $-25^\circ\text{C}$  is standard procedure. That is why Qioptiq technicians were confident that the lens would stand up well in the Antarctic climate. Additional climate tests down to  $-40^\circ\text{C}$ , as well as simulations to evaluate the lens's reaction to changes in temperature, showed that the lens can withstand these extreme conditions while maintaining its optical performance.

#### Summary

With the information gained regarding previous climate fluctuations as well as improved knowledge of the relationships between the principal indicators, scientists can better estimate the likely behavior of the climate now subject to the pressures of modern industrial society. As is so often the case, this type of unique application requires equally performant components in order to be able to realize the full potential – even in this special case, standard Qioptiq optics components were able to deliver the performance necessary. ■

**Georg Zeitlhack** is Vision Technology Sales Manager, and **Thomas Schäffler** is Head of the Vision Technology Market Segment at Qioptiq Photonics, based in Feldkirchen, near Munich, Germany.

1 The ›Hubble Ultra Deep Field‹ – the furthest reaching optical image of the universe, based on 800 individual images from the Hubble Space Telescope, with a total exposure time of 11.3 days. More than 10 000 galaxies have been discovered in the image. The light from the faintest (most distant) galaxies was emitted 13 billion years ago (Image: Space Telescope Science Institute)



2 The Hobby-Eberly Telescope with VIRUS at the McDonald Observatory in West Texas. The segmented main mirror has a diameter of 11 m (Image: University of Texas, Austin)

# Spectroscopy in astrophotonics

**FROM DWARF GALAXIES** to the immense structure of the universe. ›innoF-SPEC Potsdam‹ is a center for innovation competence and works with industrial partners from the region and international research partners to develop innovative technologies for fiber optic spectroscopy on the world's most powerful large telescopes, with the aim of helping to unravel the mysteries of phenomena such as the existence of dark matter and dark energy.

MARTIN M. ROTH  
ANDREAS KELZ  
LUZ MARINA CAIRÓS BARRETO

Appropriately for the International Year of Astronomy, the 2009 Nobel Prize for Physics was awarded for the development of optical glass fibers (Charles Kao) and the CCD detector (Willard Boyle and George Smith), two key technologies from the area of photonics that have been used to make the most important discoveries in modern observational astrophysics in the optical spectral range.

## CCD imaging

The development of the CCD detector for scientific imaging on satellite missions back in the 1980's marked a genuine revolution in image sensors – and ultimately sounded the death knell for celluloid.

The deepest view that mankind has ever had into the universe is thanks to a total exposure of more than 100 hours with the ACS camera on the Hubble Space Telescope (Figure 1). The ›Hubble Ultra Deep Field‹ (HUDF) shows more than 10 000 galaxies, including the remotest objects that emitted their light when the universe was just 10 percent of its current age since the Big Bang – an image of incalculable value for cosmology and extra-galactic astrophysics.

Scientists from all over the world can compare the brightness, morphology, color and spatial distribution of galaxies with simulations on supercomputers, in order to understand the large scale structure of matter in the universe and the evolution of galaxies up to their current appearance. For example, in the early stages of the universe, that is, among the weakest and most distant objects, there is an above average abundance of irregular dwarf galaxies – an indication that seems to confirm



3 The VIRUS-P prototype gimbal mounted on the 2.7 m Harlan Smith Telescope, McDonald Observatory (Image: University of Texas, Austin)

the theory of a hierarchical scenario for the formation of galaxies, which manifests itself as a continuous merging process from dwarf galaxies to constantly growing spiral or elliptical galaxies.

### Fiber optic multi-channel spectroscopy

Alongside direct imaging, spectroscopy is the most important technology for observational astronomy in the optical spectral range. Astrophysicists can compare spectra with theoretical model calculations to identify physical state variables such as gravity and temperature in stellar atmospheres, electron density and temperature in ionized gas nebulae (H II regions, planetary nebulae, supernova remnants), or the abundance of chemical elements and the age of stars. By utilizing the Doppler effect, the radial velocity of stars, gas nebulae and galaxies, as well as the rotation speed and mass of galaxies can be measured. In addition, one can obtain proof of supermassive black holes at the center of galaxies, the existence and mass of extra-solar planets, and many other important astrophysical variables.

Compared to direct imaging, spectroscopy is definitively more informative, but is also much more costly. Depending on the spectral resolution, objects with a continuous spectral energy distribution typically require exposure times 100 to 10 000 times longer than for a broad band image to obtain the same signal to noise ratio. In view of the exposure times of many hours per object, which are indispensable on a modern 8m-class telescope for galaxies with high redshift, the limits of feasibility are quickly reached when we consider the sample sizes required to test cosmological theories. As the operating costs alone for a large telescope are approximately 50 000 Euro per night of observation, spectroscopy on all 10 000 galaxies in the HUDF would be inaffordable.

A solution to this dilemma has been found with the development of multiplex systems, in which the spectra of multiple individual objects within the telescope's field of view can be recorded simultaneously with just a single exposure (multi-channel spectroscopy). With

multiplex factors in the range of 300 to 5000, fiber optical multi-channel spectrographs in astrophysics are by far the most powerful systems in the world.

When it comes to these instruments, we differentiate

between two basic sampling methods: multi-object spectrographs, which use a positioning robot to move fiber probes to any number of objects distributed across the field of view (one fiber per object), or integral field spectrographs, which use a fiber bundle to sample a contiguous two-dimensional field of view (imaging spectroscopy).

### The HETDEX project and the VIRUS instrument in Texas

The Multichannel Spectroscopy Group based at the Astrophysics Institute Potsdam (AIP) and belonging to the innoF-SPEC Potsdam Center for Innovation Competence (supported by the BMBF – German Ministry of Education and Research), is focused on researching new technologies for these two ►

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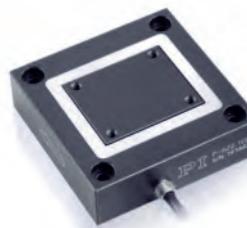
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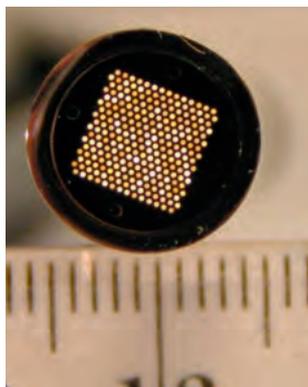
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key applications in astrophysics – preferentially those considered to additionally have significant potential for technology transfer, in particular into medical technology, food sciences and pharmaceuticals.

The most interesting current projects include the development of the VIRUS (Visual Integral-field Replicable-Unit Spectrograph) instrument (**Figure 2**), which, as part of the ›Hobby-Eberly Telescope Dark Energy Experiment‹ at the University of Texas



**4** An integral field unit fiber bundle for VIRUS

(Image: Astrophysical Institute Potsdam)

(Austin, TX, USA), is designed to spectroscopically study a sample of 1 million galaxies that lie within the red shift range  $z = 1.8$  to  $3.8$ . The aim is to deal with the complexity of the project with a consistent, modular structure made up of replicable – that is, economically produced – subsystems. Upon completion, VIRUS will contain no less than 150 spectrographs, fed by 75 fiber bundles and made up of a total of around 34 000 optical fibers (corresponding to an overall fiber length of 750 km).

In conjunction with industrial partners from the Berlin-Brandenburg region, the AIP is responsible for the design, manufacture and acceptance of the fiber optical subsystems. Following an exhaustive selection process, Leoni Fiber Tech in Berlin was identified as the ideal supplier of the fiber-optic systems.

### ›First Light‹ with VIRUS-P

Just like the launch of a ship in a maritime context, ›first light‹ is a significant milestone in the development of an astronomical observation instrument. As proof of concept, construction of the ›VIRUS-P‹ prototype demonstrated the feasibility of a small series of the fully equipped VIRUS instrument and tested the capabilities of the central assembly on the telescope (**Figure 3**). VIRUS-P is equipped with an imaging fiber bundle (integral field unit, IFU) (**Figure 4**). After passing the initial technical evaluation, the instrument is now being used for scientific work.

In the only BCD (blue compact dwarf) galaxy survey of its kind worldwide, and under the leadership of Dr. Cairós Barreto, the AIP is currently carrying out a spectroscopic analysis of the exact class of objects that appear to be the weakest and most distant galaxies in the HUDF and which are thought to be the building blocks of the galaxies that exist today, such as the Milky Way. **Figure 5** shows an image of the roughly 70 million light year distant galaxy ›IIIZw102‹, named after its discoverer Franz Zwicky, depicted with an overlay of the fiber bundle grid (top) and also shown with a color-coded velocity field for the stellar components as reconstructed from the Doppler shifts of the individual spectra (bottom).

### Summary

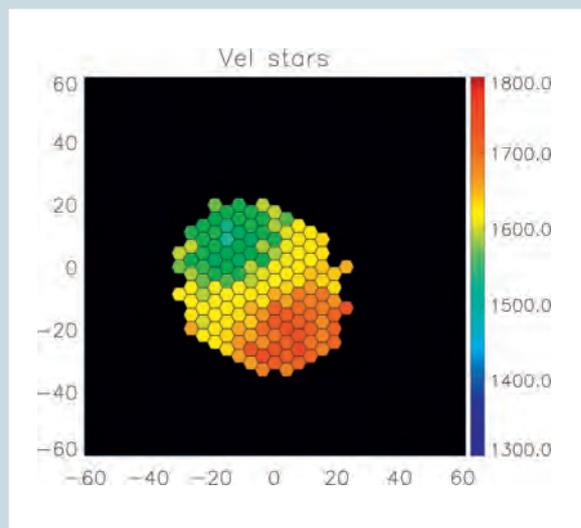
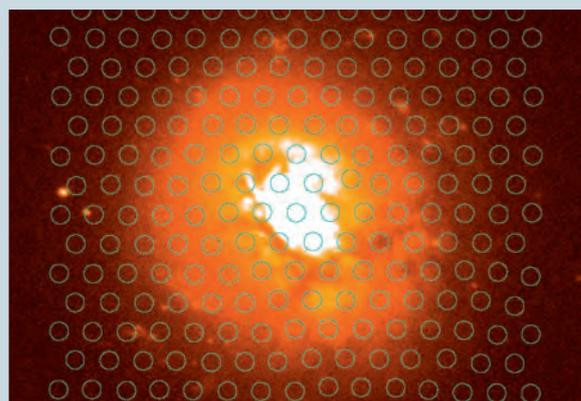
Thanks to the use of key technologies from the fields of optics, mechanics, electronics, computers, and communication, astrophysics is currently experiencing a golden age, with revolutionary findings about the structure and development of the universe as well as unsolved problems in particle physics.

Innovative fiber optics play a vital role, for example for the efficient use of high-resolution echelle and multi-channel spectrographs. Throughout the world, researchers in the relatively new field of ›astrophotonics‹ are working alongside industrial partners on new concepts for light guiding structures and photonic technologies for the next generation of instruments with applications in astronomy and other disciplines. ■

Dr. **Martin M. Roth** gained his doctorate at the LMU Munich and has been responsible for instrument development at the AIP since 1994. In 2010, he was appointed to the new position of Professor of Astrophotonics by the University of Potsdam.

Dr. **Andreas Kelz** has worked as a scientist at AIP for 10 years on the development of fiber optics for 3D spectroscopy. He graduated from the TU Darmstadt in Physics and gained his doctorate at the University of Sydney.

Dr. **Luz Marina Cairós Barreto** is a specialist in the study of dwarf galaxies. She gained her doctorate at the IAC (Tenerife) and, after holding research positions in Chile and Göttingen, came to Potsdam on a Humboldt scholarship in 2006.



**5** The blue compact dwarf galaxy ›IIIZw102‹, captured with the fiber bundle from VIRUS-P. Top: Overlay of the fiber bundle on an image. Bottom: Velocity field reconstructed from the Doppler shifts observed in the individual spectra. The rotation of the galaxy can clearly be identified above the red shift of the system (~1600 km/s)

(Image: Astrophysics Institute Potsdam)

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# Interview

**Leoni Fiber Optics**, part of the Leoni Group, is a developer and supplier of high quality fibers and customized fiber optic solutions. **Laser+Photonics** talked to **Andreas Weinert**, Vice President of Fiber Optics at the Leoni Group.

**Laser+Photonics:** Leoni Fiber Optics is a leading manufacturer of highly specialized fiber optic solutions. Which markets do you operate in?

**Andreas Weinert:** We operate in the industrial, scientific, and life sciences markets, with products for the transport of light as an energy carrier and as a carrier of analog or digital information. This enables the entire range of applications to be addressed, in laser beam guidance, spectrometry, image transmission and data communication. Our product range for these applications includes single- and multi-mode fibers, POF and PCF cables, fiber optic cables, bundles and probes, as well as special fiber optic components, such as arrays, splitters and switches.

**Laser+Photonics:** Where are the most important markets for Leoni?

**Weinert:** To be honest, they are worldwide. We look at the entire market and draw conclusions based on this. We have an excellent overview of the market situation, the competition and the current state of technology – this is the only way we can operate as a customer-oriented supplier of fiber optic technology.

We are strong in Europe, but thanks to focused measures we are closing in on our goal of generating increased growth in Asia and in North America. A key milestone was publishing our 320-page product catalog in English for the first time, which met with great response from customers.

**Laser+Photonics:** In setting yourselves such demanding targets, you need to be suitably (and vertically) well prepared.

**Weinert:** Because of the acquisition policy adopted by the Leoni Group in recent years, Leoni Fiber Optics is now one of only a dozen companies worldwide that has an expansive command of the fiber optics sector. More specifically, this means that we have development and production expertise in the areas of pre-



form production, fiber drawing, fiber bundle production, cable manufacture, component assembly, planar waveguides, connector design, optical switches and arrays. These basic technologies are split among our seven locations throughout Germany and networking our specialists enables us to supply our markets with genuinely new solutions. Our broad experience means that we can offer potential customers complete systems. In other words, we design specific fibers for the customer, produce their specific fiber optic cables with their specific components, overall a product that systematically solves the relevant problem.

**Laser+Photonics:** Where do you look for potential customers specifically?

**Weinert:** As well as our presence at leading international trade fairs and an equally strong presence at industry fairs, our websites are a key medium for us. As I mentioned already, our printed catalog, detailing more than ten thousand product solutions, is also a key element. The introduction of the four product brands – FiberConnect, FiberTech, FiberSplit and FiberSwitch – has made our marketing more structured and makes it easier for us to approach potential customers.

To get closer to our customers, we are consistently moving towards regional markets, working closely with our subsidiary in North America and our regional Leoni offices, for example those in Scandinavia, France and China.

**Laser+Photonics:** How do you stay at the cutting edge of technology? Do you take part in international projects?

**Weinert:** We are involved in some projects, both internationally and as part of national projects within Germany. In particular, we are currently involved in developing new multi-channel switches for networks and in improving fiber properties for use with high power lasers.

**Laser+Photonics:** Which technologies has Leoni Fiber Optics been working on in the recent past?

**Weinert:** As an example, we have been working on new fiber bundles for spatially resolved spectroscopy in astrophotonics [see main article – Editor]. We have developed pitch converters based on planar waveguide technology. For example, this technology enables the minimum core-to-core distance in single-mode fibers to be reduced to 40  $\mu\text{m}$ . In fiber technology, we have developed fibers that are significantly less sensitive to bending. I should also mention the development of our new solarization resistant fibers.

**Laser+Photonics:** One keeps hearing about the advance of FTTH.

**Weinert:** Japan, South Korea and the Scandinavian countries are pioneers in this technology. So far, only relatively small projects have been set-up here in Germany. We have a presence in this market with the Leoni Telecommunication Networks division. We already supply all of the required components, from cables to sleeves, connectors, branching points and the like, and we are convinced that this market segment will become more important in the future.



### TRIOPTICS GmbH

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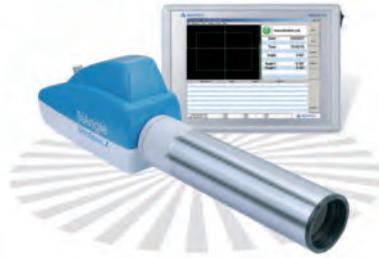
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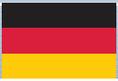
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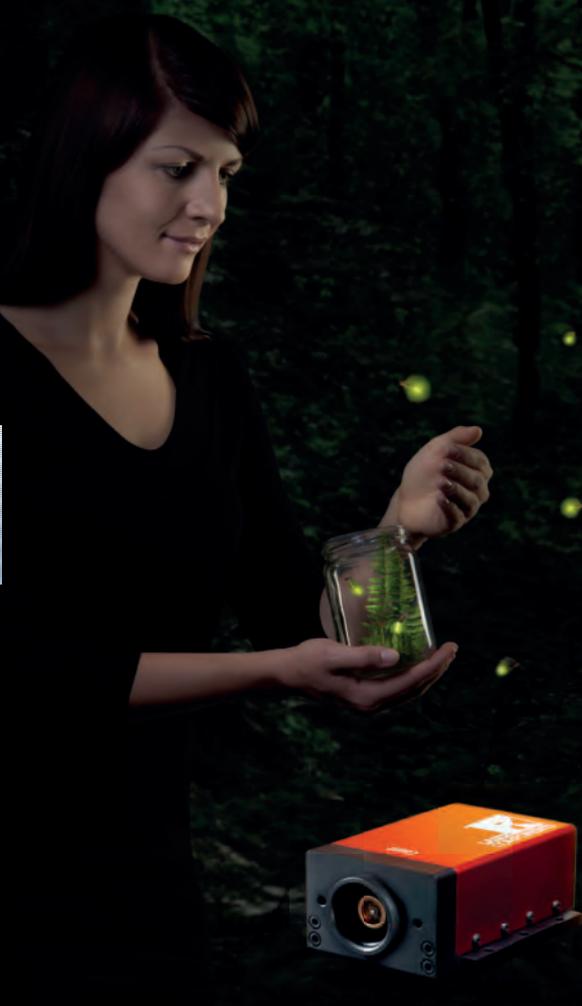
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LASER COMPONENTS specializes in the development, production and sales of components and services for laser technology and optoelectronics and offers one of the largest product portfolios worldwide. The focus of the company is clearly the manufacture of customer-specific products. More than 120 employees worldwide produce and distribute components.

Our in-house manufacturing capabilities play an important role in our product portfolio which comprises avalanche photodiodes and pulsed laser diodes for rangefinding, laser diode modules and optical measurement technology, and the assembly of fibers for e.g. medical applications.

One of the most important product lines at LASER COMPONENTS is our optical coatings. High damage thresholds and short delivery times as well as the ability to customize are the traits of our optics. Our high quality standard, our flexibility, and our fast response time have made LASER COMPONENTS a trusted name among coating manufacturers.

Expanding this reputation, we added manufacturing capabilities for optical substrates in 2008. Our customers can now enjoy the benefits of prototypes being delivered within a very short time.

Since 2010 we also manufacture photon counting modules with the lowest dark count rate and highest quantum efficiency available on the market.

**Fields of activity**

- Laser optics
- Fiber optics
- Laser diodes
- Detectors (UV-IR)
- Measurement technology
- Laser accessories

**Range of services**

- Development, production, and distribution of optical and optoelectronic components
- Calibration center for laser power meters
- Application laboratory for laser spectroscopy

**Research & development activities**

- Thin layers
- Spectroscopic diode lasers
- Pulsed laser diodes and Si and InGaAs avalanche photodiodes for rangefinding applications
- Photon counting



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### The Company

Leistungselektronik JENA GmbH (LEJ) was formed in 1991 as a spin-off of the research center of Carl Zeiss Jena GmbH. More than 25 years of continuous research and product development in the field of ballasts for gas discharge lamps and complete light sources are the basis of LEJ as a technology company. LEJ supplies a wide range of standard products, plus custom modifications for sophisticated industrial application and use in research and development.

### The products

- High-stability ballasts, lamp housings, ignition modules and compact light sources, glass fiber link, if needed, based on mercury, xenon and mixed gas lamps in the output range of 50 W to 2000 W.
- Electronic ballasts and luminaires for high-power light sources using metal halide, sodium vapor or other comparable of 150 W to 2500 W output.
- Xenon flashers for industrial use in different versions, coupling in optical fibers, flash



energy and frequency adjustable, up to 10 Ws or 100 Hz.

- Lighting modules based on high-power LEDs in different configurations
- Electronic ballasts, processor-controlled, programmable, for UV high power radiation sources for DC or AC, output range from 500 W to 2000 W
- Custom modifications of all standard products, tungsten halogen and deuterium lamp supplies

### Applications

The products find application in: precision mechanical/optical industries, industrial image processing, analytical products, projection, environmental simulation/solar simulation, UV disinfection



### Instrument Systems GmbH

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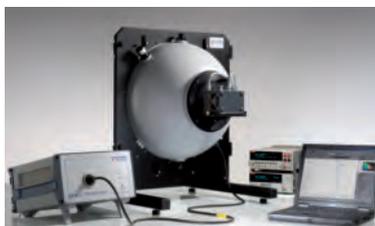
### Solutions for light measurement

Instrument Systems, founded in 1986, is a leading manufacturer for light measurement solutions. The portfolio includes array and scanning spectroradiometers, and imaging photometers and colorimeters. Headquarters are located in Munich and the global customer base is supported by a worldwide network of representatives.

### Core competencies

#### LED measurement

Instrument Systems continues to set the benchmark in LED metrology. Whether testing single LEDs (standard or high-power), LED modules, or OLEDs - the company engineers turnkey solutions ranging from high-speed production testing to high-performance spectroradiometers (e.g. CAS 140 CT series) for R&D and QC. The instruments provide accurate and reliable results as per CIE rec-



ommendations for all relevant parameters like luminous intensity, luminous flux, chromaticity coordinates and color rendering index.

#### Display measurement

Instrument Systems offers a wide range of refined and proven systems for testing displays. The LumiCam 1300 and LumiCam 4000 imaging photometers and colorimeters with GigE interface determine luminance, chromaticity, color temperature and dominant wavelength in a fast and accurate way. The high-resolution LumiCam 4000 captures and evaluates around 11 million pixels simultaneously in a single measurement.

#### Spectroradiometry and photometry

Scanning spectrometers based on single or double monochromators are used for precise determination of radiant power, radiant intensity and irradiance. The SPECTRO 320 series covers a spectral range from 190 to 5000 nm and meets the highest requirements for wavelength accuracy, signal dynamic range and low stray light.



## Solutions from Optics Balzers

Optics Balzers is the leading European competence center for optical coatings and components, and worldwide the preferred and independent partner for the photonics industry. The company possesses a broad and in-depth know-how in optical thin-film coating processes, complemented by sophisticated patterning, glass bonding and sealing, and further processing capabilities necessary for producing optical thin-film coated components up to optical subassemblies. Highly experienced and skilled development and engineering teams closely collaborate with customers to develop innovative solutions meeting their specific and unique requirements and design robust processes to manufacture the customer specific components. The combination of these capabilities and skills places Optics Balzers at the forefront of markets in the photonics industry such as Sensors & Imaging, Biophotonics, Space & Defence, Lighting & Projection and Industrial Applications.

With over 60 years of experience in optical coating technology, Optics Balzers possesses profound knowledge in optical component manufacturing. Customers benefit from state-of-the-art vacuum-deposition technologies, various adapted patterning, bonding and glass processing technologies operated in modern facilities with clean room environments.

With its acquisition of mso jena Mikroschichtoptik GmbH in Jena, Germany, Optics Balzers is expanding its competencies and manufacturing technologies into a unique portfolio, generating added value for customers.

Optics Balzers' continuous innovation, quality improvements, additions of expertise and production sites in Liechtenstein and the EU, will continue to support customers' novel product development efforts with Optics Balzers as a trusted, reliable, and innovative partner.

### Examples of Optical Coatings & Components

- Anti-reflection coatings
- Matched ITO coatings
- Opaque chrome coatings
- Bandpass filters
- NIR filters
- Notch filters
- UV filters
- Filter Arrays
- Filter-on-chip

### Sealing Technologies

- Gelot™ solderable coatings
- B-stage Epoxy

### Patterning

- Photolithography
- Laser Ablation
- Masked coatings



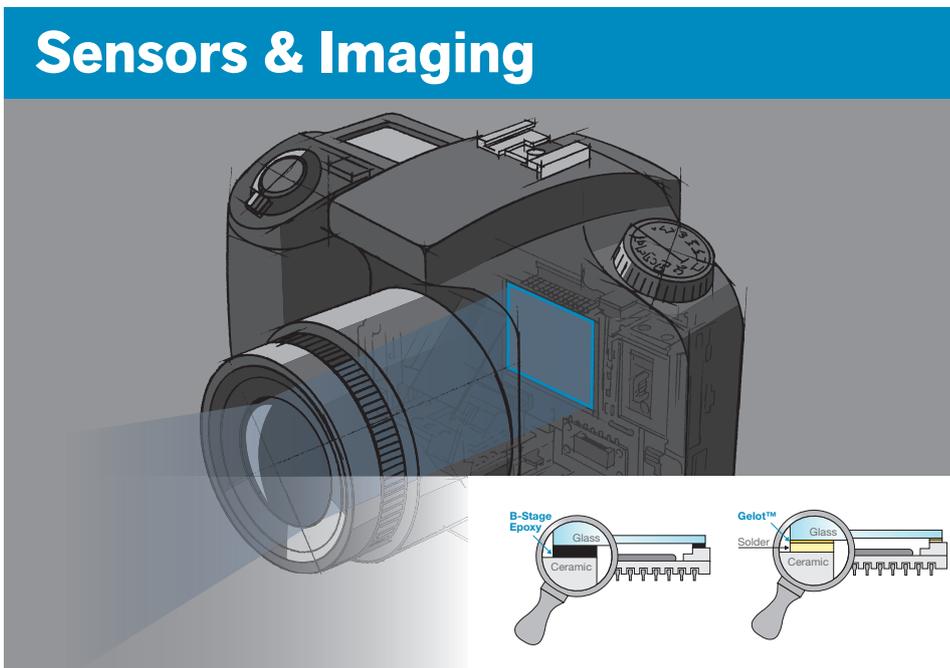
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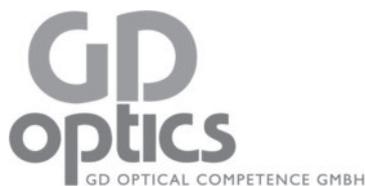
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## Sensors & Imaging





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E-Mail: info@gdoptics.de  
Internet: www.gdoptics.de

## Homogeneous lines

**Laser line modules.** IMM Photonics offers laser diode modules that project high-quality homogeneous lines. Special line generators facilitate a consistent homogeneous intensity distribution along the line – without any interference from ›intensity holes‹. The extremely straight run of the lines makes these laser line modules an excellent tool for premium measuring systems. The following aperture angles (full angles) are feasible: 10, 30, 45, 60, 90, or 96°. Typical wave



lengths are in the range of 635 to 850 nm. The optical output power can be customized and may be up to 200 mW depending on the wavelength.

