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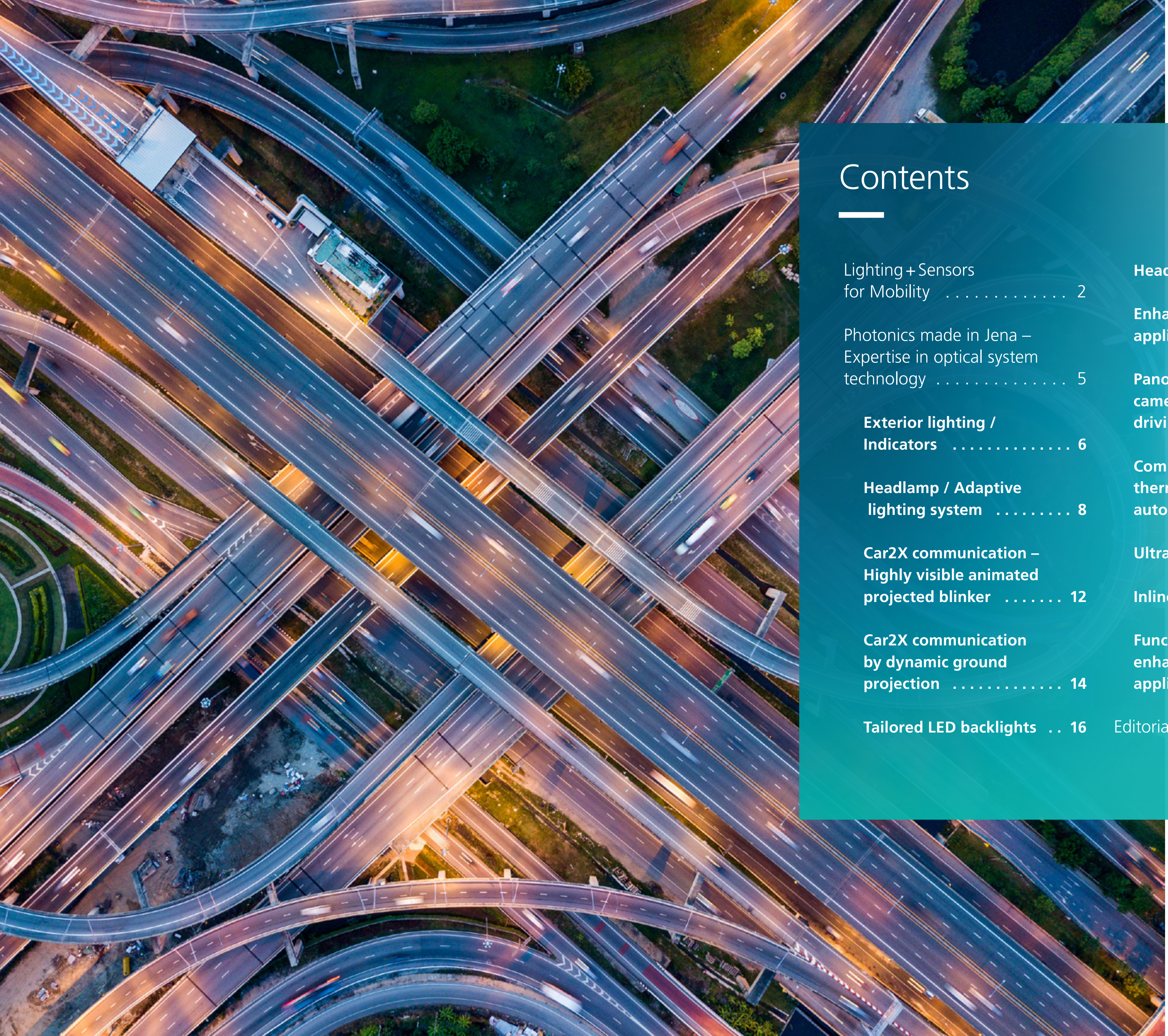
Fraunhofer Institute for Applied
Optics and Precision Engineering IOF

Photonics made in Jena

Lighting + Sensors for Mobility



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Lighting + Sensors for Mobility

Photonics powers future automotive solutions!

Photonics has undergone a revolution in the automotive industry in recent years, transitioning from mere lighting functions to providing cutting-edge technology for imaging, sensing, smart displaying, media, and for communication networks. Consequently, photonics has taken on new dimensions far beyond lighting in cars as well as in automotive manufacturing and quality control. It is not surprising that the automotive industry is showing an increased interest in innovative, photonics-based technologies. Myriad growth opportunities spur the lighting market to expand by about 5 percent p.a. An even greater boost is expected for the automotive photonics market.

Fraunhofer IOF transfers research into applicable solutions, offering the complete photonics process chain from system design and simulation, realization of custom-specific solutions to system integration. Thus, we provide our customers with the next generation of innovation in the entire field of photonic applications in cars, automotive technology, and production.

Our customers can benefit from our many years of experience in the field of automotive photonics. The demonstration of our solutions will provide ideas for future projects, which we can tailor to meet your individual needs.

We are ready to launch new innovations to realize your ideas.

Cover: BMW 7 series with array projector developed by Fraunhofer IOF.

Background: BMW Welcome Light Carpet.

Photonics made in Jena – Expertise in optical system technology

Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena is a leading developer in the field of photonics. We conduct applied research and specialize in innovative optical systems to control light – from the generation and manipulation to its application. We offer services that cover the entire photonic process chain – from opto-mechanical and opto-electronic system design to manufacturing of custom-specific solutions and prototypes. As a key player in the transformation of photonics, our current research activities focus on micro- and nanotechnologies, optical technologies for safe human-machine interaction, freeform technologies, fiber laser systems, and quantum optics.

The departments of the institute have targeted their primary activities towards optical and mechanical system design, precision-optical and opto-mechanical components and systems micro- and nano-structured optics, functional surfaces and layers, imaging and sensing, laser- and fiber-technologies, and optical quantum technologies.

The following pages present our expertise and technologies for applications in the field of automotive photonics in detail.

Prototype of a laser-based dynamic ground projection system

Exterior lighting / Indicators

When it comes to avoiding accidents, communicating with other road users while driving is critical. However, this has posed an ongoing challenge for science. Projecting information on the street beside the vehicle is one solution to the problem. This requires bright, cost-effective, and miniaturized projectors for a small number of image contents.