[www.imm-photonics.de](http://www.imm-photonics.de)

## Pulse energies up to 1 joule

**ps-laser.** The ›picoRegen High-Energy‹ is based on High Q Laser's ›picoRegen Science‹, a regenerative amplifier providing a maximum pulse energy of 3 mJ and a pulse duration of 12 ps. The laser can be operated in single-pulse mode as well as with a repetition rate of up to 1 kHz. The pulse energy of the laser system can be further increased with an additional post-amplification module. Two options are feasible: a lamp-pumped post-amplification module enabling a maximum pulse energy of 1 joule at a repetition rate of up to 10 Hz, or a diode-pumped set-up increasing the energy to 200 mJ at a maximum repetition rate of up to 200 Hz. The maximum pulse energy available varies with pulse duration and has to be customized to individual needs. The design of the picoRegen Science is based on a ›modules-in-the-box‹ set-up in which the seed laser and the regenerative



amplifier are assembled as self-contained modules onto a common, thermally stabilized base platform. This offers a high spatial and temporal stability at low maintenance cost. Additional optional modules such as pulse picker or frequency converter are integrated in the same way. To minimize system complexity, the Pockels cell and end-mirror are integrated in the amplifier module. The seed laser as well as the amplifier is pumped by user-replaceable fiber-coupled diode modules (URDM) that can be easily replaced in the field. These specifications along with the compact design make the picoRegen High-Energy an ideal tool for scientific applications in the field of high-energy physics or nonlinear optics.

[www.highqlaser.at](http://www.highqlaser.at)

## Small footprint

**Diode laser.** Lumics presents the ›LuOcean‹, a diode laser for solid-state and fiber laser pumping (Tm, Er, Nd and Yb). It emits either cw or up to 300 W pulsed power out of a 300 or 600  $\mu\text{m}$  fiber, with a wavelength tolerance of  $\pm 3$  nm. A collimated free space beam is also available. The key feature of this laser is the small footprint and a weight of only about 400 g (15 oz), enabling a slim design of fiber laser systems. A water-cooled base plate and optional Peltier elements (TEC) for stabilization and fine-tuning of the output power and wavelength can be provided. For prototype development, a complete turn-key solution including TEC-control can be offered.

[www.lumics.com](http://www.lumics.com)



## Coherence lengths of up to 100 m

**SLM diode lasers.** Laser 2000 is now offering narrow-band diode lasers in a new compact design. The narrow-band diode lasers from Crystalaser feature an internal optical feedback to force the laser diode, which normally operates in several modes, onto a single longitudinal mode. As a result, the laser diode operates in a narrow band with MHz linewidths and a coherence length of up to 100 m. A feature that stabilizes the temperature of the laser head and a low-noise controller ensure a high degree of long-term stability and low noise levels. Beam forming optics guarantees an almost perfect circular beam with a very good  $M^2$  value. The available wavelengths range from UV at 375 nm through the visible spectrum to



near infrared at 1552 nm. The optical power lies between 5 and 800 mW. Narrow-band diode lasers are typically used in interferometry, Raman spectroscopy and microscopy, sensor technology and analytical devices.

[www.laser2000.de](http://www.laser2000.de)

## With two parallel wavelengths

**Medical laser.** Limo has complemented its compact 1470 nm diode laser with an additional parallel wavelength. The laser can now be ordered in combination with one of the standard 810, 940 or 980 nm wavelengths, which can be separately controlled. The output of the fiber-coupled laser is 15 and 30 W respectively. Outputs > 100 W are available on request. The compact dimensions of the electrically floating enclosure with integrated



protective window, fiber contact switch, monitor diode and pilot laser allow for the incorporation of the laser in end-user products. This helps to save space and expenses, as additional development and production cost can be avoided. The laser can be deployed at virtually any working and ambient temperature and in virtually any operating mode from cw to pulsed at a variety of settings. The modules are all maintenance free. Flexible guarantee periods can thus be offered, with exchange free of charge. The laser is suited especially for medical procedures in surgery and urology.

[www.limo.de](http://www.limo.de)

## For photovoltaics

**Disk laser.** The laser division of Jenoptik is introducing the new infrared disk laser ›JenLas disk IR70‹, which has been developed especially for the new technologies in photovoltaics, aiming to improve the electrical efficiency of solar cells – such as ›metal wrap through‹ (MWT) or ›emitter wrap through‹ (EWT, with up to 20 000 holes per second). To increase the active area of the cell, both technologies move the electrical contacts from the front to the back of the cell. The conventional contact strips, which cover parts of the active surface, are therefore partially eliminated. Other potential applications for the JenLas disk IR70 include long-distance marking of wafers, ›laser-fired contacts (LFC) as well as laser edge isolation. The laser pulse lengths can be adjusted independently of the repetition rate to enable optimal process parameters to be set. The JenLas disk IR70 covers a wide range of applications in the infrared wavelength range at 1030 nm with pulse energies up to 7 mJ and repetition rates up to 100 kHz. Consequently, this 65 W system is ideal for the manufacture of efficient back-contact solar cells.

[www.jenoptik.com](http://www.jenoptik.com)

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# Reaching for the stars

**NARROW-BAND TUNABLE** and highly amplified diode lasers for next-generation large telescopes. For controlling adaptive optics in large telescopes, so-called ›laser guide stars‹ will be used. Combining a wavelength-stabilized diode laser with a Raman fiber amplifier and efficient frequency doubling yields tunable, narrow-band, diffraction-limited continuous wave laser light, with an output power of more than 20 W. This ›guide star‹ laser enables ground-based astronomical observations with ten times higher resolution than with the Hubble telescope.

MARION LANG  
WILHELM KAENDERS

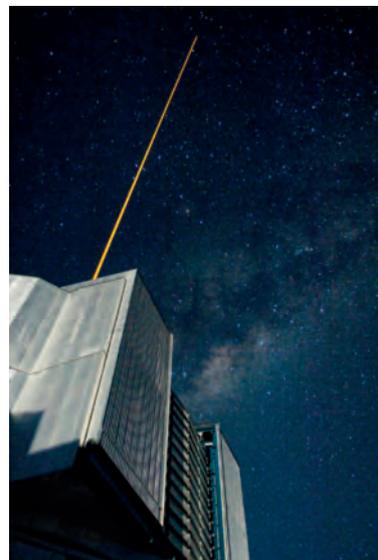
Increasing performance requirements in astronomy have led to the development of telescopes or multi-telescope systems with ever larger primary mirrors (diameters of up to 30 m). Known as ›Extremely Large Telescopes‹ (ELTs), they are capable of resolving ever finer details of the night sky. However, the actual resolution achieved by earth-bound telescopes is well below the theoretical resolution of a few tens of milli-arcseconds. The reason for this is the dynamics of the earth's atmosphere – turbulences between layers with different temperatures lead to a continual and dynamic distortion of the wavefronts arriving from the objects being observed.

To circumvent these atmospheric issues, space telescopes such as the Hubble telescope were developed. However, not only are these systems extremely expensive, the mirror diameter that can be implemented is limited by the maximum payload that modern rockets can transport into earth orbit.

## Adaptive optics

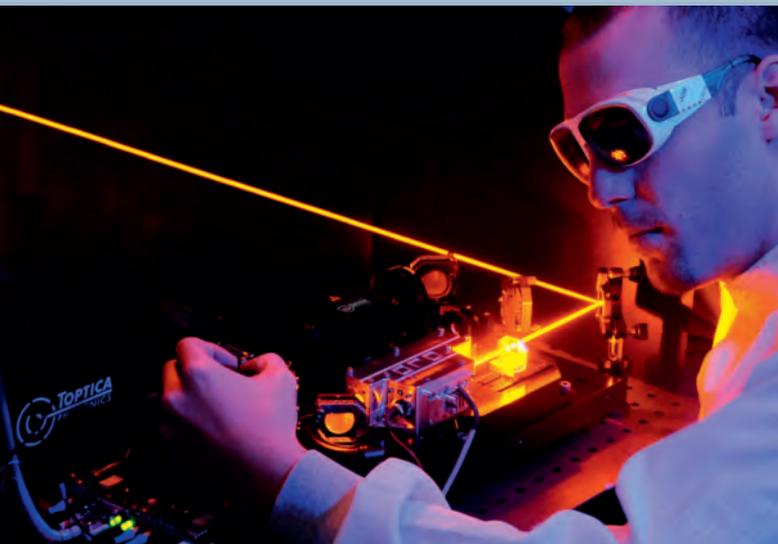
For several years, a technique called adaptive optics has been employed in earth-bound telescopes in order to increase their resolution. The technique makes use of a deformable mirror in the telescope's beam path to introduce an additional and dynamic wavefront change designed to complement (negate) the fluctuating wavefront deformation introduced by the atmosphere. With actuators on the rear of the mirror making adjustments at up to 1000 times per second, the result is a significant increase in the spatial resolution of the telescope.

Appropriate reference objects for adaptive optics are ›natural guide stars‹, or, as these are only available to a limited extent, so-called ›laser guide stars‹ (LGSs). These are artificially generated ›stars‹ that act as a point-like light source in the earth's outer atmosphere. The light emitted by a LGS is subjected to the same deformation as that originating from astronomical objects. Adaptive optics reproduces the image of the guide star as a point object on the detector, and in doing so simultaneously corrects the wavefront distortion for light emanating from astronomical objects on the same line of observation.



**1 Future application of the SodiumStar: The narrow-band tunable diode laser excites sodium atoms in the mesosphere. The resulting point-like beam spot acts as a reference for the adaptive optics of the telescope**

(Image: G. Hühdepohl/ESO)



**2** Development of the 20 W laser with TEM<sub>00</sub> at 589 nm and a linewidth of less than 5 MHz

**Generating artificial stars**

Sodium atoms are present in the mesosphere, roughly 90 to 110 km above the earth’s surface. These atoms can be resonantly excited by use of a suitable laser, and it is the resulting fluorescence signal that is used by the adaptive optics system (Figure 1). In the past, the sodium wavelength has been generated using dye lasers or sum frequency mixing of solid state lasers. However, these lasers are either somewhat cumbersome to operate, or require continuous and intensive maintenance, respectively. By contrast, a compact, robust system has now been developed – termed ‘SodiumStar’ – that

generates the required output at the resonant wavelength of the sodium D<sub>2</sub> line, all with higher efficiency, less complexity and at lower cost (Figure 2).

The operational requirements for guide star lasers are very high. In order to achieve a sufficiently strong fluorescence signal, they must provide very high power levels at the sodium wavelength of 589 nm. Their linewidth may not exceed 5 MHz and, because of the hyperfine structure of sodium, it must be possible to fine-tune their frequency. Besides the high requirements in terms of optical beam quality (TEM<sub>00</sub>), the optomechanics of the laser must also be able to cope with extreme demands.

**Reliability under adverse conditions**

As a consequence of light pollution, large telescopes are usually installed in very remote locations and at high altitude. ▶



**3** New flexure design for the ‘pro’ technology

# disco vernew sCMOS

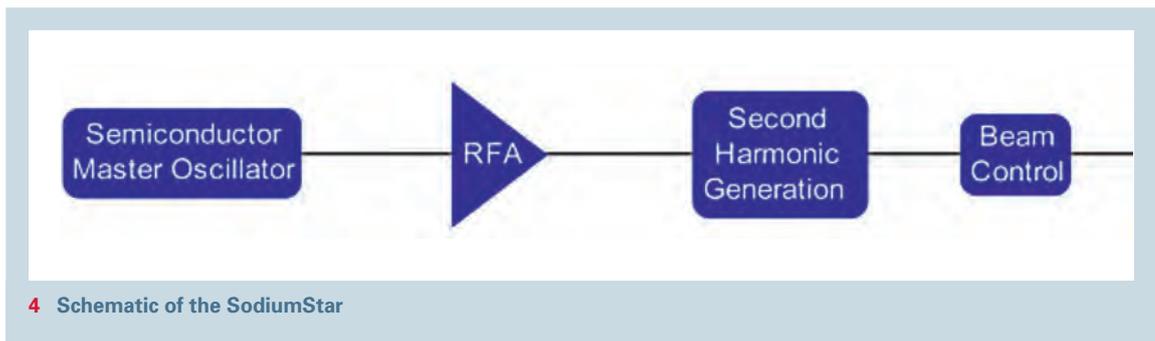
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**< 1.4 electrons**
- dynamic range  
**> 22000 : 1**
- maximum frame rate  
**100 frames / s**

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imaging



For example, the ›Very Large Telescope‹ belonging to the European Southern Observatory (ESO) is located on Cerro Paranal (Chile) at 2600 m above sea level, while the telescopes on Mauna Kea in Hawaii are located at 4000 m. Cerro Paranal is also located in an area at risk to earthquakes. This brings additional requirements in terms of stability and safety, as the system must be able to remain functional while withstanding earthquakes up to magnitude 8 on the Richter scale.

The temperature range in which the laser is operated ranges from -8 to +20°C. The temperature of the outer skin of the laser may only differ from the ambient temperature by a maximum of 1.5°C. This places major demands on the laser cooling system, in particular as fans may not be used for cooling and convective cooling at high altitude is very inefficient.

The laser head is installed adjacent to the primary mirror of the telescope. Because observation time is very expensive, the laser must be ready for use at all times. In order to correct misalignment over long time scales, remote-controlled industrial servo motors have been incorporated into the system. And, if the laser

should fail, a modular design enables straightforward replacement of individual components.

During operation the laser head swivels and rotates along with the telescope. Thus, considerable attention needs to be paid to proper function and beam steering for a variable gravitational vector. While short overall beam paths reduce sensitivity to vibrations and temperature changes, milling the entire laser head from a single block helps enhance overall mechanical stability.

### 20 W power output at 589 nm thanks to ›pro‹

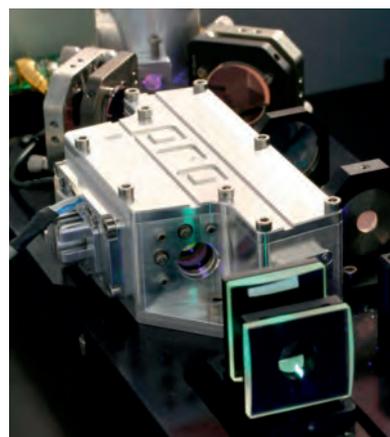
Toptica's SodiumStar uses established ›pro‹ technology to meet these demanding stability requirements. Originally conceived for scientific laser applications, the pro design was developed to achieve maximum stability against vibrations, acoustic noise and temperature changes, at the same time guaranteeing reliable and optimized hands-off operation. It features a revised optomechanical concept, making use of innovative flexures and a monolithic design (Figure 3), and has already been successfully implemented in many widely-used laser systems (for example, in ›DL pro‹ and ›DL SHG pro‹). Another innovation is

the use of special mirror holders with a totally new optomechanical concept. These patent-pending mirror holders were designed using finite element methods (FEM) and are based on non-creep flexures with pretensioned springs.

A grating-stabilized diode laser at a wavelength of 1178 nm serves as master oscillator in the SodiumStar. Both ›distributed feedback‹ (DFB) laser diodes as well as conventional external cavity diode lasers (ECDLs) can be used. Revised optomechanics for ECDLs help these systems achieve improved mode-hop free frequency tuning with maximum stability. For example, pretensioned flexures give the resonator much greater rigidity and thus increase the acoustic resonance frequency of the system to over 3.5 kHz. Coarse and fine-tuning of the wavelength have been decoupled, hence it is now possible to tune the wavelength over a greater range without the need for readjustment. A virtual pivot point for the grating outside of the mechanics allows mode-hop free fine tuning of the frequency over a range of more than 50 GHz.

The narrow band seed laser is amplified to more than 35 W (Figure 4) by a special Raman fiber amplifier (RFA). Via the process of stimulated Raman scattering an RFA generates a high power signal out of the low power seed signal. However, in the past this process was associated with an increase in linewidth. Recently, the ESO laser group achieved a major breakthrough, having developed a method that allows narrow band Raman amplification. This Raman fiber amplification technique has been licensed by Toptica and was further developed for use in the SodiumStar in cooperation with the Canadian company MPB Communications.

Following the amplifier, the laser light has to be frequency doubled to reach the sodium resonance wavelength at 589 nm. For the design of the SHG resonator (Figure 5), Toptica's pro



**5 The SHG unit of the SodiumStar has a monolithic design, making it extremely resistant to vibrations. The novel mirror holders are based on pretensioned flexures**

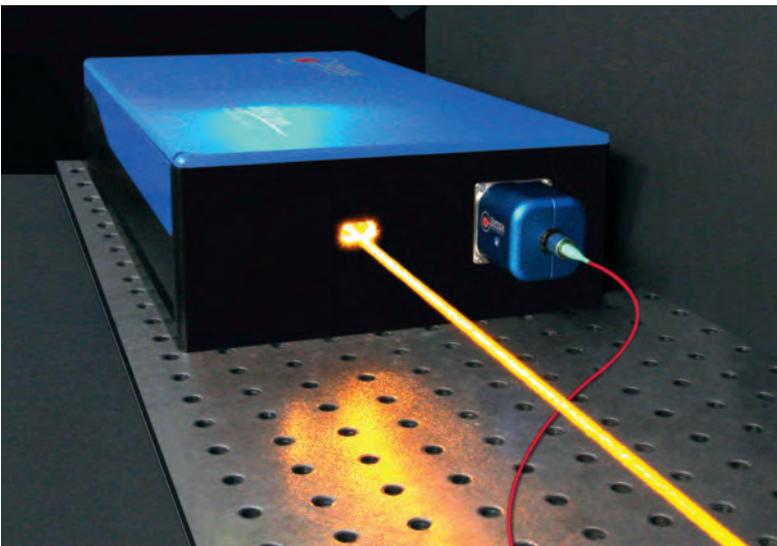
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philosophy has again been consequently applied. The novel monolithic resonator is actively stabilized with respect to temperature and length. Furthermore, it is dust proof, as any contamination inside the resonator would cause catastrophic damage to the optics at the laser intensities present inside the resonator.

**Applications beyond the stars**

The developments resulting from this project will also benefit other products. For example, the DL RFA SHG pro has been developed based on the narrow-band RFAs (Figure 6). With a linewidth of <1 MHz at an output power of 2 W, the system can be used for spectroscopy and cooling of sodium atoms.



**6** The innovative RFA technology is also implemented in the DL RFA SHG pro. The system has an output power of more than 2 W and a linewidth of <1 MHz and is ideally suited for spectroscopy or laser cooling of sodium atoms

The oscillator of this system is a DL100/pro design laser. Beyond that, RFAs enable the realization of high-power continuous wave lasers in a very compact format, at any wavelength between 515 and 620 nm and with tens of watts output power. These are set to be realized in the coming years in conjunction with leading customers.

**Summary**

The SodiumStar is a system that meets all the ESO requirements for a guide star laser. The combination of grating-stabilized diode lasers with an RFA and subsequent frequency doubling results in a narrow-band tunable diffraction-limited laser with an output power of more than 20 W at 589 nm. A revised optomechanical design, short free-beam path lengths and a compact monolithic design benefit aspects such as beam stability and resistance to external mechanical influences and temperature changes, as well as safeguarding system performance under harsh conditions. ■

Dr. **Wilhelm Kaenders** is co-founder and director of Toptica Photonics. In particular, he is responsible for developing new areas of business for the company. Dr. **Marion Lang** is a physicist and works as technical marketing manager at Toptica. She is responsible for the content and technical aspects of the company's publications.

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# High-brightness laser diodes

**A NEW GENERATION OF LASER DIODES** allows five to ten times higher intensities. Their use in particular for pumping fiber lasers or disk lasers has led to a new generation of laser diodes. While the achievable absolute peak outputs previously characterized the requirements for a high-power laser, the usable optical power (the achievable intensity) is of prime interest today. These high-brightness laser diodes are based on an advanced broad area design or the tapered laser concept.

JÜRGEN GILLY  
PATRICK FRIEDMANN  
MÁRC KELEMEN

The success of fiber lasers has led to a thrust in the development of high-brightness diode laser sources. The focus in the past on absolute optical power of a diode laser or a very high electro-optical conversion efficiency for characterizing high-power laser diodes is being increasingly replaced by the specification of brightness.

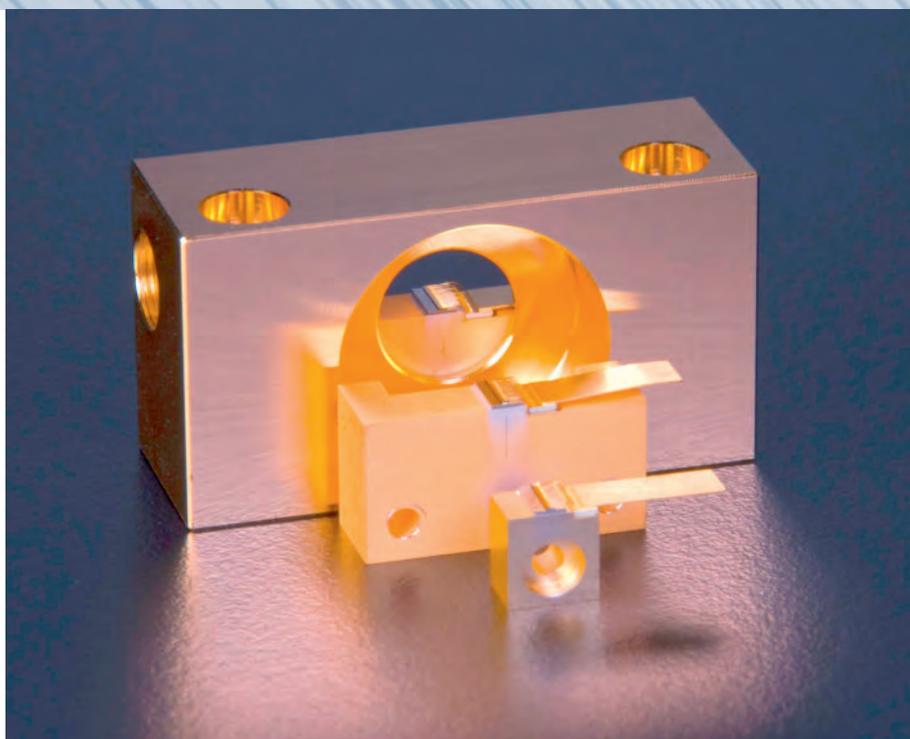
However, conventional high-power laser diodes show relatively poor performance when characterized by this type of specification. A typical brightness value below 20 MW/cm<sup>2</sup> is obtained for high-power lasers, although this level of performance is no longer considered sufficient for pumping applications where the laser light is required to be coupled into the narrowest possible fiber. In recent years, therefore, a new class of laser diodes has been developed, with specific importance given to achieving a high brightness.

The concepts discussed below are all explained on the basis of single emitters, but can of course be implemented on laser diode arrays. Single emitters are usually mounted by means of AuSn soldering via intermediate heat sinks on gold plated copper heat sinks that are then cooled passively (Figure 1).

## Definition of brightness

The brightness of a laser diode is a measure of the power per unit area and solid angle, and thus, in addition to the power specification, also incorporates information on the spatial beam profile. It is defined as the ratio of the optical power to the beam quality in both spatial directions. The beam quality is in turn described by the parameter  $M^2$ , formed by the product of the beam diameter at the exit facet and in the far field.

For laser diodes, the beam has in general an oval cross-section. Although the beam is highly divergent along the vertical axis, it is still Gaussian and can be effectively focused through use of suitable optics. A number of cavity oscillation modes define the form in the lateral direction, so the intensity distribution is not Gaussian and the beam cross-section shows strong intensity



1 High-power laser diodes mounted on different copper heat sinks

fluctuations (filaments). The range of the lateral far field is usually defined as including 95 percent of the optical power.

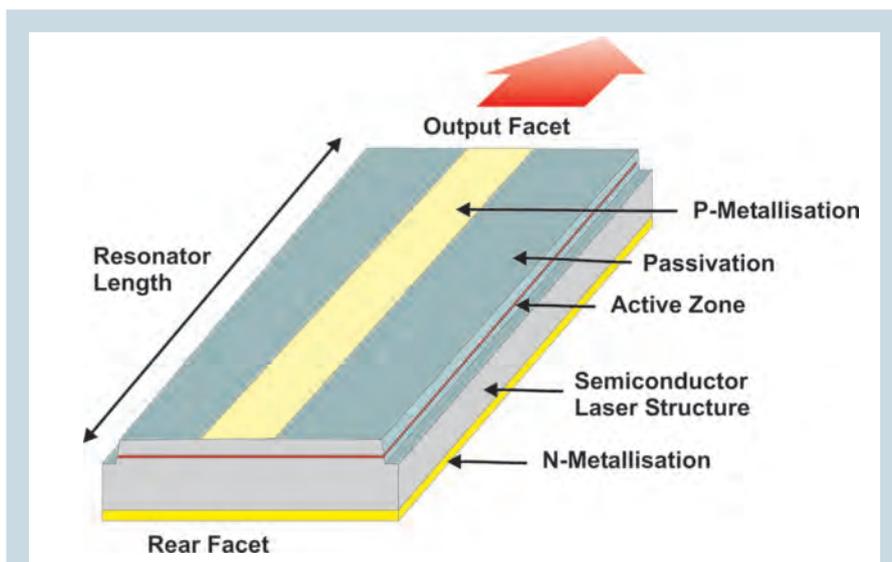
## High-brightness broad area NIR laser diodes

The most commonly used resonator design of a high-power laser diode is that of a broad area laser. This active (light-emitting) area is defined by etching during manufacture, noting that only the highly-doped semiconductor layers are etched in this case – index guiding such as for rib waveguide lasers does not (or only barely) feature. Guidance of the optical mode is achieved via so-called gain guiding, which is itself defined by the current injection into the structure (Figure 2). The width of the active area defines the maximum optical power output of a broad area laser diode, and the physical width of the emission more or less corresponds to the beam diameter at the output facet.

Near infrared refers to the wavelength range from about 880 to 1080 nm. The laser diodes in this wavelength range are based on the GaAs material system, wherein waveguides and cladding

layers are composed of AlGaAs and the active (light-emitting) layer consists of InGaAs. The specific emission wavelength can be set by adjusting the indium content in the InGaAs semiconductor layer.

The brightness is determined as indicated above by the inverse product of emission area width and far-field divergence. To cater to the need for high-brightness devices, the emission width of broad area laser diodes has thus been consequently reduced in recent years from 200 to 150, and down to the 100  $\mu\text{m}$  prevalent today. However, a major disadvantage of the broad area design is that a reduction of the emission width (while keeping other resonator dimensions constant) is always accompanied by an expansion of the lateral far field divergence with increasing operating current. The main cause of this issue is the reduced ability to dissipate the heat generated by losses within the cavity. Thus, in order to satisfactorily increase the brightness of broad area laser diodes, then, in addition to reducing the emission area width, it is also necessary to prevent a rapid thermally-induced growth of the lateral far field beam profile. This requirement can be met by utilizing the longest possible resonators, which



2 Schematic diagram of a diode laser with a broad area laser geometry

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allow for better heat dissipation over a larger area when compared to shorter resonator lengths. At the same time, the total electro-optical efficiency must remain at a high level so as to minimize power loss and thus the amount of heat produced. Long resonator designs in combination with the highest possible electro-optical efficiency can only be realized by vertical laser designs with very low internal losses. Internal losses refer

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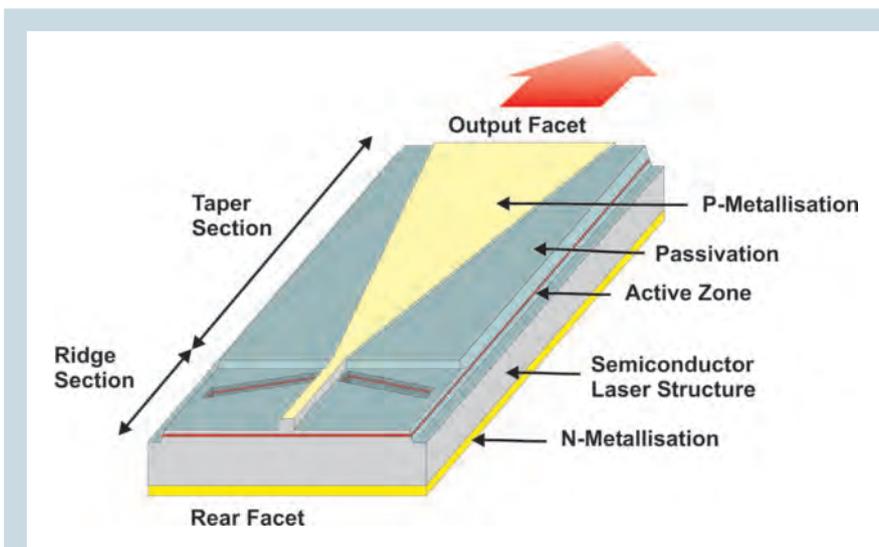
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to the loss of charge carriers in the semiconductor layers that are then no longer available for light output. Specific doping strategies are also requisite and, similarly, an appropriate choice for the semiconductor layers can help optimize the heat dissipation within the diode laser. All of these requirements place very high demands on the capabilities of the (molecular beam) epitaxy system used, and it is for this reason that the types of semiconductor laser structure available today are very much dictated by the type of epitaxy system used for their manufacture.

Finally, and supplementary to optimizing the heat dissipation by extending the resonator length, growth of the lateral far field profile with increasing operating current can also be reduced by adopting appropriate process steps during manufacture. Another major hurdle for increasing brightness results from the limited power density offered by the currently available facet coatings. For a desired optical power output (for example, 10 W), the emission area width is a result of the compromise between the requirement for high brightness and the need to achieve sufficiently long component lifetime by avoiding excessive optical power density through the facet coating.

The overall result is that laser diodes with resonator lengths between 3 and 5 mm and efficiencies of 55 to 65 percent allow a sufficiently high brightness to be achieved for most fiber laser pump applications. A brightness of about 100 MW/cm<sup>2</sup> is obtained, for instance, in a broad area laser with an emission area



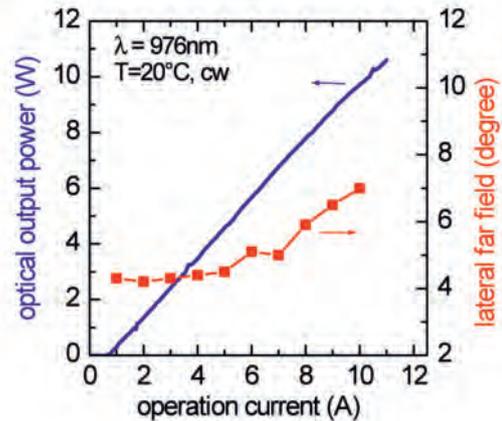
4 Schematic diagram of a diode laser with a tapered laser geometry

width of 100  $\mu\text{m}$  and a resonator length of 5 mm, delivering a lateral far field divergence of less than 8° at an optical power of 10 W (Figure 3). This represents a five-fold increase in brightness compared to conventional broad area laser diodes.

### Tapered laser diodes

To summarize the above case for broad area laser diodes, their brightness is limited principally by the facet technology and the emission area width, the thermally-induced expansion of the lateral far field and the capabilities of the epitaxy system.

Many of these limitations can be circumvented with the concept of the tapered laser diode, a structure that consists of two



3 Optical power and lateral far field divergence for a high-brightness broad area laser

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components that have been monolithically integrated as a MOPA structure onto a single chip. The so-called ridge section is formed by a single-mode laser diode that serves as the oscillator (seed laser). Moving away from the seed laser (with a typical width of 3  $\mu\text{m}$ ), the following tapered structure opens out (as a consequence of the taper angle over the length of the gain channel) to a width of several hundred micrometers at its

output facet. The input power of several tens of mW can thus be boosted to optical powers of several watts (Figure 4). Through suitable choice of the design and an appropriate epitaxy system, then, currently available tapered laser diodes exhibit the same degree of homogeneity in their electro-optical and spatial beam characteristics as the aforementioned high-brightness broad area lasers, with these characteristics remaining constant right across a full production wafer.

Contrary to a broad area laser, the minimum beam width is not determined by the width of the (tapered section's) output facet, but by the width of the ridge section – the result is a beam width 25 times less than comparable broad area lasers of same optical power. Additionally,

the lateral far field is determined by the angle of the tapered section, so that, for example, an angle of 4° results in a far field divergence of 12°.

Because of the angle of the tapered section, an increase in power output can be easily realized by simply extending the length of the tapered section and thus widening the output facet. The minimum beam width remains constant, so too the lateral far field and thus also the beam quality. In this instance, the facet coating no longer plays a limiting role as for broad area laser diodes.

However, one disadvantage of this concept lies with the astigmatism that is introduced, an aspect that must be taken into

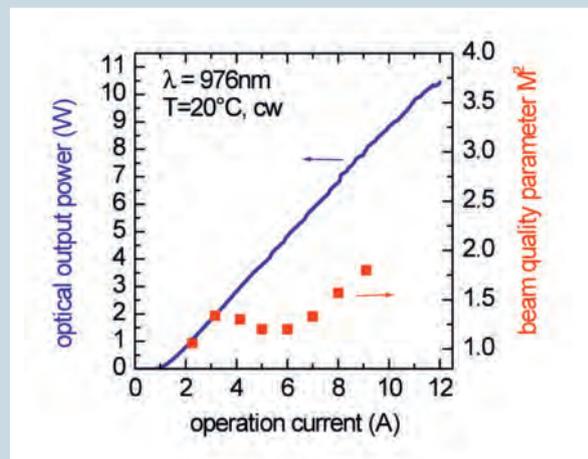
account in the design of the optics to be used. Astigmatism refers to the difference between the position of minimum beam width along the lateral and vertical beam directions. In a broad area laser, both minimum beam widths lie on the emission facet – a result of the symmetrical geometry – and the astigmatism is correspondingly zero. However, for a tapered laser, the minimum beam width in the lateral beam direction lies within the structure. The exact position and thus the degree of astigmatism is determined by the length of the tapered section and the corresponding refractive index of the semi-

conductor layers used. As the effective refractive index also depends on the temperature and the operating current, astigmatism changes upon modification of the parameters.

Depending on the tapered laser design, optical output powers from 5 to 10 W with nearly diffraction-limited beam quality have already been demonstrated in practice. A brightnesses of 200 MW/cm<sup>2</sup> is more or less standard, while record values of over 600 MW/cm<sup>2</sup> are possible (Figure 5).

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5 Optical power and beam quality of a tapered laser

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**Summary**

A new generation of high-power laser diodes provides five to ten times higher optical power densities than conventional laser diodes and are thus particularly well suited for pumping applications. These laser diodes are based either on an advanced broad area design or a tapered laser concept. While the broad area design is increasingly limited in its brightness by the requirements on semiconductor technology and facet coating, tapered laser designs facilitate much higher brightness but also place higher demands on the subsequent optical design needed for collimation. ■

Dr. Marc Kelemen is partner and Managing Director, while Jürgen Gilly and Patrick Friedman are responsible for the development work in the field of high-brightness laser sources at m2k-laser.



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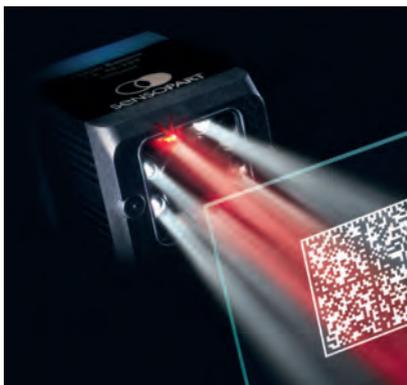
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**Code reader.** The ›FA 46‹ code reader from SensoPart Industriesensorik combines code reading and object recognition in a single unit. It reads both 1D barcodes and 2D data matrix codes complying with the ECC 200 standard and can analyze up to five data matrix and/or barcodes in a search zone, while allowing any number of search zones to be defined. In the same reading process, it is also able to identify other object features such as date imprints or stamps. To do this, it has three additional detectors for object detection (pattern recognition, gray scale and contrast). Thanks to the

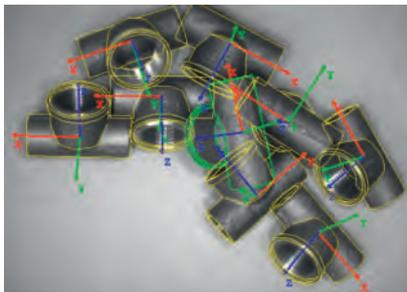


integrated position tracking option, codes and object characteristics can be reliably detected even if they deviate from the taught position. According to SensoPart, the FA 46 is capable of handling complex automation tasks that previously called for a classical image processing system or the use of several sensors, such as applications in which several codes have to be read. The FA 46 consists of a compact camera (45x45x64 mm<sup>3</sup>) with a digital signal processor, integrated infrared, red and white light LEDs, Ethernet and serial RS 422 interface along with digital I/O. Besides versions with integrated 6 or 12 mm lenses, a C-Mount version is also available. The sensor is supplied complete with the required configuration and monitoring software.

[www.sensopart.de](http://www.sensopart.de)

## Halcon 10

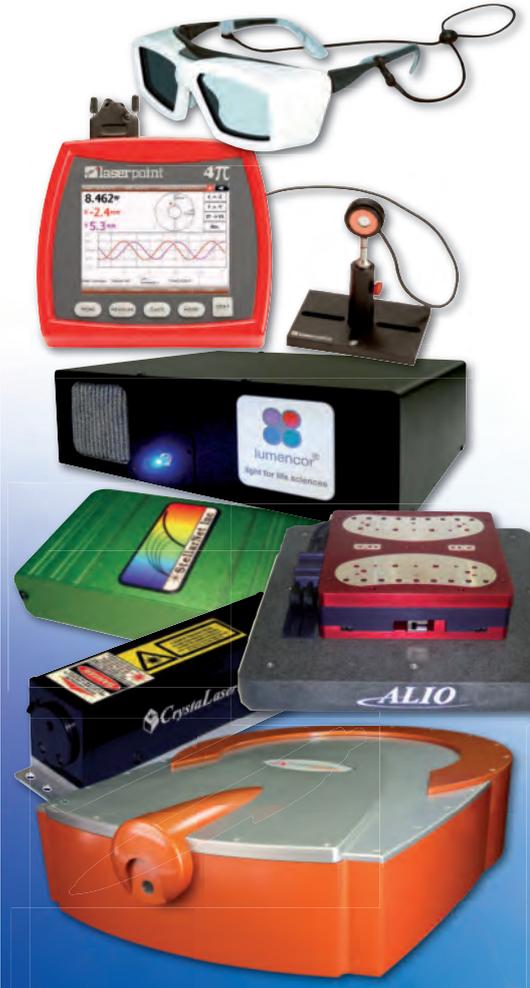
**Machine vision software.** The new ›Halcon 10‹ machine vision software from MVTec Software has expanded its 3D vision features. It includes, for example, a new surface-based 3D matching capability optimized to identify arbitrarily shaped 3D objects in long-range images,



and that is supposed to be particularly adept at recognizing rounded and edgeless objects. The new multi-view stereo capability allows the use of any number of cameras for detailed 3D reconstructions. It compensates for occlusions and facilitates robust robotics applications. Halcon's calibration capabilities have been improved and expanded: a new multi-view 3D calibration function supports an unlimited number of cameras. Halcon 10 is now capable of finding 3D primitives in the image by analyzing 2 1/2 D point plots. A smart text finder supports segmentation in OCR applications and barcode reading. The integrated development environment (IDE) and documentation have also been improved. [www.mvtec.com](http://www.mvtec.com)

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## For extended recording times

**Video system.** Mikrotron has launched a complete high-speed video system for extended recording times. The ›Motion-Blitz LTR1‹ (long time recording) comes as a ready-to-use, complete system including a 19-inch rack PC, a compact 1.3 megapixel high-speed CMOS digital camera from the EoSens-series, Camera Link frame grabber, Camera Link cable, and control software. It can produce video recordings at 506 fps for up to 165 min at full 1280x1024 pixel resolution. Recordings can also be made at rates of up to 30 000 fps with the integrated ROI function, which allows the stepless adjustment of the image area's position, resolution and recording speed.

The high photosensitivity of 2500 ASA for monochrome imaging and 2000 ASA for RGB imaging means the camera can handle complex requirements while also minimizing lighting expenses. The switchable non-linear dynamic range adjustment delivers dynamics of up to 90 dB and ensures extremely detailed images even with large contrasts between dark and light. The integrated

Camera Link interface with a data transfer rate of up to 680 MB/s) enables images from the camera to be saved on a PC's hard drive in real-time using a ring buffer.

[www.mikrotron.de](http://www.mikrotron.de)

## High speed live images

**Microscope cameras.** The Digital Imaging business unit of the Jenoptik Optical Systems Division has added two new USB camera types to its ›ProgRes‹ CCD microscope camera range: the ›ProgRes SpeedXT<sup>core</sup> 3‹ and the ›ProgRes SpeedXT<sup>core</sup> 5‹. These cameras feature a high live image speed of 17 and 13 fps (respectively) at the corresponding maximum possible resolutions of 2080x1542 and 2580x1944 pixels (also respectively). When maximum resolution is not required, even higher frame rates of 30 respective 45 fps are possible. Thanks to the 2 to 3-fold enhancement of the live image speed in combination with the high



resolution, specimens can be focused and positioned more easily and quickly – a clear advantage in the analysis of moving objects and routine work in laboratories. Exposure times up to 180 s ensure optimum captured images, even under low-light conditions. The maximum possible color depth is 36 bit. In combination with a C-Mount connection, the cameras can be easily connected to any microscope, computer or notebook via the USB 2.0 interface.

[www.jenoptik.com/os](http://www.jenoptik.com/os)

## A powerful package

**GigE Vision cameras.** Kappa presents its extended GigE Vision camera series ›Zelos‹ as a powerful package with SDK, easy control software and real-time recording. All Zelos models are based on a modular high-performance platform with 14-bit digitization. The series promises rugged quality, durability and outstanding color processing. The camera models with HDTV, 5 megapixel, WVGA and VGA offer a variety of features such as PoE, protection class IP 54 and up to 200 fps. Easy to integrate, the cameras are suited for a wide range of applications. Due to their clear signal quality, proper characterization and precise synchronization, the Zelos cameras are also ideal for 3D applications. All Zelos cameras are offered as a package with the control software ›KCC Zelos‹ and an SDK. With the new optional real-time recording, live sequences (also in high-definition) can be compressed in real-time at full resolution and full frame rate and then saved as high-quality video files.

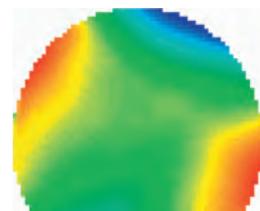
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## Faster cameras

**Camera driver.** IDS presents an updated driver version that expands the range of functions offered by its new cameras with global shutter CMOS sensors from e2v. This new 1.3 megapixel global shutter sensor offers excellent light sensitivity and color fidelity combined with a high frame rate. A fast line mode will thus be available for the USB and GigE models UI-1240 and UI-5240, enabling the sensor to record image lines at a rate of 12000 per second. The driver update will also provide an additional readout mode that allows up to four regions of interest (ROIs) to be defined per frame and transmitted simultaneously. The cameras with e2v sensors are furthermore enhanced by digital scaling, creating reduced images with almost no steps whilst maintaining the full field of view and enabling a frame rate of 100 fps. Thanks to the overlap trigger mode, the same frame rates are achieved for externally triggered images as in live mode. Available in monochrome and color, the sensor's global shutter renders these CMOS cameras ideal also for inspection tasks at high cycling rates and fast-moving objects, for example in bottling, printing or manufacturing of yardware.



[www.ids-imaging.de](http://www.ids-imaging.de)

## Full performance with 240 MB/s

**Dual GigE Interface.** With the new ›Dual GigE‹ interface, Baumer offers a GigE network solution for the implementation of cameras with fast sensors and high frame rates. The new interface doubles the standard bandwidth to 240 MB/s, supporting the full potential of the Kodak Quad Tap sensors, which provide excellent image quality and high frame rates simultaneously. With a transfer distance of 100 m, the Dual GigE interface offers all the advantages of the standard GigE interface. However, the redundant concept of the Dual GigE system provides

better transfer security, ensuring data transfer and reliable camera operation even if one of the two Ethernet cables is disconnected. The industrial ›SXG‹ cameras are the first series Baumer is equipping with the new technology. These offer excellent images with resolutions from 1 to 8 megapixels and simultaneous frame rates up to 120 fps. All cameras are supplied with ›power over the Ethernet‹ (POE) for easy integration.

[www.baumer.com/cameras](http://www.baumer.com/cameras)

## For quick inspection

**Industrial camera.** SVS-Vistek recommends its new ›SVCam EV‹ series for fast and accurate inspection tasks – available with DualGigE-Vision or CameraLink output. The dual Ethernet output enables the 1 MP model to speed up to 150 images/s, for instance. The SVCam-EVO series is enclosed in a compact housing measuring 50x50x48 mm<sup>3</sup> and is offered in 1.2 and 4 MP versions, planned for production in the 1<sup>st</sup> quarter of 2011.

[www.svs-vistek.de](http://www.svs-vistek.de)



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1 The pco.edge sCMOS camera system – thermoelectrically cooled to 5°C and with compact housing dimensions of 88.3x70x76 mm<sup>3</sup>



# Scientific CMOS camera

... FROM MICRO TO MACRO.

A year ago, the new ›scientific CMOS‹ image sensor technology was presented to the public. Twelve months later, the first camera systems incorporating this technology are appearing on the market. For the case of the ›pco.edge‹, we want to test whether the promises have been met and, at the same time, identify the applications that could make use of the sCMOS sensor's qualities.

GERHARD HOLST

Because the technical parameters of an image sensor and the camera that uses it can vary widely, we should first take a look at the datasheet for the ›pco.edge‹:

- resolution: 2560x2160 pixels,
- readout noise: <1.4 electrons at 30 frames per second,
- usable full well capacity: 30000 electrons,
- dynamic range: > 22000:1,
- maximum frame rate: 100 frames/s (full resolution), and
- quantum efficiency: max. 57 percent (front illuminated).

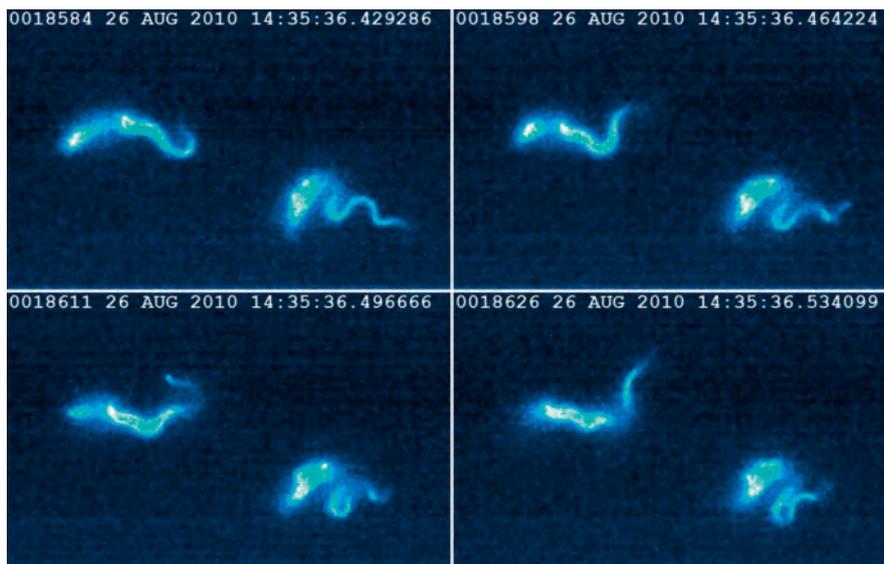
Compared to the values described earlier [1], the resolution has remained the same. However, the achievable readout noise is lower than previously expected, as at frame rates of 30 frames/s the camera achieves noise values of <1.4 electrons, which, with the usable full well capacity, corresponds to intrascene dynamics [2] of 22000:1 (better than the 16000:1 announced last year). Therefore, the use of 16 bit A/D converters appears to be fully justified when we take into account their characteristic error rate of typically 0.5 bits.

The maximum frame rate is still specified at 100 frames/s, albeit with one minor caveat. The theoretical maximum data rate possible with the fastest camera data interface currently available (›Camera Link‹) is 850 MB/s, although practically, and even then only with a sophisticated raid system and an excellent frame grabber, 800 MB/s is more realistic. Given that



2 The pco.edge sCMOS camera system connected to an inverse ›iMIC‹ digital microscope (Till Photonics) to observe trypanosomes (sleeping sickness parasites) marked with a fluorescent dye attached to their cell membrane

(Image: Department of Cell and Development Biology, Biology Center Würzburg)



**3 Image details** (550x350 pixels) from a sequence of images showing the movement of trypanosomes, captured with the pco.edge sCMOS camera system at a resolution of 1120x502 pixels and a frame rate of 400 frames/s. The rapid movement of the trypanosomes is easily interpreted from the intervals between the individual images

the sCMOS camera can deliver 1.14 GB/s, the actual data transfer rate is ultimately limited by the currently available interface standards. The net result is that the full frame rate can only be utilized together with data compression or a reduced dynamic range. The second limitation, at least compared to the information made available last year, lies in the slightly reduced quantum efficiency. The actual specification includes losses from cover glasses and the slightly lower values attained for the series production sensors, although the minor drop from 60 to 57 percent is very likely tolerable for most applications. In spite of this, the sensitivity in the NIR is still significantly higher than conventional CCD or CMOS image sensors.

On the whole, the pco.edge camera (**Figure 1**) not only delivers the promised sCMOS specifications, in some instances the final performance is actually better. What we now need to explore is the applications that require all of or a significant subset of these specifications when addressing their specific objectives.

### Micro – frame rate, noise and sensitivity

According to Prof. M. Engstler, the trypanosome parasites that cause sleeping sickness are 'ravenous swimmers' [3]. In the blood of the host, these 20 µm long parasites use a characteristic motion to generate a hydrodynamic flow on their cell surface that effectively renders the defense mechanisms of the host useless. This hydrodynamic flow drives the host's antibodies back along the parasite membrane and on to the rear end of the parasite cell. Here the antibodies are passed into the mouth of the cell, where they are devoured and finally consumed.

Transmitted by the tsetse fly, a huge number of people in Africa still die of sleeping sickness (30 000 new cases per year [Source: Wikipedia]). Unfortunately, the treatment methods are outdated and place a significant additional strain on the patient, so research into more effective and patient-friendly treatment methods is an important field. These parasites also destroy entire herds of buffalo and cattle, which, in the corresponding ▶

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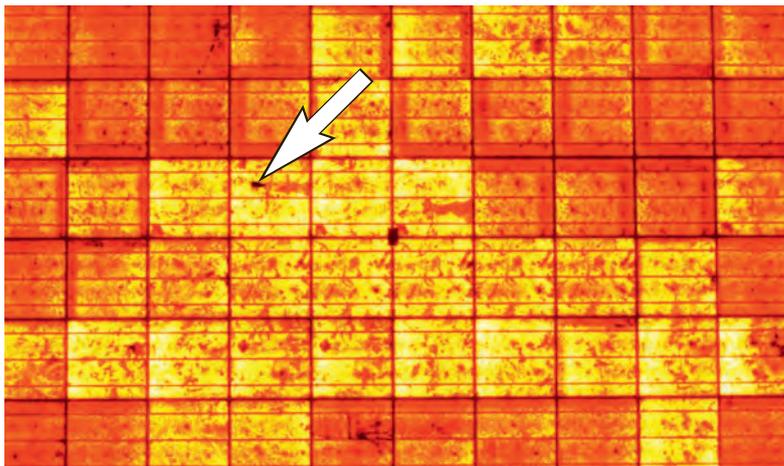
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**4** Electroluminescence image of a solar cell module taken with a pco.edge sCMOS camera system with a 50 mm NIR lens from Carl Zeiss and using an exposure time of 700 ms. The black speck (marked) shows a defective area of the solar cell that makes no contribution to the photovoltaic current

tropical lands of Africa, is a cause of significant economic hardship. One potential new method of therapy could be to influence the motion of the trypanosomes, but this needs to be studied in greater detail first.

In order to influence the flagellates as little as possible, appropriate tagging proteins were used to mark the cell membrane with a fluorescent dye, and the trypanosomes were then observed in a liquid environment on the slide of an inverse digital iMIC microscope (Figure 2) coupled to a sCMOS camera. For the very first time, image sequences of the characteristic movement of the fluorescent trypanosomes were captured with sufficient time resolution. Sequences with 1120x1080 pixels were captured at 200 frames/s and with 1120x502 pixels at 400 frames/s. A sequence of four (cropped) images can be seen in Figure 3.

Given the short time intervals between images, the significant changes in posture of the two trypanosomes are indicative of how quickly these flagellates move. The light signals comprise around 100 photons at the brightest locations, which is of course a very weak signal. These sequences of images are currently being studied and processed, particularly in terms of the three-dimensional characteristics of the movement, and further investigations will follow.

#### Macro – NIR sensitivity, resolution and noise

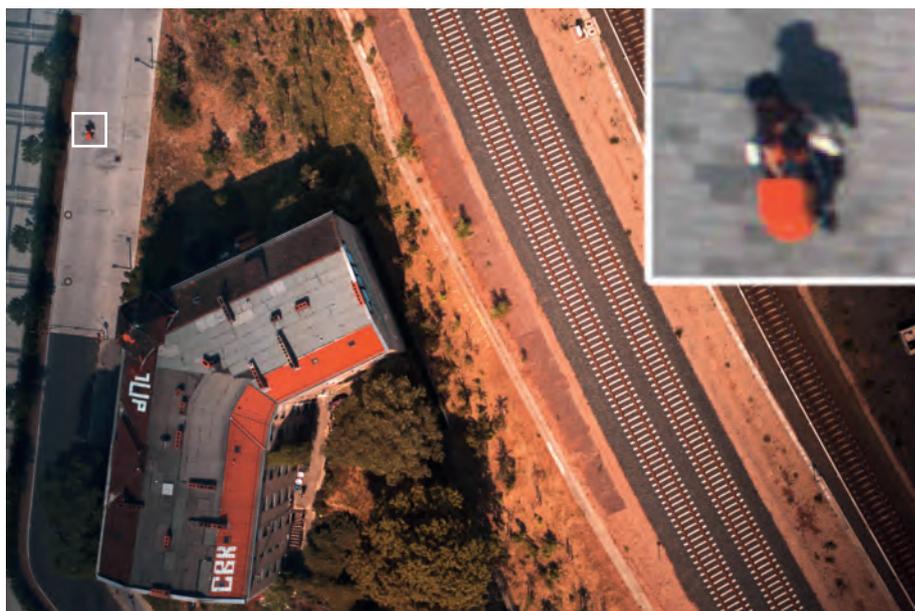
For several years now, the electroluminescence (EL) of solar cells has been used as a significant parameter in research and quality assurance. Scientific studies have shown that the areas of solar cells that do not exhibit EL also do not make a contribution to the generated photoelectric current. Solar cell research is currently engaged in particular on the proper interpretation and

significance of EL measurements. To produce the EL, a safe nominal current is applied in flow direction that mimics the expected photovoltaic current through individual solar cells or entire modules. Light with an intensity maximum around 1150 nm in the near infrared is generated in the cells – nominally outside the sensitivity range of the camera sensor. Nevertheless, the component of the EL intensity with a wavelength below roughly 1050 nm is sufficient to generate a usable signal. Until recently, specially optimized CCD cameras have been used for this task, but they either needed to utilize pixel binning to produce a sufficiently visible image or required longer exposure times in the range of 30 to 60 seconds or more.

In addition to the high resolution, the sCMOS image sensor also has a better quantum efficiency than front-illuminated CCDs. And unlike the deep depletion CCDs, all of which are illuminated from the rear through the substrate, there is also no etaloning. Figure 4 shows the EL for a solar cell module, captured using a special IR objective from Carl Zeiss. The exposure time was 700 ms, meaning that the type of EL image capture needed for quality assurance can be taken easily during manufacture. In Figure 4, a defect is marked with an arrow. Current research still needs to provide answers to improve understanding and identify the significance of the other darker areas.

#### Aero – frame rate, dynamic range and resolution

The DLR Institute for Robotics and Mechatronics in Berlin has been developing aerial reconnaissance systems for some time. Through the utilization of additional sensors, the absolute position of the aircraft is very accurately known and it becomes possible to ensure that adjacent images of a target area always have at least 90 percent overlap. Sophisticated algorithms can



**5** An aerial photo taken with a pco.4000 CCD (11 megapixels) from an altitude of approximately 150 m. One pixel corresponds to a ground resolution of 2 cm, thus the 100x100 pixel detail corresponds to an area of 2x2 m<sup>2</sup> on the ground. This camera is to be replaced by two sCMOS cameras, which are more compact and will be able to capture images with improved dynamic range

then be applied to these images to obtain a height profile of the target area.

At present, high-resolution CCD cameras such as the pco.4000 (4008x2672 pixels with color sensor) are being used, and that capture images with sufficient speed (3 frames/s). With this camera a single pixel corresponds to 2 cm on the ground (**Figure 5**), achieved at an altitude of around 150 m, and the resolution for the calculated height profile is around 3 cm. The disadvantages of the pco.4000 include its size and, above all,

the tendency to 'smear' images (the stripe-like artifacts left behind in the images due to very bright spots of light in the imaged scene).

sCMOS cameras with a color sensor are now to be integrated into these aerial

photographic systems. Although they only have half the resolution, they produce no smear effects and also have a considerably higher frame rate. In addition they benefit from a better dynamic range, a more compact format (**Figure 1**) and they weigh less. The aim is to improve the resolution of the height profiles from 3 to 1 cm for this research work. By flying over a road construction site before, during and after construction, this kind of system could then be used to determine exactly how much excavation was actually carried out. Other applications include creating height models of major population centers, so that detailed emergency response plans can be formulated, or determining the exact size and extent of cities in countries where building activity has not been continuously recorded.

**Summary**

The original announcement of the sCMOS camera systems and the significant interest in the performance specifications prompted a deluge of potential applications in fields ranging from micro to macro. From microscopy through to aerial photography, there is certainly no lack of interest in the capabilities of the sCMOS image sensor technology. Potential applications can easily be envisaged that range from super-resolution microscopy, over DNA analysis and even on to 3D film capture and 2D stereo image acquisition. The term »scientific CMOS« also appears to have drawn so much attention that it is increasingly being used even for lesser performant CMOS image sensors in order to emphasize their qualities. ■

**Literature**

- 1 Laser+Photonics 5 (2009), p.18.
- 2 The intrascene dynamic range is defined as the ratio of the maximum fill level to the smallest distinguishable signal level (comparable to the noise). This dynamic is the customary dynamic range generally specified for digital camera systems.
- 3 Department of Zoology I (Cell and Development Biology) at the Biological Center of the University of Würzburg, in his article in Labor & More 3 (2010).

**Gerhard Holst** studied information technology at the RWTH Aachen. After seven years in the microsensors research group at the MPI for Marine Microbiology in Bremen, he moved to PCO, where he is now Head of the science and research department.

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## For rapid scanning

**3D sensors.** With its ›CX Compact‹ sensors, Automation Technology is launching a new generation of detector heads for high-speed 3D scanning. The high resolution sensors are available with a resolution of 2352x1728 pixels and a maxi-



mum profile frequency of 23.5 kHz or with 1280x1024 pixels and up to 71.5 kHz. These, along with the complete laser electronics, are built into a compact and durable anodized aluminum housing (IP 64/67) that can be adapted to customer-specific demands. Both Camera-Link and the GigE Vision standard interfaces are available. The CX sensors

support the GenICam protocol, making them easy to integrate. The Gigabit Ethernet version is also available as a smart camera with a 1 GB image memory. According to the manufacturer, the sensors provide outstanding depth of field and image intensity and are able to scan even materials and surfaces with non-homogeneous reflectivity properties. The sensors can be combined with a wide range of commercially available image processing tools.

[www.automationtechnology.de](http://www.automationtechnology.de)

## Compact and fast

**CMOS cameras.** The new, small, fast and high resolution ›ace‹ cameras from Basler use the new CMOS sensors from Cmosis. They have resolutions of 2 and 4 megapixels and achieve up to 340 and 180 fps, respectively. With a global shutter and Camera Link interface, these cameras are suited for a wide range of applications – especially high-throughput



applications. Features such as trigger or flash support via separate I/O ports and optional ›Power over Camera Link‹ (PoCL) functionality facilitate hardware installation. Thanks to GenICam support, all camera properties can be flexibly adapted via software commands. According to Basler, these highly compact cameras – with a footprint of 29x29 mm<sup>2</sup> – also boast an impressive price-performance ratio. In late 2011, Basler will also offer the ace Cmosis cameras with a GigE interface.

[www.baslerweb.com](http://www.baslerweb.com)

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## With 8192 pixels

**Color line scan camera.**

Vistas is extending its ›CLISBee-S‹ CMOS range of line scan cameras to include a color version, the ›XCM2740MLC‹, with serial RGB pattern in which the line length of 8192 pixels at 7x7 µm<sup>2</sup> provides a color resolution of 2730 x RGB pattern. The pixel frequency is 120 MHz at a scanning rate of 14 kHz and 24 bit RGB resolution. Data is transmitted via a CameraLink interface. Integrated correction functions are used for pixel correction, FPN and PRNU minimization and to correct for non-uniform illumination and lens vignetting. Thanks to an adjustable characteristic curve, it has a specified dynamic range of 106 dB. The offset and gain are individually programmable for each RGB color channel. Gain is precisely adjustable in 0.0039 dB increments. The camera, in a compact metal housing measuring 80x120x65 mm<sup>3</sup>, is supplied with the standard ›M72x075‹ lens connection. A version with a Nikon F-Mount adapter is also available but its resolution is limited to 4096 pixels or 1365 x RGB patterns.

[www.vistas-gmbh.de](http://www.vistas-gmbh.de)



## Pre-calibrated

**3D Area Sensor.** VRmagic presents a 3D area sensor based on digital stripe light projection that supplies pre-calculated 3D data records for industrial image processing. The ›AreaScan3D‹ sensor outputs the recorded 3D data directly as a point cloud or a grayscale-coded range map to the evaluation computer via the industrial Ethernet interface. The 3D sensor is addressed via a GenICam transport layer (GenTL), making it compatible with all image processing libraries and packages that communicate with a GenTL, such as Common Vision Blox or Halcon.



The sensor is encased in a robust metal housing with IP 65 protection, screw-type standard industrial connectors, a 24 V connection, an Ethernet interface as well as hardware and software triggers. It is available with measuring fields ranging from a few millimeters up to a square meter. It offers a guaranteed accuracy in the submicrometer to millimeter range, depending on the measuring field size. Stripe projection, image recording and generation of the point cloud are performed in an integrated manner based on an intelligent camera from VRmagic. The DLP pico projector from Texas Instruments and the camera are synchronized with a frequency of 60 Hz. Output of a complete 3D data record is currently possible with approximately 360 000 individual points per scan.

[www.vrmagic-imaging.com](http://www.vrmagic-imaging.com)

## ARM'd with intelligence

**Intelligent camera.** Matrix Vision's new intelligent camera series ›mvBlueLynx-X‹ uses Texas Instruments' ›OMAP 3‹ processors with an ›ARM-Cortex-A8‹



core and offer an efficient performance up to 1 GHz with an additional, separate DSP. When designing this series for automation, Matrix Vision deliberately chose ARM processors as these require less power and are smaller in size. As a result, mvBlueLynx-X is able to operate with 5 W under a full load and is compact in size, measuring 85x55x35 mm<sup>3</sup> without lens. The cameras feature a wide range of interfaces: 100 Mbit LAN, two USB 2.0 interfaces, RS-232, digital inputs and outputs, display output as well as MicroSD card interfaces. A wide range of global shutter CMOS sensors from WVGA to SXGA are also available. For the lens holder, a S-mount is standard, but C- and CS-mounts are available as an option. Models with integrated illumination improve the handling and guarantee image quality. Models with IP 65 protection are available as well. A ›.NET‹ compliant ›Mono‹ interface allows the development and implementation of .NET based cross platform applications without further compiling.

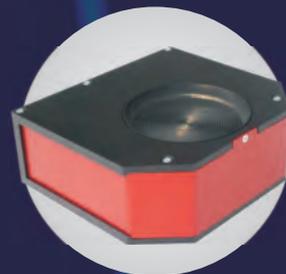
[www.matrix-vision.de](http://www.matrix-vision.de)

## Customizable

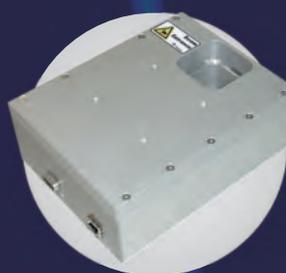
**Telecentric lenses.** With its ›TZ Coax‹ series, IB/E provides telecentric measurement lenses for the most demanding requirements. With reflected light, they are particularly suitable for inspection of tiny surface defects such as scratches, grooves, burrs and dents. On request, the lenses can also be equipped with variable aperture, polarizing filter and retarder plates. IB/E Optics can provide ›OptiBench‹ as a protocol for precise distortion, MTF and telecentric data. The TZ Coax series covers scales from 0.5 to 3.00. LED and fiber inputs for coaxial illumination are available as accessories.

[www.ibe-optics.com](http://www.ibe-optics.com)

# LASER BEAM ANALYSIS



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# Laser Doppler vibrometry

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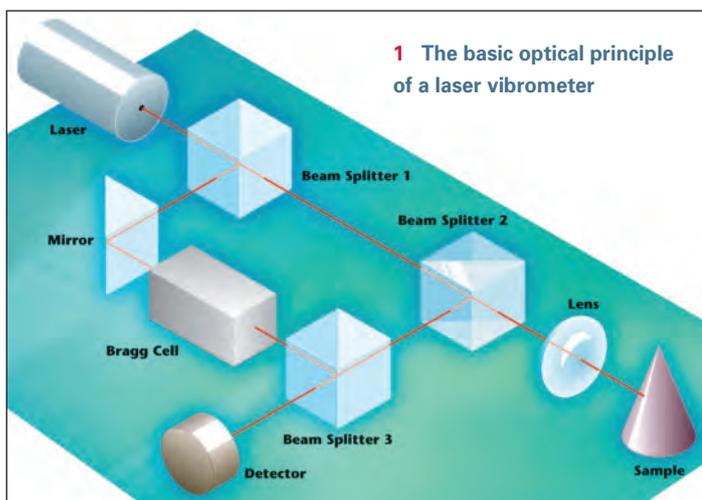
**N**on-contact laser vibrometers are firmly established as an indispensable method for studying the structural dynamics of physical and biological systems and for optimizing the response of mechanical products with respect to vibration and noise. A laser vibrometer is built around an

interferometer where a laser beam (usually HeNe at 633 nm,  $P < 1$  mW) is divided into a measurement and a reference beam by a beam splitter. The measurement beam strikes a point on the vibrating surface, which then scatters light back to the vibrometer with a shift in frequency and phase due to the Doppler effect. The returning light is captured by the vibrometer optics and spatially overlapped with the reference beam, giving rise to a time-varying interference.

The frequency shift in the measurement beam caused by the movement of the structure being tested results in a modulation in time of the combined beams' light intensity. Each time the measurement point on the vibrating surface moves by a half wavelength, the intensity of the superposed light completes a full light/dark cycle. The intensity fluctuation is converted into a corresponding electrical signal by a photodetector. The frequency  $f_D$  of these light/dark cycles is proportional to the speed  $v$  of the measured point according to:

$$f_D = 2v/\lambda$$

Laser vibrometry has almost limitless application possibilities and is already used in a broad range of fields. It has several important advantages including efficient and practical measurement setups, extremely accurate vibration measurement, zero mass loading and suitability to applications where conventional sensors cannot be used.

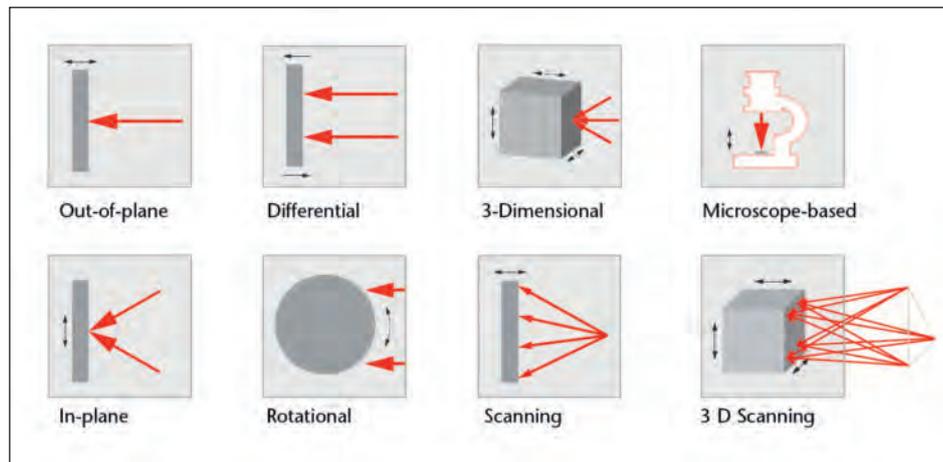


### Vibrometer types

The fundamental principle of non-contact, non-impinging (or zero mass loading) and high-resolution optical vibrometry (as illustrated in **Figure 1**) is the basis for most standard vibrometers as well as for a series of more versatile and specialized instruments (**Figure 2**). For example, the second interferometer beam, which normally plays the role of the refer-

### Vibration diagnostics on wind power plants

Wind power turbines must satisfy stringent design requirements for the mechanical properties of the components. In operation, the effect of the wind can induce vibrations that on larger turbines can lead to dynamic deflections of the tower and of the rotor blades of up to 1m, at frequencies of several Hz.



**2 Overview of different vibrometer types. This collection of powerful optical vibration measurement systems provides users with an optimum solution for almost any measurement task**

ence beam, can also be used as a measurement beam. This enables differential optical measurements that can, for example, eliminate ambient vibrations from the measurement data by overlaying the actual object vibration with the measurement point data.

Another two-beam concept forms the basis for the in-plane vibrometer. For an object located within the volume outlined by two overlapping light beams, vibrations perpendicular to the principal optical axis can be measured. And then for three overlapping beams, as is the case for a 3D vibrometer, the entire three-dimensional vibration vector can be conveniently evaluated. Finally, the double interferometer detector head of the rotational laser vibrometer can be used to record the dynamics of rotating systems, such as on the drive train of a vehicle during ramp-up tests.

In addition to single-point vibrometry systems (those used to observe a single point on a vibrating structure), there are more powerful vibrometer systems, known as scanning vibrometers,

that measure over an entire surface. A scanning vibrometer is typically a high-performance all-in-one combination of interferometer, precision scanner optics, an integrated video camera and a powerful data acquisition system.

Such systems enable vibrometry measurements to be carried out on vibrating surfaces and structures by automatically scanning the entire surface of the measurement object with an interactive and flexible user-defined array of measurement spots. The ultimate extension of this approach is the three synchronously controlled scanning vibrometer detector heads of a 3D scanning vibrometer, capable of recording 3D vibration data for complex structures.



**3 Vibration measurement on wind power turbines**

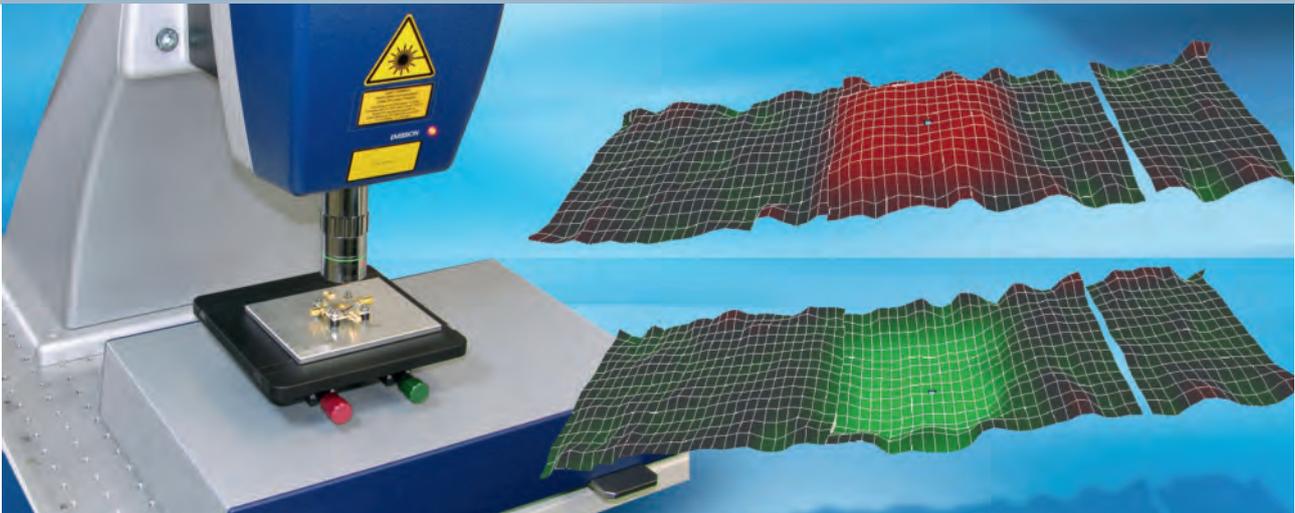
The motivation for characterizing the wind power turbines is to compare, contrast and optimize the simulation models used in the design and to ensure that the mechanical operation remains fault-free by promptly identifying the critical material loads and the corresponding fatigue data. This kind of preventive maintenance or condition monitoring is often carried out using contact sensors positioned at assorted points throughout the power train. For example, appropriately placed sensors can provide information about bearing wear and tear induced by power transmission. For the rotor blades, particularly during operation, a non-contact optical measurement method is obviously preferable for practical reasons. Laser vibrometry is non-contact and has the additional advantage that measurements can be carried out at a safe working distance and, in ideal situations, without prior preparation of the measurement points (**Figure 3**).

### Ultrahigh-frequency measurements on microsystems

Microsystems with ultrahigh-frequency mechanical movements are often characterized by sub-picometer (pm) displacements ▶

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**4 Full area measurements on an ultrasound transducer at approximately 105 MHz, measured with a Polytec UHF-120 ultrahigh-frequency vibrometer**

in the GHz range. To measure these movements directly and without contact presents a major challenge for the measurement technology.

A new ultrahigh-frequency vibrometer can now be used to measure these movements directly at frequencies of up to 1.2 GHz and with amplitudes in the sub-pm range. The measurement is straightforward and non-contact. The software even allows the vibration to be visualized in slow-motion. Because of the large frequency bandwidth, this vibrometer is an ideal tool for studying high-frequency RF-MEMS, while its high lateral resolution makes the system perfect for studying and dynamically characterizing devices with short acoustic wavelengths, such as surface acoustic wave (SAW) devices or bulk acoustic wave (BAW) devices. Because of the large speed measurement range of up to 120 m/s, it is also ideal for precision characterization of high-performance ultrasonic transducers (Figure 4).

### Product development in the automotive sector

Optimizing acoustic and vibrational behavior is an important objective in product development, in particular in the automotive industry, as the dynamic and acoustic properties are key quality aspects for a vehicle's 'look and feel'. In recent years, non-contact optical measurement technology featuring laser Doppler vibrometers has become the established tool for experimental vibration analysis in many applications. The reasons for this rapid acceptance include its high throughput and accuracy, its suitability for even the most difficult, complex or

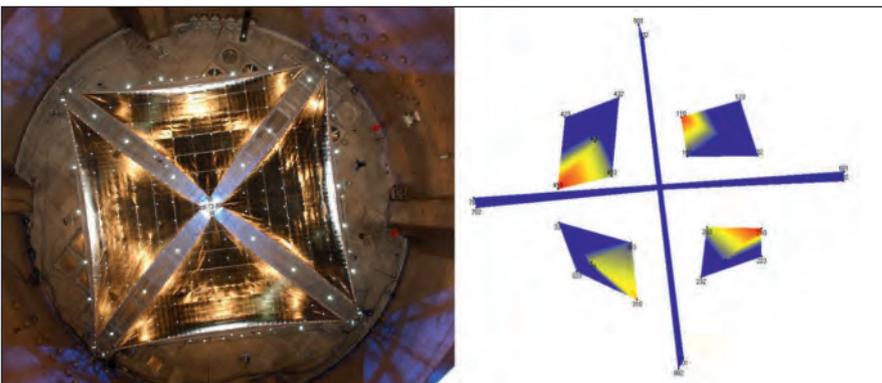
microscopic measurement tasks, and its ease of use.

In the development of a new motor vehicle, the use of numerical calculations to predict the vibrational behavior of components, of assemblies and of the vehicle as a whole has become a standard procedure and makes a major contribution to optimizing operational safety and long-term performance. Confidence in the numerical simulations comes from the comparison of the predicted model's response with data obtained experimentally (modal test) on a real component.

Here too, laser vibrometers have become the preferred instrument for capturing experimental data. In particular, laser vibrometers exhibit some crucial advantages over mechanical accelerometers that are mounted to the structures (see below). 3D scanning vibrometers have additional advantages such as measuring vibrational components along all three axes at each defined measurement point covering the test object – even over the entire area of a full vehicle in just a few hours when combined with an industrial robot.

In experimental modal analysis, a specific broadband force is transmitted into the structure. To input this tailored force, one or more electrodynamic vibration generators, known as 'shakers', are used. During data acquisition, the vibrometer system calculates the frequency response function (FRF) between the force and the vibrometer signal (speed) in a specified frequency range for each measurement point, which is then saved for further signal analysis. The operational deflection shapes are formed from piecing together the individual measurement points and tying them together temporally and spatially to form an animation of a geometric model, against frequency or time, and superimposed over the video image of the measured object. Standard interfaces are then used to provide the FRFs for post-processing using modal analysis software. When performing modal tests of this nature, scanning 3D vibrometry provides some key advantages:

- quick and easy measurements, even with a very high density of measurement points,
- mass loading from an attached sensor,
- considerably shorter setup time compared to the time-consuming instrumentation of the measurement object with accelerometers,



**5 Test setup for determining the modal properties of a 20 m solar sail for NASA**

- comprehensive frequency response functions (FRFs) with high spatial resolution, ideal for correlation with FE models (model updating), even at high frequencies),
- full automation of the measurement, including robot support for large structures, and
- simultaneous actuation of up to four vibration generators allowing MIMO modal tests.

The user benefits from the extremely high density of measurement points, far superior to that captured by conventional contact measurement technology, and a reduction in total test time from weeks down to a few hours.

This innovative dynamic testing methodology with laser vibrometers helps understand and optimize the acoustic signature of disk brake systems. Under certain operating conditions, the complex dynamics between the brake caliper, pads and disk can cause intolerable brake squealing, perceived by vehicle users as an indication of inferior quality. By measuring the operational vibrational forms with a 3D scanning vibrometer on the brake test bench, the 3D dynamics can be properly characterized and understood. These measurements reveal the interactions between the primary vibration modes in the plane of the disk and the secondary modes vibrating out of the plane of the disk. With this information, one can determine which modes are responsible for the acoustic issues. These types of measurements can be performed on all substructures of the braking system, both at rest and in operation on the test bench.



6 Medication nebulizer and the compact laser vibrometer used for testing

## Aerospace

In the aerospace industry, vibrations are almost always undesirable and must be detected quickly and then eliminated. It is important to catch these vibrations in the design and test phase and during the manufacturing process as part of quality control. Typical applications for laser vibrometry include data for design reviews, characterization of components as part of production monitoring and investigation of material fatigue. Measurements on wings, turbine blades and satellites provide data for modal analyses and finite element validations. Vibrometers are ideal for measurements on large objects that are difficult to access with contact methods. As a special example, in **Figure 5** a test setup for determining the modal properties of a 20 m solar sail for NASA is shown, along with the measured results obtained. In order to perform measurements in a realistic operating environment for the solar sail, the investigations were carried out in an immense vacuum chamber.

## Applications in production monitoring

In industrial production, non-contact optical sensors offer a range of advantages – extremely precise measurement values, flexible integration and reliable, low maintenance operation. They make an important contribution to optimizing processes and thus to overall profitability. Structural properties and faults manifest themselves directly in the dynamic properties of structures and products. Standard

components and assemblies can be characterized in terms of Eigen frequencies, damping and mode shapes. Appropriate measurements allow for evaluation and classification of these properties, enabling a rapid and automated pass/fail selection of components. For many applications subject to final production inspection, laser vibrometers have considerable advantages over conventional structure-borne sensor technology, such as mechanical accelerometers. As well as the high-dynamic range and the large bandwidth of the vibrometers, the non-contact and therefore massless measurement technology also plays a critical role.

The production inspection for nebulizer membranes at Pari, one of the leading manufacturers of aerosol generation systems in Germany, is a good example. Here, a compact laser vibrometer is used to perform 100 percent testing of the quality of the systems during production. Measuring the vibrational behavior at the aerosol producing membrane – the core of the nebuliz-

er system – goes a long way towards ensuring the final quality of the aerosol generator as a whole (**Figure 6**).

## Metrology and calibration

As a calibration standard reference, laser vibrometry has the unique advantage that the measured quantities used to calibrate vibration sensors can be traced back directly to the wavelength of the laser light used. And, for the first time, velocity measurements using laser vibrometers enable the study of the dynamic behavior of force transducers under known impact loading.

## Summary

Laser vibrometers are an indispensable and reliable tool for optical vibration measurements in countless applications. The range of use covers everything from characterization of microstructures to high-performance, fully automated measurement of entire motor vehicles. Because the method is non-contact and massless, vibrometry is often the only solution for very demanding measurement tasks and, in terms of simplicity and efficiency, is significantly superior to mechanical measurement technology in many applications. ■

Dr. **Arno Maurer** is the head of Polytec's Operative Marketing department, **Jörg Sauer** is Polytec's Product Manager for Laser Vibrometry and Dr. **Heinrich Steger** is the head of Polytec's Strategic Product Marketing in the Optical Measurement Systems division.

# Twice as good

**HYBRID TECHNOLOGY** for high-precision positioning tasks. Nanotechnology is predicted to be a key enabler of future products and technologies. For precision engineering, this is just one of many factors that drive the continual improvement of current products as well as the development of new products and processes – and that enable an increasingly interdisciplinary approach to problem solving.



## MARKETING OWIS

**R**esolution and repeatability play an increasingly important role in positioning tasks in fields such as microscopy, nanotechnology, semiconductor technology, quality assurance, photonics and surface processing. Specifically regarding these two key properties, the performance of the positioning technology utilized is often subject to very high demands.

To meet these growing demands, positioning stages with different drive technologies are continually being developed and optimized. Direct drives with linear motors (those without a spindle) have established themselves in industrial pick-&-place applications, for example. Similarly, the development of nanometer-precision positioning systems has also moved forward considerably, enabling small loads to be accurately positioned within a few millimeters of overall travel range. However, specific applications in many fields of industry and research, such as in

measurement technology, laser technology and the life sciences, often require high-precision systems capable of transporting higher loads over longer travel ranges. In order to meet these new market demands, Owis has specially designed and developed a new positioning drive with hybrid technology.

### **Classical positioning precision engineering**

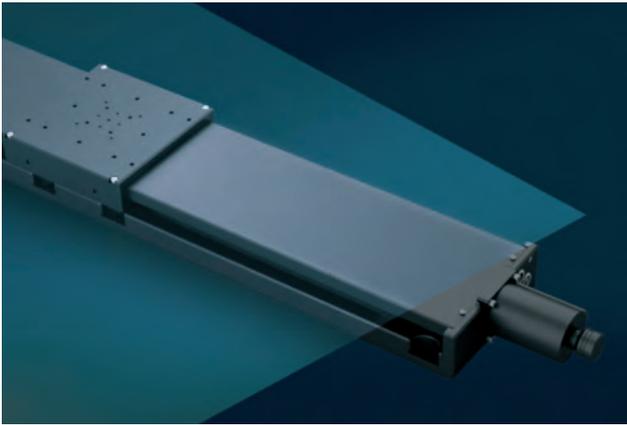
Current standard linear positioning technology uses a high-quality pre-loaded ball-screw spindle – driven by servo-controlled motors or stepper motors – as the principal transmitting element. In systems equipped with servomotors, the position is tracked in most cases indirectly via an incremental encoder mounted on the motor, the information thus provided forming

the basis for accurate control of position and speed. Fine positioning in this instance is usually accomplished via the well-known digital PID control algorithms.

Stepper motor drives are widely used in micropositioning technology due to their considerable advantages, as they enable an open loop – that is, a conventional con-

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**1 Nano-hybrid linear stage NHL 170 with 600 mm of travel**

troller is not required. With this type of drive, high resolution can be achieved by microstepping. Owis' precision linear stages of the ›LIMES‹ series are based on conventional drive principles and already have very good repeatability down to below 2 µm, even for high actuating forces and fast positioning speeds.

### Piezo actuators

Piezo actuators make use of the so-called inverse piezoelectric effect, where the application of a DC voltage to a piezoceramic material results in deformation (change) of its length. Commonly used piezo actuators feature micrometer ranges together with a relatively high maximum actuating force and a compact design, and are therefore ideally suited for fine adjustments.

### Hybrid drive

The integration of piezo actuators into positioning systems with conventional spindle drives – a combination of the two technologies in a single hybrid drive – enables the construction of positioning stages with large travel ranges and high translation speeds, all with high actuating forces and with resolution in the nanometer range.

Positioning in a hybrid stage is performed in two steps. The stepper motor-driven spindle drive undertakes initial coarse positioning, placing the stage in an appropriate target window (within micrometers of the final target position and with a pre-defined positioning tolerance). Immediately after completion of the first step, the piezo actuator performs the necessary fine adjustment to reach the desired final position. Appropriate use of follow-up control can achieve a bidirectional positioning repeatability error of less than 200 nm.

The hybrid positioning stages of Owis' ›NHL‹, ›NHC‹ and ›NHH‹ series feature high-resolution linear measurement systems, incorporating highly accurate reference marks (±1 increment), for the direct detection of actual position.

Linear translation stages are available that feature up to 600 mm of travel (**Figure 1**). The NHL 170, for example, can take a maximum load of 1500 N, has an actuating force of 150 N and can be positioned with a repeatability of less than 200 nm. The elaborate engineering of the hybrid design using a single slide mechanism minimizes the accumulation of production tolerances in the construction. A further advantage is that the translation stage can be designed with a lower overall height. In addition to the linear stages, Owis has also developed xy ►

## 5 STARS



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### Precision Optics & Mechanics From Idea to the Product

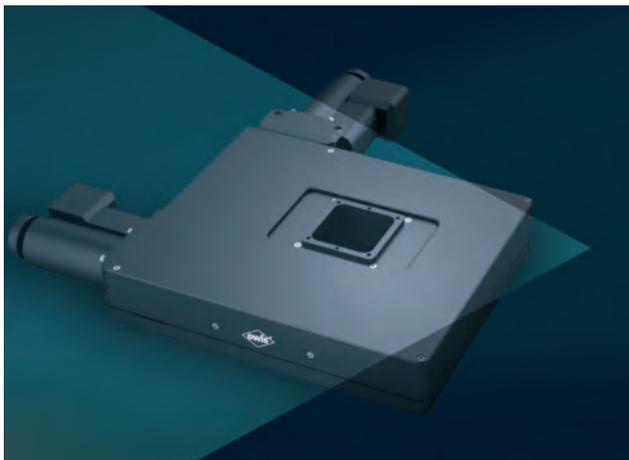
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**2 Nano-hybrid xy stage NHC 50 with 50x50 mm<sup>2</sup> aperture**

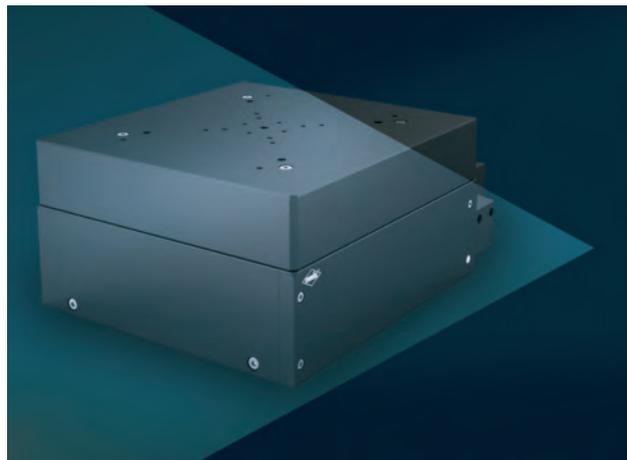
and elevator stages as nano-hybrid versions. As with their classical counterparts, the nano-hybrid NHC xy stages also feature an aperture that remains largely free across the entire travel range (**Figure 2**). Microscope positioning applications requiring light transmission – and even involving loads of up to 15 kg – can now be realized with nanometer precision. For applications in which no aperture is required, this can be closed with an appropriate insert.

Z-axis translation is provided by the NHH series elevator stages. Versatile mounting options enable their flexible use – even upside down. One example of this series is the NHH 200 (**Figure 3**) with its large actuating force of 200 N. This type of stage is especially useful whenever free space is required above the level of the mounting surface.

The physical dimensions of all of the newly developed hybrid linear, xy and elevator stages are all identical to their conventionally driven counterparts. Conventional stages can thus be conveniently swapped out for high-resolution hybrid stages if more precise positioning is required. Despite all the advantages, Owis' hybrid positioning technology is available at a very attractive price/performance ratio.

### Positioning control

All nano-hybrid positioners can be moved and controlled with the »PS 90« positioning control unit. The PS 90 allows standard control modules for conventional stepper or DC servomotors to be used in parallel with those for the new hybrid positioning



**3 Compact z-adjustment with the NHH 200 elevator stage**

stages. For example, structures incorporating three translation axes, whereby only one or two axes need to be positioned with high precision, can be managed with just a single controller and the appropriate software. For customers who already own a PS 90, they can have this modified by Owis for use with the new nano-hybrid modules.

The PS 90 also provides different operating modes for positioning with hybrid drives. The user can select, for example, whether the control process is terminated automatically after reaching the target position, or maintained actively in order to compensate for drift in position caused, for example, by temperature fluctuations.

The PS 90 even automatically identifies which of the two interconnected positioning loops needs to be activated, that is, which motor needs to be addressed. No additional switching or use of two different types of equipment is required here, thus making operation easier for the user.

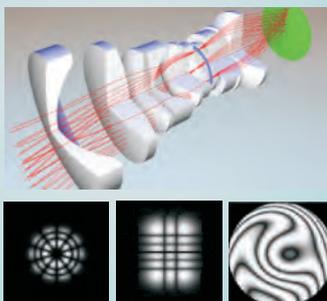
### Summary

With the 600 mm of travel provided by the NHL 170, Owis offers the longest travel range for any nano-hybrid linear positioning stage available on the market. Furthermore, compact stages for applications in all three dimensions are feasible via the nano-hybrid xy stages of the NHC series and the nano-hybrid NHH 200 elevator stage. Even when all stages are capable of carrying heavy loads and feature large travel ranges, bidirectional repeatability is still always less than 200 nm. ■

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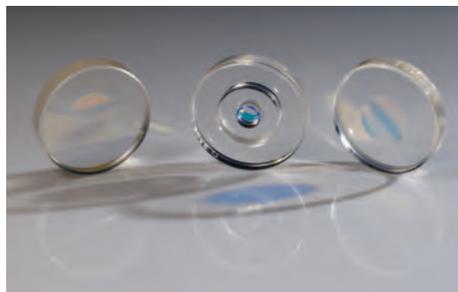
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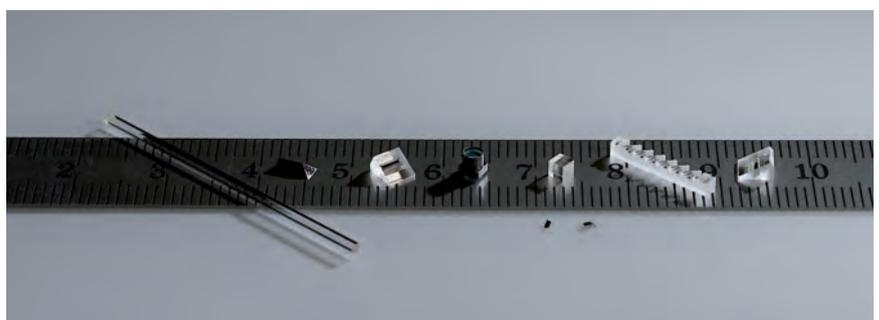
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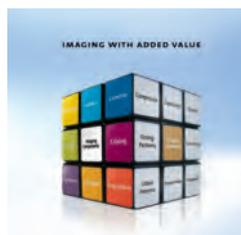
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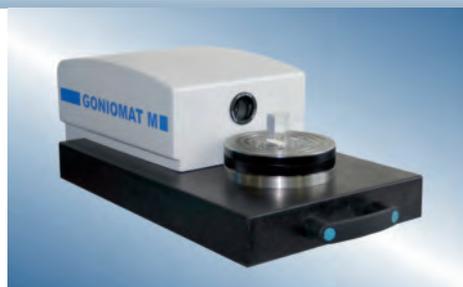
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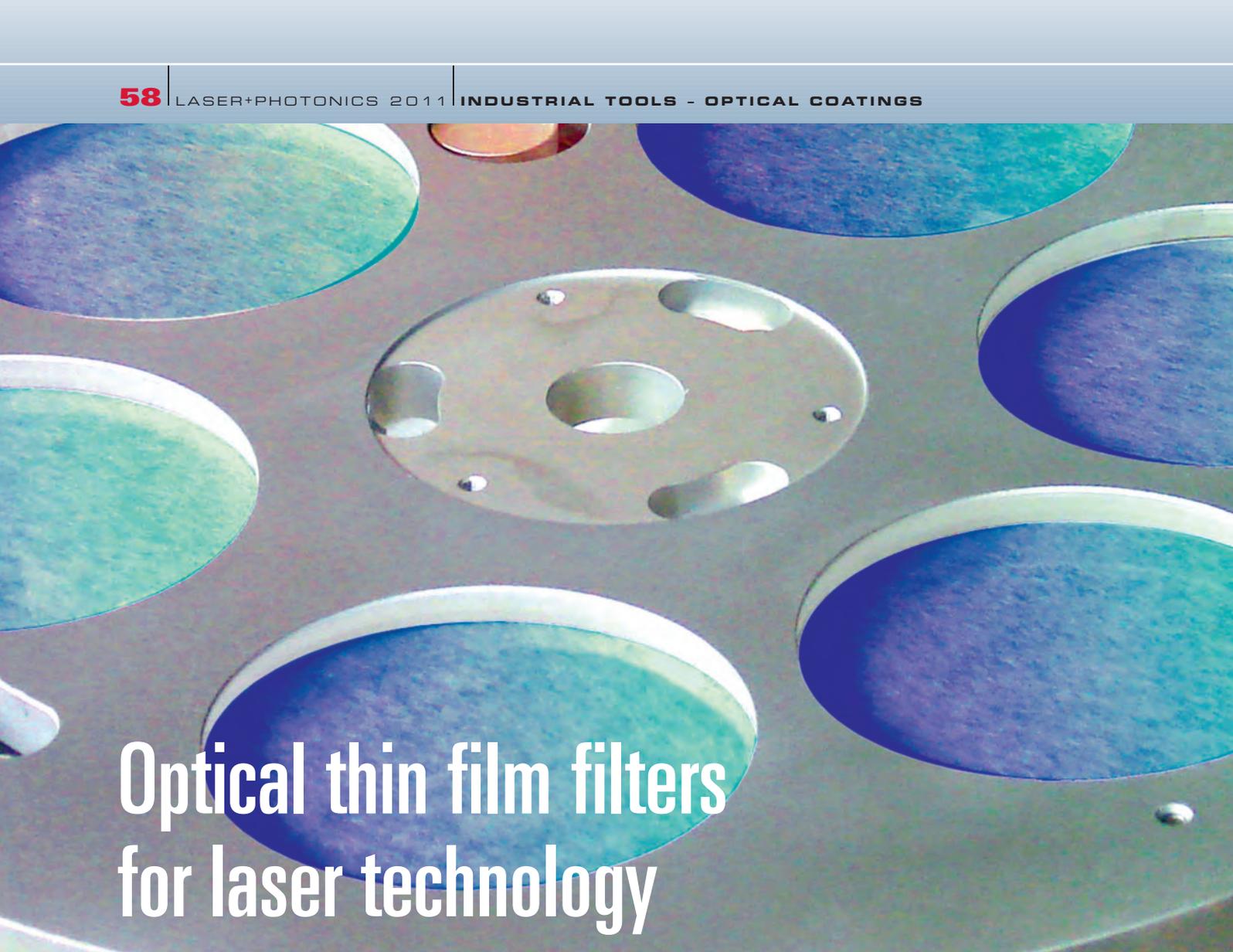
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# Optical thin film filters for laser technology

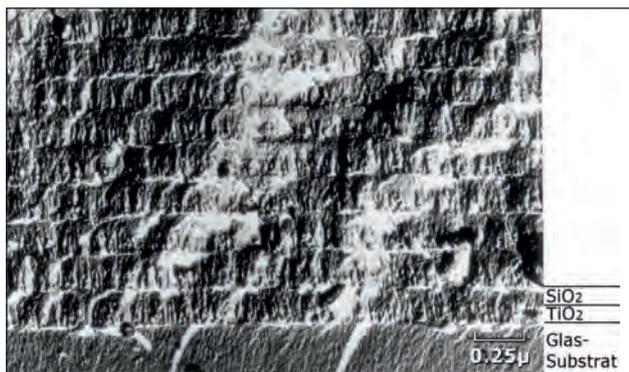
**OPTIMIZED COATING PROCESSES** as the key to success. The quality of coated optical components is critical for a laser's capabilities. Damage threshold, internal stresses and environmental pressure all play key roles, in addition to the standard optical parameters that characterize thin films. There is currently an increasing demand for coatings on temperature- and moisture-sensitive crystals, on organic substrates and on laser glass substrates where the adequate adhesion of the coatings represents a major hurdle.

WOLFGANG EBERT  
TOBIAS GROSS

The coating technique most often used in precision optics is known as electron beam deposition. In this technique, the thin film material is bombarded with an electron beam in a vacuum chamber until it evaporates and is deposited onto the substrate as a thin film. In addition to this conventional method, other, more specialized optical coating techniques have been developed. Today, ion assisted deposition (IAD), pulsed magnetron sputtering, ion plating (IP) and, finally, ion beam sputtering (IBS) offer a wide range of efficient processes that enable cost-effective fabrication of high quality thin film systems for a host of applications.

While the highest damage thresholds for laser mirrors can still be achieved with conventional electron beam deposition, the more elaborate ion beam sputtering is by far the most effective at generating the highest reflection while simultaneously minimizing losses. Ion-assisted deposition is ideal from the point of view of thermal stability and stress elimination, while microwave amplified magnetron sputter coatings have proven effective in aerospace applications.

Despite its versatility and cost-efficiency, electron beam deposition has its limitations, as is highlighted by the existence of the alternative techniques specified above. Unsteady process parameters and the contamination of the growing thin films with particles (splashes) from the deposition source limit the degree of precision as well as the cleanliness of the thin films that can be produced.



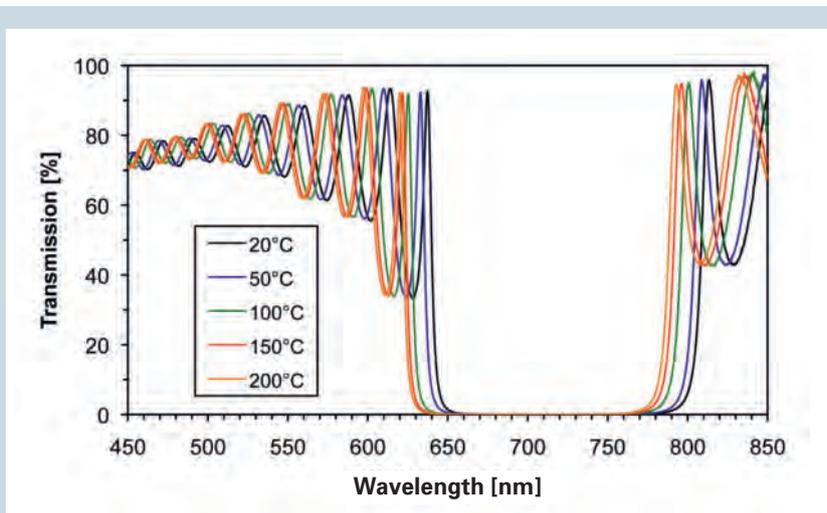
**1** One of the first images of a fracture edge of TiO<sub>2</sub> and SiO<sub>2</sub> captured on an electron microscope by K.-H. Günther in the early 1980s. The porous column structure is clearly visible. The column structure of the titanium dioxide has even been carried over to the otherwise smooth silicon dioxide

A further restriction is posed by the relatively low kinetic energy of the adatoms (<1 eV). The films typically have a reduced packing density and exhibit pores and, in some cases, column formation (**Figure 1**). The voids between the columns, which may account for up to 30 percent of the volume, fill with water when exposed to humid air. Some of this water is expelled through evacuation or – for example, when using laser power – are heated. The subsequent desorption of the water causes the spectral properties to shift to shorter wavelengths. For example, the transmission profile of a typical mirror shifts by approximately one to two percent on the wavelength scale when the temperature is increased from 20 to 120 °C (**Figure 2**). Conventional deposition is therefore unsuitable for certain complex applications. Higher energy techniques minimize this effect, while for IBS it is barely perceptible (**Figure 3** and **4**).

**(Almost) perfect laser mirrors with IBS**

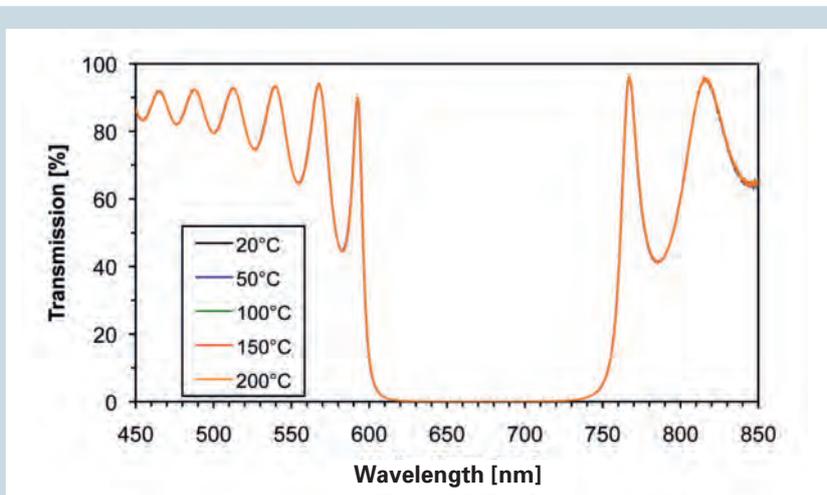
The IBS technique originated in a patent dating from 1978 [1]. This patent describes a method of fabricating high quality mirrors for laser gyroscopes that minimizes losses due to light scatter. An ion beam source directs inert gas ions onto a plate of the coating material, referred to as the target. Due to the high kinetic energy of the inert gas ions (typically 1250 eV), a cascade of collisions causes atoms to be sputtered or ejected out of the target. These then condense onto the substrate that is to be coated. As the mean kinetic energy of these adatoms is in the region of several eV, and therefore higher by one or two orders of magnitude than in thermal deposition, the thin films that are fabricated are absolutely compact, have an amorphous microstructure and a low roughness value (**Figure 5**).

Thanks to the application of industrial technology, ion beam sputtering evolved into an established technique and took a huge leap forward in terms of development. A key factor in this development was the replacement of the high maintenance Kaufman sources (based on hot cathodes) with high frequency ion sources with long-term stability. The latter had originally been developed as a means of propulsion for aerospace applications at the University of Giessen [2]. Industrial IBS systems today are equipped with a second ion source directed at the substrate, which can, if required, be used to pre-treat the substrate (cleaning/etching) prior to coating, or to assist with coating (**Figure 6**). Current coating rates are in ▶



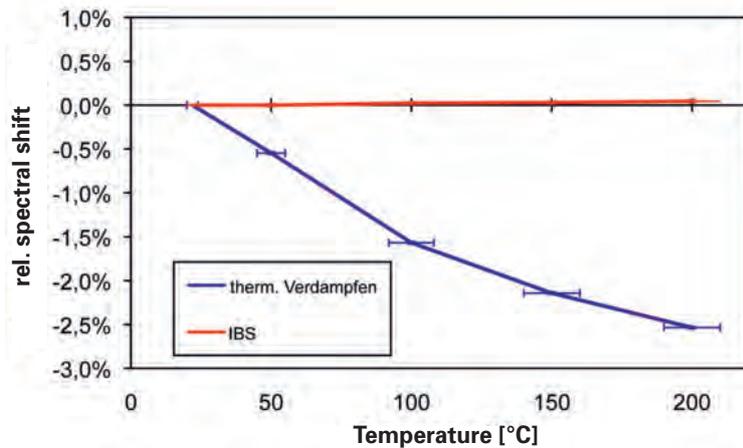
**2** The filter curve of a mirror coated with electron beam deposition is highly temperature-sensitive because of the porous nature of the microstructure. The spectral shift can be explained by water ab- and desorption and the associated changes in refractive index

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**3** The transmission curve of an IBS filter is temperature-stable

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**4** A comparison between the thermally induced spectral shift for the IBS filter from Figure 3 and the thin film system from Figure 2. Other, considerably more minor effects dominate in the absence of the negative shift caused by thin film pores (the temperature sensitivity of the refractive indexes and the thermal expansion of the thin film and substrate materials)

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the region of 0.25 nm/s (depending on the material), with substrates occupying areas up to approximately 500 cm<sup>2</sup>.

The technique is clearly inferior to other methods in terms of productivity, but is nevertheless often the only workable solution for certain applications. For example, so-called super mirrors need to show light scatter losses of significantly less than 10 ppm at 633 nm in the laser gyroscope application mentioned above, specifications that are achievable with IBS. Indeed, light scatter loss measurements (TBS, total backscattering in accordance with ISO 13696) undertaken by the Fraunhofer Institute for Applied Optics and Precision Mechanics in Jena on a mirror manufactured by Laseroptik was found to exhibit a TBS of just 1.1 ppm. With typical absorption and residual transmission measuring <15 ppm in total, the resulting reflectivity of >99.998 percent comes very close to that of a perfect mirror [3]. This type of result can, however, only be achieved with super polished substrates (surface roughness <1 Å rms) and provided that all rules relating to cleanroom procedures and cleanliness are scrupulously observed.

Another key application for super mirrors is in cavity ring-down measurements. Cavity ring-down spectroscopy [4] measures the ring-down time of a resonator and so too the resonator losses, thus revealing trace gas concentrations in the resonator. Alongside IBS, CRD is used as a measuring method in quality assurance to determine the losses of such highly reflective optics. As a result, measurements of more than six nines (99.9999 percent) are achievable, provided that the reference optics in the measuring instrument are adequate.

### IBS for precise high performance coatings

In contrast to conventional electron beam deposition, IBS coatings have no column structure, no voids or splashes and demonstrate no contamination due to poor vacuum conditions, all of which could lead to absorption or scatter. In addition, the stability of the optical constants is excellent. For most coating processes, and as is standard in all sputtering processes, thin

film growth can be determined based on time interval measurement using the vibrating quartz method.

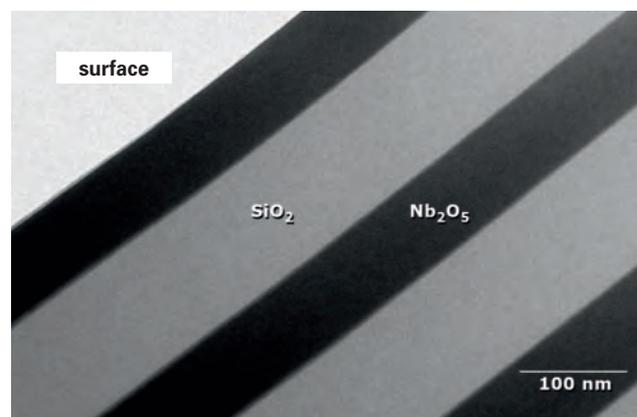
However, for broadband, chirped mirrors for fs pulse generation, very steep-edged filters, non-polarizing beam splitters or bandpass filters, then thin film thickness needs to be monitored via its broadband optical transmission. This technique measures the transmission curve *in situ* at the corresponding target spot on the rotating substrate within the coating system. Comparison of the actual transmission spectrum with that expected for the current layer stack reveals the thickness of the top layer, and this information is used to control the continuing process appropriately. Minimizing the unexpected in this fashion yields a high level of process reliability and simultaneously reduces the risk regarding cost-intensive substrates such as for nonlinear or laser crystals, fiber end-facets, semiconductors or the

super polished optics mentioned above.

The fabrication of phase-optimized mirrors represents another field of application that justifies the use of the IBS approach in conjunction with sophisticated processes control. So-called chirped mirrors are used in femtosecond lasers to negate the normal dispersive effects of other laser components. For example, a mirror can be modified to stretch fs pulses before the amplification stage, while a complementary mirror recompresses them again following the amplification stage, thus protecting the components within from excessive intensity. New directions are also being explored with novel approaches such as the sputtering of fluoride materials or the fabrication of rugate filters. Instead of a sequence of thin films with alternat-

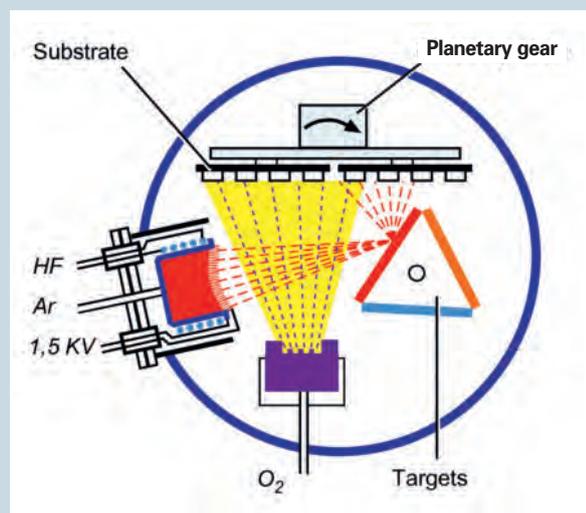
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**5** Electron microscope image of an Nb<sub>2</sub>O<sub>5</sub>/SiO<sub>2</sub> composite film fabricated using IBS. The films are free of voids and have a perfectly amorphous microstructure and extremely smooth surfaces

# High-speed Champion



**6** Schematic of a modern IBS coating system. The primary high frequency ion source (left) emits a beam of high energy inert gas ions, which is directed at a target changer. A secondary ion source (at the bottom of the picture) can be used for preconditioning of the substrate or to influence the optical and mechanical properties of the thin film

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ing high and low refractive indices, rugate filters are based on composite thin films fabricated by appropriately limiting component ion beam deposition by passing zone targets through the beam paths, again all under the control of a broadband monitor. The result is a layered microstructure with a thickness dependent, continuously varying refractive index. The gentle transition between the deposited materials yields, amongst other factors, higher damage thresholds.

## Summary

For most applications, laser components can be coated cost-effectively using the conventional technique of electron beam deposition with only minor losses and high damage thresholds. However, higher energy coating methods, such as IAD, magnetron sputtering or ion beam sputtering, must be used instead if interference filters with nanometer precision and stability are required. Among these techniques, IBS reigns supreme in terms of precision, process reliability and optical losses, and therefore represents an important other string to any coating firm's bow. ■

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- 3 With sincere thanks for the measurements to Dr. Angela Duparré at the Fraunhofer IOF, Jena
- 4 A. O'Keefe, D.A.G. Deacon, 'Cavity Ring-down Spectroscopy for absorption measurements using pulsed laser sources', Rev.Sci.Instrum. 59, 1988, p. 2544-2551

Dr. **Wolfgang Ebert** is owner and CEO of Laseroptik, specializing in the fabrication of coatings and laser mirrors. Dipl.-Phys. **Tobias Groß** is responsible for the IBS division at Laseroptik.

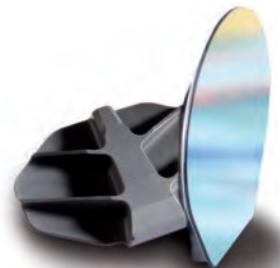


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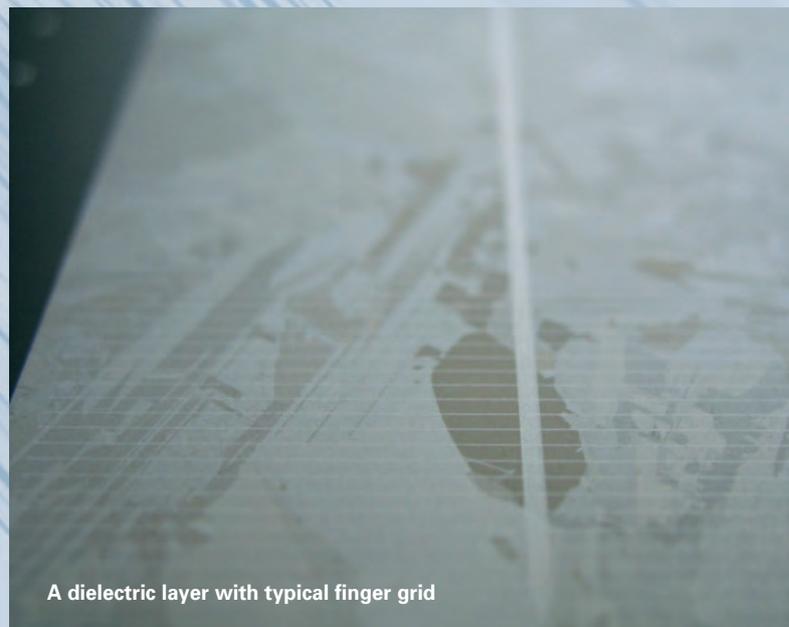
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# Selective doping

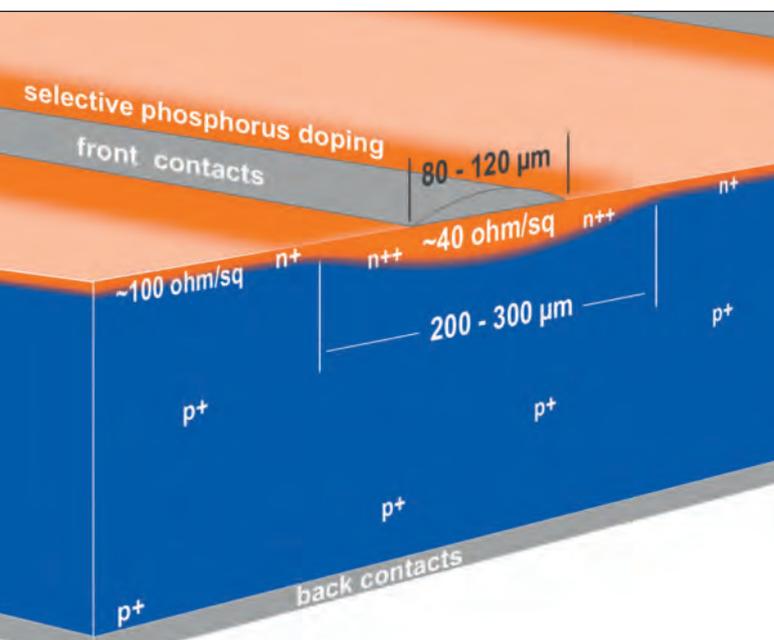
**LASER TECHNOLOGY HELPS SOLAR CELLS** with selective emitters to enter mass production. Within a year, the photovoltaics market has seen a price fall of 30 to 50 percent. The forthcoming new regulations to reduce energy feed-in tariffs (FITs) will exert further pressure on prices. To cope with the intensified competition, costs have to be reduced – one way to do that is to optimize efficiency.



A dielectric layer with typical finger grid

RICHARD HENDEL

To cope with the intense competition in the solar market, costs need to be reduced. However, manufacturers of crystalline cells have very little scope when it comes to reducing costs. Their current focus is on saving material by reducing wafer thickness or the silver pastes used, cutting production losses and further improving system availability. What all of these have in common, however, is that the potential cost savings are relatively small. As a result, attention is being increasingly given to a second variable for optimizing the price per watt – optimizing efficiency. The performance of research-grade crystalline cells with up to two thirds better efficiency demonstrate what is technologically feasible, although, of course, any increase in efficiency at the market level needs to be achieved with the lowest possible additional investment costs.



1 Schematic diagram of the selective emitting region

Cell manufacturers and suppliers of photovoltaic production lines alike are now faced with the task of identifying optimization technologies that require few additional process steps and that can be integrated into existing production line installations. Material processing using lasers is a very popular process here. It allows optimum control and, compared to etching and diffusion methods, runs at lower cost and with fewer materials, allowing it to be integrated into production processes with comparative ease.

## Selective emitter technology

The most promising solution at present is actually ancient by photovoltaics standards. It is based around selective emitters, which were already being discussed back in the 1970's. This technology promises to deliver an efficiency increase of up to one percentage point (to around 17 percent for multi-crystalline and 18.5 percent for mono-crystalline cells).

Traditional crystalline solar cells essentially consist of a full-metalized rear, a thick, p-doped silicon layer, a passivation and anti-reflection layer, and the fine metallic contact grid on the front. In the past, a compromise always had to be found for the negative phosphorous-doping of the silicon layer. While high doping around the contact fingers is desirable for effective conduction and low transition resistances, this reduces the efficiency in the areas in between due to unwanted absorption and recombination effects. In particular, this results in an efficiency loss of up to a third for solar cells in the short-wave near-UV spectral range.

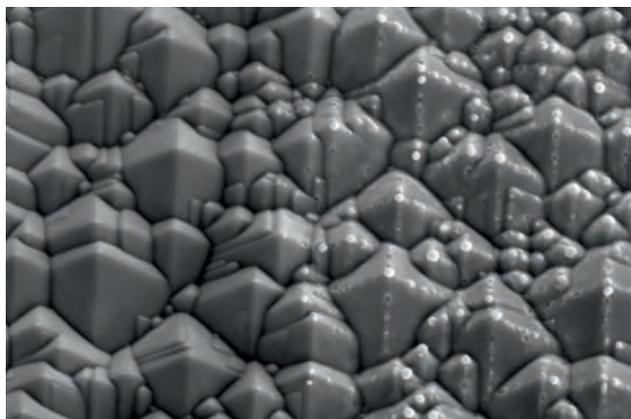
## Selective emitters for mass production

The solution has actually been on hand for a long time – selective doping of the emitter layer (Figure 1). However, in the past, the process was seen as too complex for mass production. This is because a second, separate doping step to achieve the different doping levels complicates the production process, as it actually involves several complex steps (marking, diffusion, etching). In addition, precise alignment of the higher doped areas with the contact fingers (attached later) calls for an extremely accurate process technology.

These days there are several new process concepts that avoid these disadvantages. All of the major German integrators and system suppliers – Roth & Rau, Manz, Schmid and Centrotherm – are working intensively on this problem. China Sunenergy has become the first major manufacturer to integrate selective emitters into its volume production. Apart from the ›etch-back‹ technology, which first creates broad-area highly-doped emitters and then selectively weakens the same layer by etching, they all use laser technology in one or more process steps.

**Laser ablation to achieve selective doping processes**

The ›diffusion masking‹ method is currently at a very advanced stage of development. It involves masking the wafers with a dielectric layer before phosphorous diffusion, and selectively opening this mask with the laser in the areas where the contacts will subsequently be located. This enables the subsequent standard diffusion process used for doping to act at different strengths on the different areas of the surface. After comparing numerous processes available, one manufacturer of production systems chose this technology and presented it at the 24<sup>th</sup> European Photovoltaic Solar Energy Conference in September 2009. In the process outlined, the



**2** PSG doping in a scanning electron microscope image



**3 PowerLine L with fiber and scanning head**

laser ablates the dielectric layer at a width that is slightly above the contact path that will subsequently be printed. The laser process is designed to be as fast and effective as possible and, at the same time, optimized to ensure the least possible damage to the underlying silicon.

**Direct selective laser doping**

Direct, selective laser doping is another interesting method for producing selective emitters. With its accurate, precisely controllable local heat injection, a laser is the best way to meet the requirements for a selective doping process. Earlier concepts used the laser for doping with gaseous or liquid doping sources, combined with correspondingly sophisticated process technology. By contrast, new technologies are mainly based on ›dry‹ methods with local ›driving-in‹ of solid doping materials previously applied.

The simplest method, which was first discussed back in the 1990's, uses the layer of phosphosilicate glass (PSG) (that is, the layer that is found on the surface after conventional doping) as a doping source for a second, selective doping step (Figure 2). A laser locally heats or melts the silicon surface below the PSG layer, thus allowing deeper penetration of additional phosphorous doping. However, the task of subsequently aligning the heavily doped emitter with the contact grid remains. Other concepts move this step backwards in the process, and apply a phosphorous doping source to the passivation layer immediately before producing the upper contacts. A laser beam ablates the dielectric layer and melts the silicon underneath in a fine lattice, thus allowing the additional doping to penetrate. The metalization for the contact fingers can then be immediately applied to the open, highly-doped emitter layers.

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## Green solid state lasers and innovative fibers

The requisite beam quality at high powers and pulse frequencies make Q-switched solid state lasers an ideal tool for this kind of application. They are often used with frequency doubling to provide optimum interaction with the thin film materials used. The proper balance of pulse duration and energy provides the most selective ablation possible. The short cycle times available in mass production of solar cells necessitate beam sources with output powers of up to 100 W, depending on the application.

While the absorption at the fundamental wavelength of 1064 nm reaches too far into the deeper silicon layers, it can be limited with frequency-doubled green lasers in the range of 1  $\mu\text{m}$ . Frequency-tripled beam sources in the near UV range demonstrate slightly better absorption properties in some cases. However, this is offset by the relatively narrow choice of UV-compatible optical components and the significantly more critical maintenance issues, meaning they are not ideally suited for the requirements of industrial mass production.

Current projects by various research institutions and solar cell manufacturers are confirming the exceptional suitability of Rofin's new ›PowerLine L 100 SHG‹ at 532 nm (**Figure 3**), both for selective ablation of dielectric layers and for direct laser doping. New optical fibers developed specifically for this wavelength play a crucial role. They produce a ›top hat‹ beam profile, which represents the optimum solution for homogeneous input of laser energy over the entire area of the laser spot. This enables ablation and diffusion processes

with a much more uniform, two-dimensional intensity distribution to be realized.

## Summary

Photovoltaics remains a promising and yet demanding market for laser manufacturers. Both new high efficiency concepts and optimizations in mass production can only be achieved through close cooperation with research institutions, system suppliers and producers. With selective emitter technology, an old idea has been successfully applied to research-grade solar cells and is now starting to move into mass production. It will definitely not be the last idea to do so. Lasers are also the key technology for a range of other high efficiency concepts that have already been realized in practice, from ›laser fired contacts‹, to ›laser buried contacts‹ to ›back contact‹ cells.

In addition, the capability of lasers in terms of laser doping and selective ablation of dielectric layers is opening up a wide range of new methods for increasing efficiency. Because the layer thicknesses for selective ablation are in the range from 10 to several 100 nm, the requirements in terms of beam quality, pulse to pulse stability and long-term stability of the lasers are huge. This will call for the continued development of special beam sources optimized for photovoltaics, such as the Rofin PowerLine L series. ■

**Richard Hendel** is Sales Manager for Solar at Rofin Baasel Lasertech in Starnberg. With 1600 employees, Rofin is one of the world's leading manufacturers of industrial lasers and laser systems and has installed well in excess of 1000 beam sources in the PV sector.

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## Innovative Products

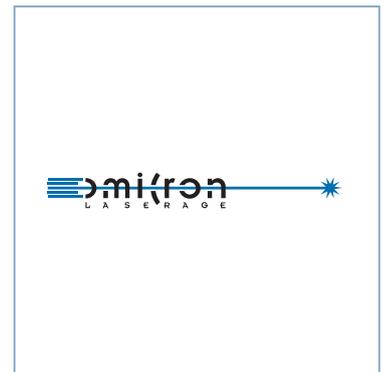
### LuxX<sup>®</sup> Compact CW Diode Lasers

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into a co-linear beam, which can then be used in free-space or fiber coupled applications. Whereas the SOLE<sup>®</sup> laser light engines mainly address end-users, the LightHUB<sup>®</sup> compact beam combiners are very attractive for OEM integration. For both products, the customer can choose from over 20 different wavelengths in the range of 375 to 830nm. Various power levels of up to 200mW per laser line are available.



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### RAYLASE AG – TOTAL CONTROL OF YOUR LASER BEAM

As a global market leader RAYLASE develops and manufactures galvanometer-scanner based components and subsystems for laser beam deflection, modulation and control. Since its foundation in April 1999, RAYLASE has been facing the challenges in this field and supplying the market with innovative, high performance and quality scan solutions.

DIN EN ISO 9001:2008 standard certified RAYLASE offers customized solutions for the increasing requirements of laser technology in many industries such as automotive, electronics, packaging, textiles, security and solar.



In these industries laser technology is used for diverse applications like cutting, marking, perforating and welding of plastics, metal, glass, textiles and other materials.

In addition to reliable 2-axis laser beam deflection units and 3-axis laser beam subsystems, RAYLASE offers customers the right combination of application software and control electronics.

With our subsidiary in Shenzhen, customers can benefit from our services in mainland China and Asia region. In addition to our footprint in Asia we recently opened a RAYLASE Certified Service and Repair Center in Sao Paulo, (Brazil) in 2010; this activity underlines our focus on the BRIC states (Brazil, Russia, India, China). Our new center in Brazil acts as an important hub for South America. Further we have a RCSC in St. Petersburg together with our partner Laser Technology Centre.

These RCSCs are able to maintain and repair all RAYLASE products supplied to each relevant country. International sales are handled by a worldwide network offering you global know-how and local expertise.



### mechOnics ag

#### Competence in Micropositioning

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### mechOnics ag

#### – Competence in micropositioning –

mechOnics ag, a German company founded in 2003, is specialized in development, production and sales of systems for micro- and nanopositioning applications.

These systems are driven by a new developed, innovative piezo inertial drive, which combines high resolution in the nm-range with large travels up to 50 mm. Together with piezo controllers with very low power consumption this permits main voltage free applications in laboratories and out of doors.

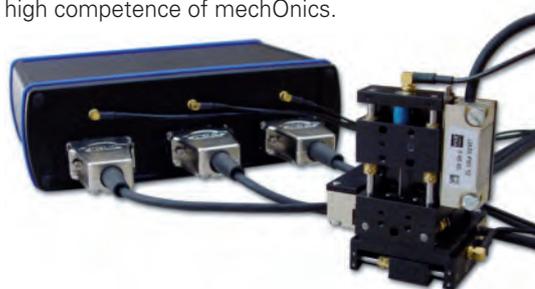
In telecommunication, semiconductor industry, laser- and bio-technology, sensors and space industry multiple customers profit of the high competence of mechOnics.

### Range of standard products

- Linear stages up to 50 mm travel
- Ultra compact xyz-stages (travel  $\leq 10$  mm)
- Monomode coupler (travel  $\leq 2$  mm)
- Ultra low temperature stages ( $\leq 300$  mK)
- Ultra high vacuum stages ( $\leq 10^{-10}$  Torr)
- Mirror mounts for transm. optics (tilt  $\pm 3$  deg.)
- Linear measuring systems (resolution  $< 50$  nm)
- Handheld battery driven controller
- USB-controller (open or closed loop)

### Customized products

- Positioners for ultra low temperature applications
- Low temperature microscopes
- Slits for electronic microscopy
- Filter slider for space applications
- Positioners for UHV applications





### Custom made Microstructures – Optical Components.

Optical component with complex microstructures and grids are used for a wide range of applications.

For the manufacture of complex microstructures several processes are required. Due to the high complexity of the manufacturing processes several sub-suppliers have specialised in only one of these steps.

Handling a chain of sub-suppliers generates additional costs and a considerable logistical effort with no added benefit for the end-user.

For the designer or end-user of an optical component, it is an advantage to work directly with a manufacturer who understands all the steps in the manufacturing process, who is able to provide technical support also in the development phase of an optical component and who can then carry out the manufacture of the finished product in-house in a swift and cost effective manner.

The mission of IMT Masken und Teilungen AG is to provide custom made microstructures and solutions in the field of microlithography.

All manufacturing processes are in-house.

Top-of-the-line process controlled PVD facilities enable coating with metal and dielectric coatings of a very high and uniform quality.

Exposure either takes place with laser (IMT was among the pioneers in the Direct Write Laser Technology) or as a print from an extremely accurate master plate.

Mask-aligners are used to carry out exposure of products with more than two layers of structure.

The wet-processes are as automated as possible in order to guarantee a high level of uniformity through SPC (Statistical Process Control).

An innovative machining of glass allows also for the manufacture of very large quantities.

IMT currently has a staff of 70 experts in the fields of optics, physics and microlithography and operates a 1000m<sup>2</sup> clean room near Zürich.

IMT Masken und Teilungen AG is a subsidiary in the HEIDENHAIN Group of companies.

**IMT**  
PRECISION ON GLASS

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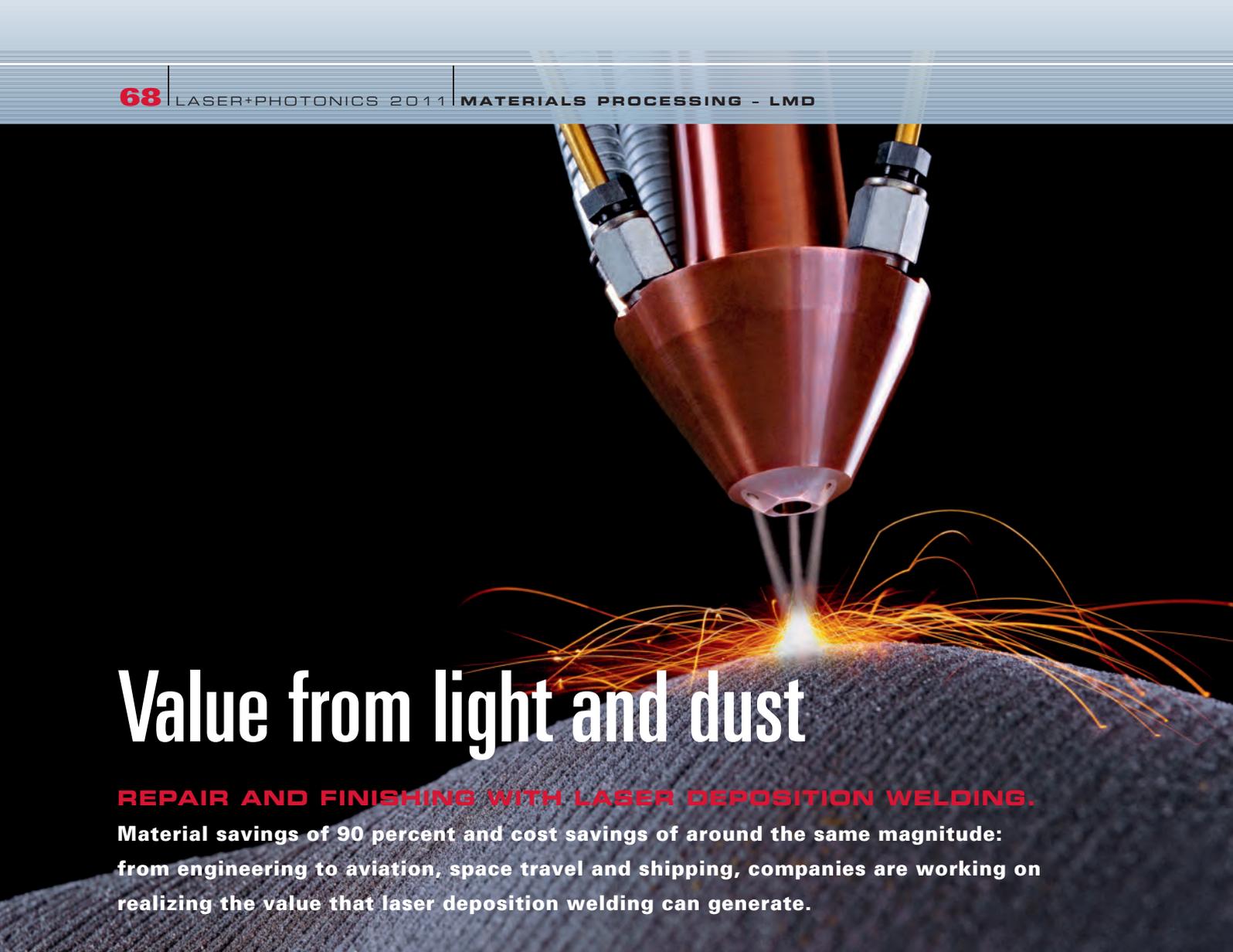
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# Value from light and dust

## REPAIR AND FINISHING WITH LASER DEPOSITION WELDING.

**Material savings of 90 percent and cost savings of around the same magnitude: from engineering to aviation, space travel and shipping, companies are working on realizing the value that laser deposition welding can generate.**

ANTONIO CANDEL-RUIZ

Approximately 44 000 ships currently sail the world's oceans. The auxiliary diesel engines that are used for power generation wear out an average of 260 000 four-stroke pistons every year. Replacing all of these pistons with new parts consumes five million tons of steel and around 93.5 terajoules of energy for their production. This calculation was recently published by Gall & Seitz Systems, a family company from Hamburg, which has worked in the repair of ships and shipping equipment for more than 120 years.

In cooperation with technology partner Trumpf, Gall & Seitz Systems has developed an industrial process that would enable around 90 percent of these pistons to be reconditioned. According to estimates, this would see the raw material requirement for replacement of these 234 000 pistons fall by 99 percent and the energy requirement by 95 percent. The technology at the heart of the process is laser materials deposition (LMD) welding.

### **Metallic coating via laser deposition welding**

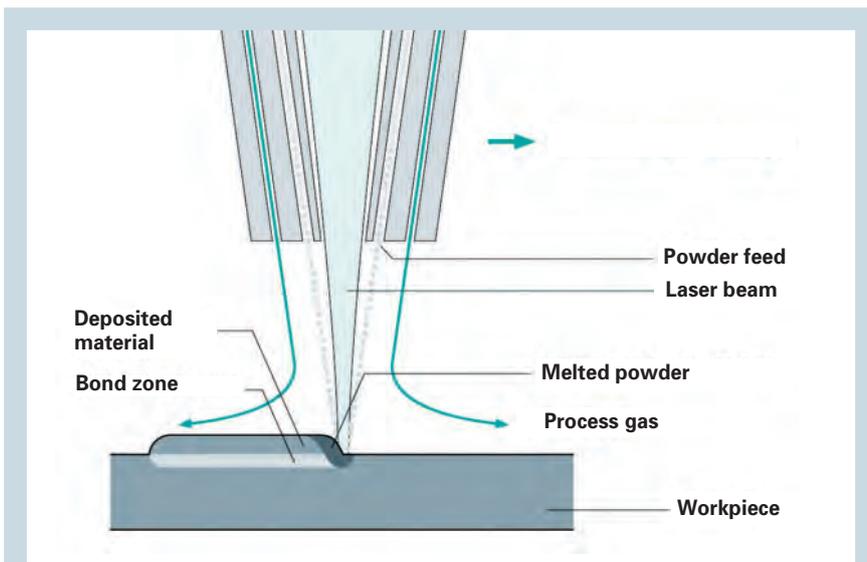
Calculations such as this illustrate the huge potential value of laser deposition welding. The process had its origins back in the 1970's and is based on a very simple

concept: a laser beam produces a weld pool on the surface of a component. Powder jets blow a metallurgical powder into this weld pool coaxially to the working beam – this additional material also melts and is permanently deposited. This enables new layers of metal with defined properties to be applied, even against the force of gravity. Depending on the application, individual materials or powder mixtures consisting of different materials can be used, allowing the properties of the new layer to be very precisely defined. Iron, cobalt, titanium and nickel alloys, as well as materials containing carbides, are all applicable. It is possible to choose a powder composition and the laser power in such a way that the carbides have a homogeneous distribution in the layer. For example, this enables tungsten or titanium carbides to be embedded into a welded-on metallic matrix to increase the wear resistance of the component surface (**Figure 1 and 2**).

The weld path, drawn linewise over the surface of the part to be repaired or finished, normally has a height of 0.2 to 1.5 mm and a width of 0.5 to 6 mm. These are normally applied with an overlap, so that the paths combine to form a homogeneous layer, and several paths can be applied on top of one another to increase the thickness of the layer. Within an hour, roughly 2 kg of material can be applied. In spite of this, like all laser welding processes, the process only transfers a small amount of

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**1** The powder jet blows metallurgical powder into the focus spot. The powder melts in the weld pool and combines with the workpiece surface, which is also melted

© LASER+PHOTONICS

However, leading manufacturers such as Trumpf now offer complete technology packages for LMD applications that guarantee proper control of these aspects.

They normally consist of three functional units – the powder feed, the processing optics with powder jet and the powder transfer line (which connects the feeder) and the optical system. For Trumpf systems, the powder feed is normally a mobile unit with up to four independently programmable powder containers. The feeder combines the powder/gas mixture from the containers into a precisely adjusted powder mass flow. Sensors continuously monitor the composition of the flow, ensuring that there are no fluctuations in the metallurgical composition of the layer.

### Repairs and finishing

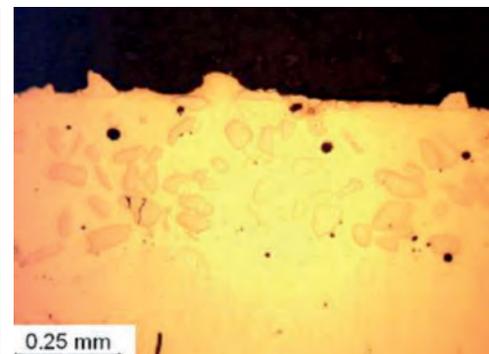
The economic potential of the technology lies in the possibility of increasing the value of basic components with a functional layer or significantly increasing the service life of expensive components. In this context, a functional layer often means increased temperature, corrosion and wear resistance.

heat into the workpiece and thus does not cause distortion. All dimensions are retained and post-processing is limited to improving the quality of the new surface.

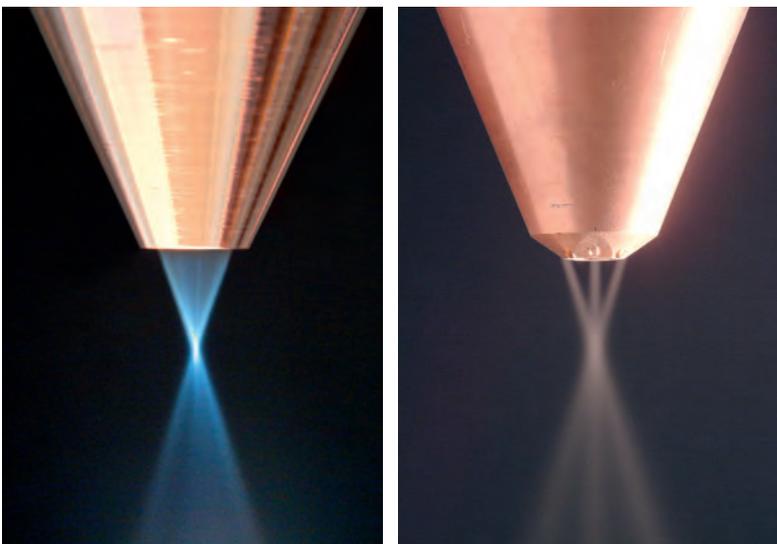
Additional layers can be applied with each cycle, either to create a new workpiece surface or to repair machining or wear damage and restore the original geometry of a component. The process can additionally (re-)create three-dimensional structures, such as the tip of a turbine blade.

### Process optimization

Despite its huge potential, laser deposition welding long remained a process confined to the laboratory. The main challenge lay in adequate process control – to achieve a homogeneous layer with the specified properties, the laser power, powder composition and the supply, frequently of multiple materials, must be precisely coordinated and controlled.



**3** Manufacture of wear-resistant layer systems for agricultural machinery: Coated cutting disk and cross-section of the carbide layer (right)



One of the best known current applications is the hard coating of drilling rods for oil drilling. A complex system of layers on a simple steel tube protects the sensitive and expensive sensors in modern drill lines that can be guided through the ground. In total, around 40 kg of material is applied to each rod. Another example is wear-resistant blades for agricultural equipment (Figure 3). One manufacturer of these blades, MWS from Schmalkalden, embeds tungsten carbide into a metallic matrix when applying the coating. The decision to replace the flame spraying technique previously used with the laser deposition process was not alone based on the fact that the LMD process makes supplementary operations such as postmelting super-

**2** From left to right: Coaxial jets apply fine structures in a flatbed configuration. Multi-jet nozzles for direction-independent 3D applications can work up to 90 degrees from the horizontal (Image: Fraunhofer ILT)

fluos. Above all, it allows MWS to adjust the carbide component and the layer thickness very accurately thanks to precise control of the process parameters.

The second important application area in which the LMD process could mature is repair welding – rescuing expensive components that are still fully functional apart from some localized damage. The best known application is the repair of non-replaceable turbine blades on turbine wheels, known as ›blisks‹. The turbine blades on a blisk cannot be replaced. If one of them is damaged, the entire turbine wheel is rendered worthless. This is why service companies in aviation are working intensively on repair processes that enable damaged edges or broken tips to be reconstructed with the original geometry and material properties.

### Piston repair

The laser deposition welding process from Gall & Seitz Systems also aims to maintain the value of worn components. The value created for each cylinder repaired is not as high as that with blisks, for example. Instead, the economic potential lies in the opportunity to create a highly automated process for repairing large quantities. On the pistons in four-stroke auxiliary diesel engines, there is increased load on the first piston ring

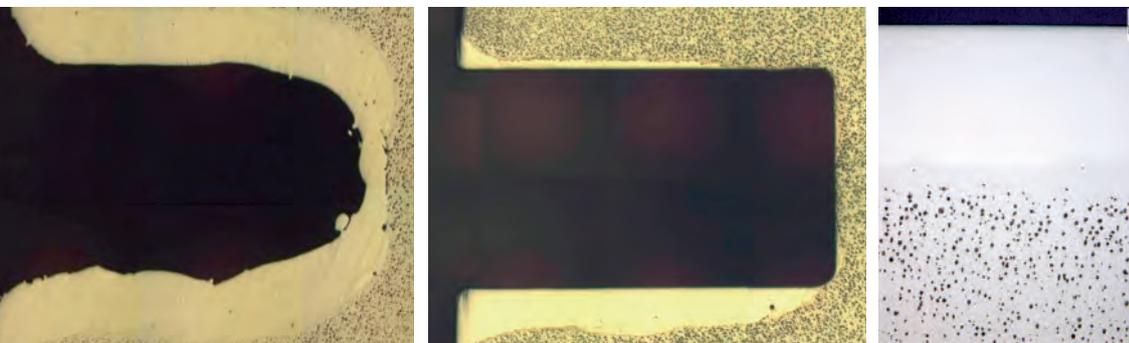


**4 Spheroidal graphite cast iron piston with reconditioned first groove** (Image: Gall & Seitz Systems)

- general reduction in post-processing work, and
- improvement of local properties by selection of appropriate materials for coating.

Accessibility, reproducibility and, above all, the requirement for low thermal load rule out conventional deposition welding processes. The only technology that can meet the demands of this process is LMD. Because of the working distance, the laser beam and powder jets meet the requirement for processing very fine, difficult to access geometries. In addition, the processing head is so compact that it can be guided by a robot. The beam and powder feed are also controlled by computer, resulting in a highly automated and therefore economical overall system. The operator ultimately has a relatively free choice of powder material, which enables Gall & Seitz Systems to optimally adjust the properties of the layer to be welded for the subsequent finishing work (Figure 4 and 5).

Laboratory tests show that the heat affected zone remains small, with a thickness of around 150 µm, and does not influence the usage properties of the piston. With its homogeneous hardness distribution of 450 to 500 HV0.1, the new layer is actually more resistant than the original laser-hardened base material. Gall & Seitz Systems is currently testing recon-



**5 From left to right: Ring groove immediately after material application and following post-processing. The minimal heat affected zone between the coating (light) and the spheroidal graphite iron GGG60 (spotted gray) can be easily identified**

(Image: Gall & Seitz Systems)

ditioned pistons in a field trial. The results are very promising and confirm what laboratory tests had already suggested. The reconditioned pistons are not only as good as new, they are actually better than new pistons. After 4500 hours of operation, the engineers from Gall & Seitz Systems could only measure minimal wear, better than the wear observed in the first ring groove on brand new pistons in the same machine.

groove. This is more directly exposed to corrosion from the combustion gases and wear from hard particles in the fuel than the subsequent piston ring grooves. As a result, substantial wear can often be seen here, although the piston itself only demonstrates minimal wear, such as burnout on the piston crown. However, the damage from the ring groove wear is so significant that the entire piston has to be replaced or repaired. Until recently, there were no appropriate repair processes that enabled the original geometry of the groove to be restored. Gall & Seitz Systems describe the requirements of such a process as follows:

- adequate accessibility to restricted areas of the component,
- accessibility to grooves with an aspect ratio of 2:3,
- high precision and reproducibility,
- no damage to the basic material,
- no distortion,
- cost-effective process,
- high level of automation,
- opportunity for subsequent machining,

ditioned pistons in a field trial. The results are very promising and confirm what laboratory tests had already suggested. The reconditioned pistons are not only as good as new, they are actually better than new pistons. After 4500 hours of operation, the engineers from Gall & Seitz Systems could only measure minimal wear, better than the wear observed in the first ring groove on brand new pistons in the same machine.

### Summary

The results are convincing and one engine manufacturer is keen to use the process. Their aim is to offer a second product line alongside their new pistons, made up of economical, replaced, and reconditioned pistons. Thus, the LMD process from Gall & Seitz Systems will give the company a way to compete with suppliers of cheap spare parts – a high quality yet economical range of original parts with a manufacturer's guarantee. ■

Dr. Antonio Candel-Ruiz is responsible for the industrial laser surface processes unit at Trumpf Laser- und Systemtechnik.



**GWU-Lasertechnik:  
The Experts in Tunable Laser Systems and  
Non-linear Optics**

GWU-Lasertechnik Vertriebsges. mbH was founded in 1988 as a sales and service organisation for lasers and laser accessories. Starting as an agent for the predecessor of Fujian Casteck Crystals GWU-Lasertechnik started to develop products around crystals delivered by these Chinese world-leading specialists for BBO and LBO. First results were demonstrated at Laser show 1989 in Munich where GWU introduced the first commercial BBO-OPO



worldwide pumped by the third harmonic of a q-switched pulsed Nd:YAG laser at 355 nm. Since then the OPO technology has been permanently improved and matured by GWU. Now they are offering the fourth generation of BBO-OPOs suited for a variety of applications including spectroscopy, environmental analysis, process control in the chemical and pharmaceutical industry, and lidar systems. The product line of OPOs is completed by useful accessories like a wavemeter that fully integrates into the OPO installation and software thus allowing fully automated wavelength calibration, and frequency converters to cover the UV range efficiently down to about 205 nm. GWU also integrate Nd:YAG laser heads and OPOs/harmonic generators on a common platform or completely sealed housings some of which have been successfully used outdoor and in harsh environments. These systems have no need for extra optical tables and are easily movable. The pulsed OPO product line is completed by versions pumped at 532 nm (2nd harmonic of q-switched Nd:YAG lasers) or 1064 nm. Non-linear materials used in these systems include BBO, KNbO<sub>3</sub>, and KTP thus allowing to cover the spectral range between 205 nm and >4000 nm. Customised solutions are developed and offered as well.

GWU's OPOs are available in a variety of configurations among which you find broadband and

midband systems as well as a version with a smooth round beam profile and symmetric low divergence beam characteristics. Unique feature of all these BBO-OPOs is the low pump threshold in combination with the most conservative pump scheme on the market ensuring highest reliability and lifetime of the optical components inside.

Besides these nsec OPOs GWU develop and manufacture OPOs and harmonic generators for pumping by commercial lasers in the psec and fsec regime such as Spectra-Physics Tsunami lasers.

GWU offer a selected range of third party products. These include a wide spectrum of laser crystals and nonlinear crystals. Most popular crystals are BBO, LBO, KTP, KD\*P, Nd:YVO<sub>4</sub>, Nd:YAG among many others manufactured by the world-leading company Casteck. Periodically-poled crystals such as MgO:PPLN, manufactured by HC Photonics, available as bulk or waveguide with a variety of grating structures (single, multiple, fan-out chirped,...) are of increasing interest especially due to their high conversion efficiency for continuous wave and low power applications. This portfolio of optical components is complemented by prisms, wave-plates, polarizing optics and standard items.

Latest members in GWU's product family are fiber lasers and ASE products of the leading manufacturer in this field – NP Photonics. These products include low phase noise narrowband and ultra-narrowband fiber lasers with powers from 10 mW to several Watts. The proprietary in-house fiber production technology ensures unsurpassed, and reproducible quality of the product line.

Due to their superior service and competence GWU have generated a broad base of satisfied customers in the industry and in scientific research laboratories.



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### The company

NUMERIK JENA draws from over 30 years of experience in the development, manufacture and sale of position encoders. The roots of production metrology and its associated technology for the manufacture of precision scales go back to Carl Zeiß and Ernst Abbe.

In following this great tradition, the goal of all our activities is continuous innovation and the improvement of our products.

We orient ourselves to the demands of the international market to which we can react flexibly thanks to the modular character of our encoders.

### The products

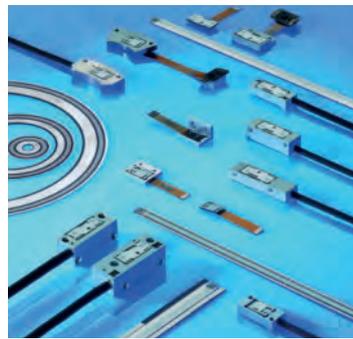
NUMERIK Jena offers positioning sensors with a wide variety of options according to the demands of the application.

- High resolution for the precise dynamics of the actuator
- High accuracy for accurate and repeatable positioning

- Low short-range errors for constant and smooth motion
- Low profile requirement for ease of implementation and to allow simple integration with existing mechanics
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- High traversing speed for fast positioning and high productivity
- Customer friendly mounting tolerances for low assembling costs
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### Applications

- suppliers and users of linear and rotary actuators
- Production equipment of semiconductor industry
- linear, rotary and planar direct drives
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FRAMOS has been active in the area of industrial image processing for the last 30 years and as an innovative partner provides a broad range of high-quality components and services. Along with offering image components such as sensors, companion chips, camera modules, cameras and accessories, we provide a real variety of development support services for camera manufacturers and users.

#### FRAMOS Imaging Components

Sells our partner companies' image processing components and systems across the globe.



In our component portfolio, we focus on the areas of machine vision, medical, traffic and security and provide you with every possible component, from sensors to the GigE interface, tailored to your needs.

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You have an idea for a camera or an image processing system? Your prototype needs to be developed? Or you're not happy because the design is finished but it didn't turn out as you had hoped? We will support you throughout the whole value chain of your image processing system. We consider the whole surrounding architecture (optics, lighting, mechanics, server infrastructure, data editing etc.).

#### FRAMOS Solutions

FRAMOS Solutions works in linking our expertise for system integrators to camera users. Specialist engineers will support you in implementing your ideas and projects, comprehensively and competently. If you want to use an image processing system, we will help you to select the best possible combination of all components such as cameras, lenses and lighting, as well as the right software.



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#### CompoTRON

is a **pan-European** technical representative and distributor of fiber-optic components for datacom, telecom (incl. FTTx & PON), Industrial Ethernet, medical and metrology applications. Working exclusively together with a small number of carefully selected suppliers, we can provide our customers focused support and a complementary set of product portfolios. We strive to establish long term relationships by providing the best product support through technical competence.

Our strengths include a dedicated product line management team with a solid technical background, short reaction times from committed sales engineers within each geographical region and strong and long term relationships with our suppliers.

Our range of standard products covers

**MSA transceivers** in form factors 1x9, SFP and SFP for 200 km FE and 120 km GbE. Optical transceivers for 10 Gb/s to 40 Gb/s applications in SFP+, XFP and 300-pin footprints.

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**Customisation, buffer stocks** and **short lead-times** complement our standard service offering.



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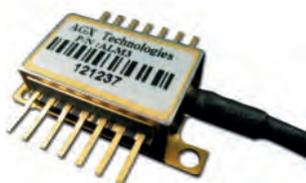
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# Three-dimensional components cut product costs

## NEW LDS SYSTEM FOR COST-EFFICIENT MASS PRODUCTION.

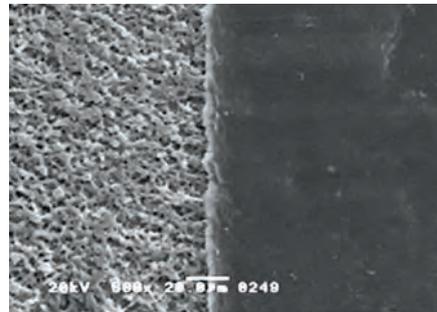
Laser direct structuring (LDS) has previously allowed 3D interconnect devices to be produced cost-efficiently in small and medium runs or even as individual units. The new Fusion3D system from LPKF cuts the structuring times and costs to around a third, thus making three-dimensional LDS interconnect devices attractive for the mass market.

WOLFGANG JOHN

There has been one dominant trend in electronic and mechatronic products for a long time now – components are shrinking, yet simultaneously have to do more and more. Particularly in cars, the additional sensors and components for new driver assistance systems, including their cabling, require an increasing amount of space that is not easily available. They also make vehicles heavier, which is not desirable either – the wiring harness

for the BMW 3 Series now weighs approximately 30 kg. Then there are the rising costs for manufacturing and installing the systems, which does not appeal to the OEM or potential customers.

In communication technology, manufacturers are under extreme pressure to constantly bring new products to market in a very short time-frame, primarily in order to maintain their commercial position. And, of course, in order to succeed in the market these new products must have a collection of unique selling points that sets them apart from the mass of competitors. This calls for MID (molded interconnect devices), a technology that makes new products with previously unattainable functionality possible.



1 The structure activated and roughened by the laser beam (left) is subsequently metal coated

## Increased functionality thanks to MID

MID means that conductors can be attached to three-dimensional plastic components and electronic components can be arranged in a very small space. This enables chips to be stylishly stacked in their assembly or aerials for smartphones or netbooks to be created on the housing in order to save space. At the same time, integrated functionality also reduces the number of individual components, eliminating a range of production steps and thus automatically saving additional costs and simultaneously delivering a higher quality of components.

Various methods are available for attaching conductors to the plastic components. Hot embossing involves a stamp for pressing thin, flexible films onto the component. The surplus film is then removed. The process is simple and it works with a large number of materials, but it is unsuitable for very fine conductors and cannot achieve genuine three-dimensionality and more complex circuits. With sandwich molding, the interconnect device is produced first from plastic. A second plastic, one that can be metalized, is only deposited where conductors will subsequently run. The process allows almost unlimited design freedom in three dimensions, but the two molds required make it expensive. Production of fine conductors is also problematic. The relatively long lead time before this kind of product can come to market is also a factor (the lead time for the molding tools alone is roughly two months).

As in many areas of manufacturing, the incomparable flexibility of lasers is opening up totally new perspectives in MID. In this subtractive process, the laser removes layers of metal

where they are not required, or opens a resist for a subsequent etching process. The technology prerequisites reliable laser performance and extensively metalized components.

### Laser direct structuring

The laser direct structuring (LDS) process patented by LPKF is more convincing from both a technical and an economic perspective. The LDS process uses a thermoplastic that is doped with a laser-activated metal/plastic additive. When the laser

BMW Z4, the handlebars for the BMW K1300 motorcycle, seat adjusters, control cabinet modules and solar sensors for climate control in cars are also produced using LDS technology. At present, research is even in progress into the production of multi-layer LDS components.

### Cell phones become ever more capable

Increased functionality with an ever smaller volume – this is a key requirement in the communications industry. Thanks to LDS, up to twelve aeri-als can currently be integrated into a cell phone. However, cell phone manufacturing is mass production and demands a considerably higher throughput than is normal for small and medium-sized runs. This is where the new ›Fusion3D‹ laser structuring unit from LPKF comes into play (Figure 3). Up to four laser heads work simultaneously on a precisely manufactured granite base plate from seven possible positions. This increases the throughput compared to previous systems by up to five times and cuts the processing time by up to 75 per cent. Feed times and component rotation are eliminated.

The standard version of the Fusion3D has a laser focus of 65 µm diameter. This enables conductors with a width ▶



2 From a simple molded part to a fully equipped three-dimensional interconnect device

beam strikes the plastic, the metal complex breaks down and forms a roughened track. The metal particles act as seeds for the subsequent metalization. The laser draws the required structures onto the component and the conductor layers are then precisely deposited on these tracks in an electroless plating bath. Copper, nickel and a gold finish can be applied in turn (Figure 1). This is where the great flexibility, speed, resolution, and precision of the laser comes into its own. If the course of the conductors changes, it is only necessary to send new control data to the laser unit. This enables different functional components to be produced from a single basic component, depending on the design of the circuits inscribed

#### CONTACT

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[www.lpkf.de](http://www.lpkf.de)

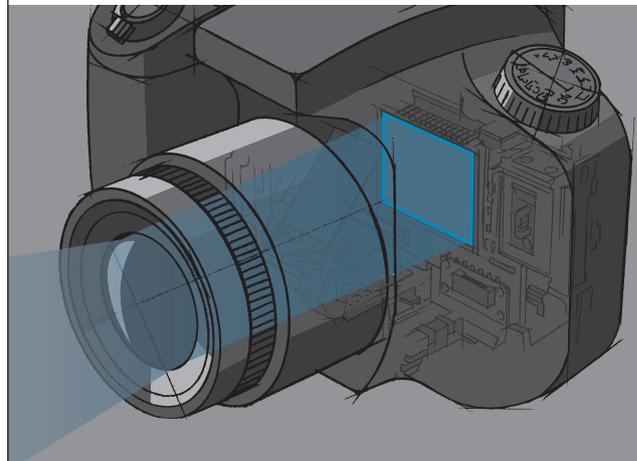
on them. And because the control data for the laser can also be switched during production, an operator can manufacture small and medium-sized runs cost-efficiently. One-off production is not limited by cost or technical grounds either. The path from prototype to series production is short and cost-effective, allowing the company to respond quickly to the needs of the market (Figure 2).

The LDS process has already achieved success in a wide range of applications. The best known product group is complex aerial structures for high quality cell phones, PDAs and laptops. The technique has also proved effective in compact and high performance medical technology, pressure sensors and a coupling system for digital model railways. A pipette system with automatic volume detection, a steering wheel switch for the



## Sensors & Imaging

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of 150 µm to be realized at a spacing of 200 µm. With different laser sources and optimized focusing, the system can create even finer structures, significantly surpassing the limits of other MID processes. The system saves the production data and all parameters, and this can then be retrieved at any time. The software supplied distributes the control data to each individual laser head, thus optimizing cycle times. In conjunction with robot automation, this guarantees speed, accuracy and maximum reproducibility while simultaneously minimizing personnel costs and downtimes. The Fusion3D is designed for continuous operation. It thus combines great flexibility, efficiency and short times to market with the option of mass production – recommending it for many other applications.

### Growing market potential

Because it is a software-based production system, it is only necessary to change the structure template file for the next product. This simplifies production and ensures minimal downtime, optimum utilization of system capacity and correspondingly low unit costs.

With its ›MicroLine3D‹ and ›Fusion3D‹ systems, LPKF supplies the ideal technology for future markets. They can be used for everything from one-off production through to mass-production. The advantages of MID technology are most noticeable

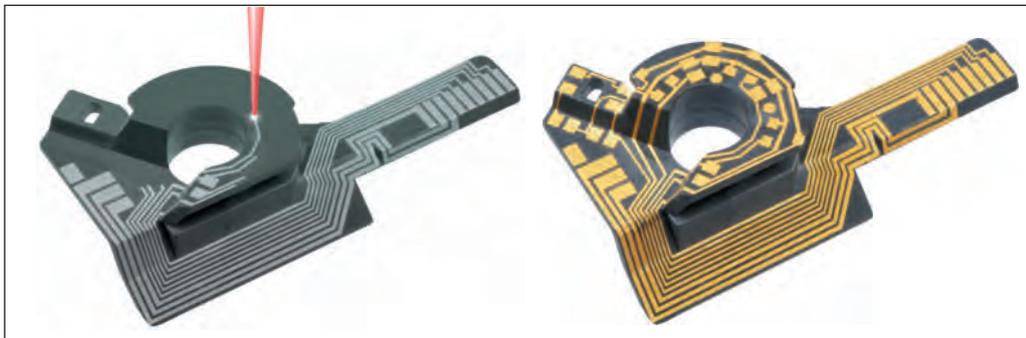


3 The new Fusion3D laser structuring unit from LPKF

aerials per year. Dr. Ingo Bretthauer, Chairman of LPKF, expects LDS technology to increasingly expand out of the high-end sector and gain a foothold in mid-price cell phones.

### MID has huge potential

The key to LDS is ›function follows form‹ – which not only allows for new functionality but also visually new products. Use of defined plastics complies with the RoHS regulations and recycling is easier than with PCBs, for example. Because the entire process takes place under one roof, there is no need for sophisticated and costly just-in-time management or for incoming inspections.



4 The layout of a structure can be adapted on the computer in little to no time and immediately transferred to the component

where maximum functionality is required. Thanks to the third dimension, they open up totally new perspectives for designers, with performance that cannot be achieved using conventional methods.

### Design steps

To make developers' work easier, LPKF provides a direct interface to LDS in the MID module for Nextra. Here, 3D molded shapes can be conveniently designed and virtually fitted with conductors and electronic components. The features available include a 3D splitting tool. The LPKF software uses the three dimensional CAD data to generate the optimized control data for the structuring process (Figure 4).

The design rules specially tailored to LDS explain the general parameters and assist in laying out the circuit. With the LDS rules, the optimum process advantages of the method can be achieved from the component layout phase onwards.

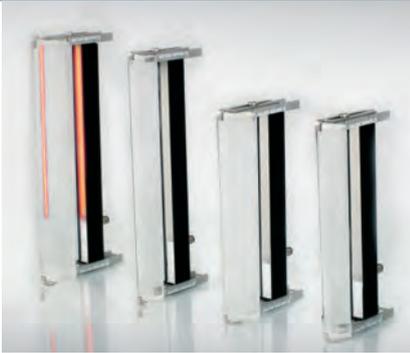
With its LDS technology, LPKF is heading in the right direction, as the production method is increasingly replacing conventional manufacturing processes. For example, the Fusion3D systems already installed have increased capacity to up to 100 million

Particularly for companies in the automotive industry, the use of LDS is ideal, as engineers have to combine electronics and mechanics as efficiently as possible, while saving space. And there is even more fertile ground to work on, such as the development of aerial modules for UWB (ultra wide band) and MIMO (multiple input and multiple output), which can also combine satellite services such as GPS and SDARS.

### Summary

The possibilities of LDS technology are a long way from being exhausted. MID applications will probably never be able to replace the entire wiring harness on a car, but they can drastically reduce its complexity, weight and costs, while simultaneously adding new functionality. LDS technology not only replaces existing components, but also allows unique functions and layouts to be achieved. ■

Dr. Wolfgang John is a Senior Consultant in LDS at LPKF Laser & Electronics. He has spent his entire career working at the boundaries between chemistry and electronics. Since 1994, he has been involved in the ongoing development of MID technology.



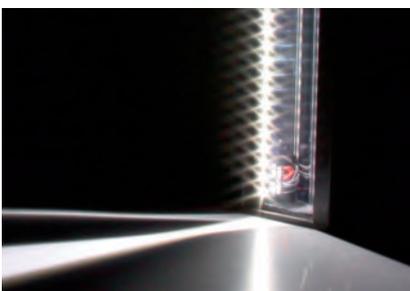
## Versatile range

**LED linear lighting.** Vision & Control is introducing a new linear lighting range ›LLL7‹, suited for line scan as well as area scan cameras. The LED lights produce a uniformly illuminated line. For the most intense brightness, the light can be focused to a tight line illumination with up to 130 000 lux, using special linear lenses. The lights do not need active cooling devices. Special integrated optical components ensure homogeneity in excess of 90 percent while maintaining a high light efficiency. They are therefore suited for extremely fast line scan camera applications with diffuse back lighting as well as for demanding applications with incident lighting, for instance for the inspection of shiny surfaces – thanks to the adjustable and exchangeable rod lenses, which allow adjustment to various working distances and line widths. This compact range, with a cross section of 9x12 mm<sup>2</sup>, is offered in lengths of 25 to 250 mm, with 25 mm increments. The linear lights are available in nine different wavelengths, from ultraviolet (395 nm) to infrared (950 nm).

[www.vision-control.com](http://www.vision-control.com)

## Bright scannig light

**LED line illumination.** Chromasens has optimized their ›Corona‹ LED illumination system, a photometrically optimized and regulated LED line illumination system

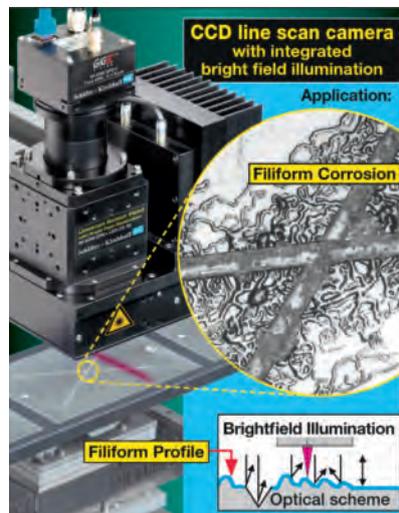


with a flexible cooling concept and especially designed for applications with line scan cameras. The high-power LEDs with an illuminance of well over 1 000 000 lux promise to satisfy the highest quality requirements with respect to brightness and illuminance. The LEDs are driven by an external controller; the operating current is set via an integrated micro-controller. The brightness can be adjusted via PC with the operating software ›Illumination Setup Tool‹ (IST).

[www.chromasens.de](http://www.chromasens.de)

## Analysis of filiform corrosion

**Scanning microscope.** Filiform corrosion is a special form of corrosion that occurs on coated aluminum and low alloy steels. Interaction with water and oxygen cause corrosion cells to form between the metal surface and the coating, which slowly migrate, leaving behind filiform infiltration and causing major damage. The



newly developed filiform scanner from Schäfter+Kirchhoff automates the analysis of standardized test plates using a resolution of 6 megapixels. The CCD line scan camera with integrated bright field illumination ensures very high contrast images of the filiform infiltration. The software identifies the characteristic structures from the digital images obtained and evaluates them objectively against the standards. This enables quantifiable results to be obtained and documented extremely quickly.

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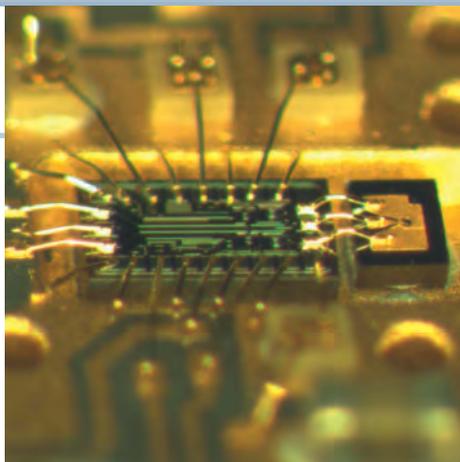
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## Up to 45 Gbit/s

**Optical receiver.** VI Systems has recently presented the optical receiver package ›R40-850TB‹ with an extremely low power consumption for data rates of up to 45 Gbit/s. The device features a multimode-fiber compatible photodetector chip, a transimpedance amplifier (TIA) integrated circuit and the matching components within a high-frequency ceramic micro-assembly. The integration is designed to improve dramatically the quality of the signal transmission. A multimode-fiber coupled vertical cavity surface emitting laser (VCSEL) module V40-850M from VI Systems was used as the transmitting device. The signal-to-noise (S/N) ratio measured at the receiver at -3 dBm optical power using non-return-to-zero pseudo-random bit sequence (PRBS 27-1) encoding at 40 Gbit/s exceeded  $S/N = 6.5$ . The targeted applications include short-reach (0.5 m to 10 km) and very short-reach systems as well chip-to-chip optical interconnects used in the high-performance computing industry. The work has been supported in part by the project ›Vertical Integrated Systems for Information Transfer‹ (VISIT) funded within the Seventh Framework Programme (FP7) of the European Union.

[www.v-i-systems.com](http://www.v-i-systems.com)

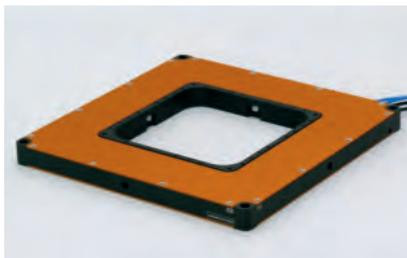


color measurements in combination with a suitable light source. Mazet offers this sensor in combination with an extensive software library for highly accurate and fast color measurements. Evaluation boards are available for initial test measurements and these may be linked to own test software via DLLs, if required.

[www.mazet.de](http://www.mazet.de)

## With large internal aperture

**Two-axis positioning.** The ›PXY 500 AP‹ is a two-axis piezo positioning system with a large internal aperture of  $100 \times 100 \text{ mm}^2$ , which piezosystem jena has especially designed for implementation on microscopes and illumination systems. With a height of just 15 mm and external dimensions of  $185 \times 185 \text{ mm}^2$ , the travel per axis is  $700 \mu\text{m}$ . The systems have been specially optimized for extremely high z-axis rigidity. The special actuator parallel kinematics guarantees the most accurate guidance possible. The drive elements in the monolithic solid joint system produce entirely backlash-free movement. Overshoot is actively minimized by controllable advance



## High quantum efficiency

**Single photon counter.** Laser Components' single photon counting modules (SPCM) of the ›Count‹ series achieve an unrivaled quantum efficiency of over 70 percent in the red region. In addition, claims the manufacturer, they offer a significantly higher quantum efficiency in the blue spectral range than currently available on the market. These modules are ideally suited for measurements across the entire wavelength range from 400 to 1000 nm. The Count series is based on a silicon Geiger-mode APD developed specifically for this series. Standard modules are available with dark count rates ranging from 20 to 250 counts. Modules

with  $< 10$  cps (counts per second) are also available. These modules are available either with an easy-to-use FC connection for optical fibers that have a core diameter of up to  $105 \mu\text{m}$  or as a free-beam module. Thanks to its compact housing and plug-&-play compatibility with photon counters currently available on the market, existing SPCMs can easily be replaced with the Count module.

[www.lasercomponents.com](http://www.lasercomponents.com)

## Integrated module

**Multiple color sensor.** Mazet has expanded its product range of long-term stable color sensors with the addition of the integrated ›TIAM4‹ module, which can also be used at higher temperatures without drifting. Apart from the spectrally sensitive detector, all the sensor electronics are also on-chip. The photon stream from the detector is converted to voltages that are available via S&H on a MUX output as an analog voltage signal which may then be converted to digital. The TIA based amplifier is programmable via eight stages individually and is characterized by its excellent linearity of the amplifier stages and very low noise. The TIAM4 is especially suited for fast and/or mobile

and reset forces. Defined positions can be reached in milliseconds with nanometer accuracy even under full load – a key criterion for high-speed scans. Digital amplifiers from piezosystem jena also allow dynamic local adjustment of the PID control parameters, the rise limitation and notch filter bandwidth. An integrated wobble generator allows mechanical resonances to be determined, so that they can be eliminated from the control signal by notch filter adjustment. This enables the optimum system setup to be gradually determined according to the current load scenario by trial and error during operation.

[www.piezojena.de](http://www.piezojena.de)



## Fits in small spaces

**Infrared sensors.** The temperature sensors ›thermometer CSmicro‹ from Micro-Epsilon have a diameter of just 14 mm, making them some of the smallest IR sensors on the market. The miniature electronic unit can be completely integrated into the cable. The basic model covers a temperature range of -20 to +350°C and has an analog voltage output. In the two-wire version, the signal is output via a current output and covers a temperature range of -30 to +900°C. The high resolution version provides a resolution of 0.025°C. A model is also available for extremely high temperatures of up to 1600°C. The optional USB connection including software can be used to program all models in this series.

[www.micro-epsilon.de](http://www.micro-epsilon.de)



measuring area of the Si-PIN photodiode plus lens is 0.75 mm<sup>2</sup>. The amplification at  $\lambda = 760 \text{ nm}$  is then 1.625 V/mW. Optical power can therefore be measured down to fractions of a mW. The DC offset at the input can be adjusted. The iC212 is suited especially for measuring laser beam rise and fall times, optical power, time-of-flight, for measurements in optical fiber transmission lines and for quality control in laser module production. M6 threads and an optional optical fiber socket are provided for easy mounting. Apart from the transport case, the scope of delivery also includes a mains unit, a coaxial cable and fiber-to-BNC and SMA-to-BNC adapters.

[www.ichaus.de/iC212](http://www.ichaus.de/iC212)

## For fast laser pulses

**Optical measurement amplifier.** The new optical measurement amplifier ›iC212‹ from iC-haus covers a continuous input frequency range from DC to 1.4 GHz, together with a wide spectral range, which makes it ideal for measuring fast laser diode pulses, for instance. The optical spectral sensitivity range is from near UV radiation at 320 nm to infrared at 1000 nm. The active optical

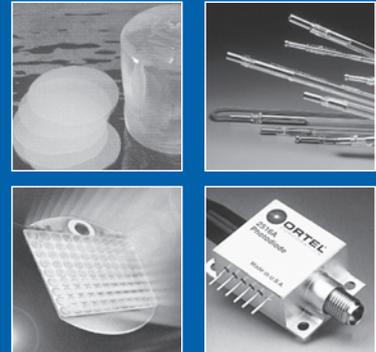
## Piezo controller

**Controller for nano positioning.** The single channel piezo controller ›E-709‹ of Physik Instrumente (PI) is now also available for precision positioning systems with capacitive displacement sensors. Since most of PI's nano positioning systems are equipped with these sensors, the E-709 enables lower system costs compared to the digital controllers previously on offer. The E-709 amplifier produces 5 W output power (10 W for <5 ms) and is designed in such a way, that classic nano positioning systems with travels up to approximately 200  $\mu\text{m}$  can be operated with medium scan frequencies up to 100 Hz. This includes, for instance, the ›P-620 PIHera‹ linear actuator and the objective scanner of the ›P-721‹ and ›P-725 Pifoc‹ series. The serial SPI interface offering up to 25 Mbit/s is a new feature. This interface allows you to issue a voltage or positioning value per control cycle – the controller is addressed virtually in real time. The data format is selectable via parameters: floating or fixed point values with variable bit width. This enables the user to address the E-709 to suit his application. As is common practice at PI, the operator programs ›PIMikroMove‹ and ›NanoCapture‹ are supplied with the controller, as are LabView drivers and DLLs for programming under Windows or Linux.

[www.pi.ws](http://www.pi.ws)

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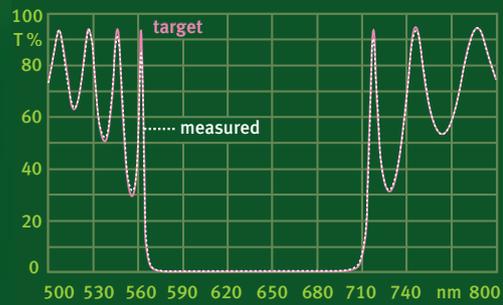


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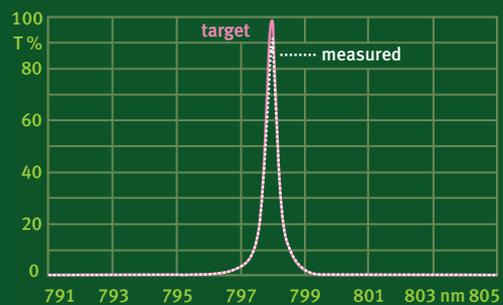
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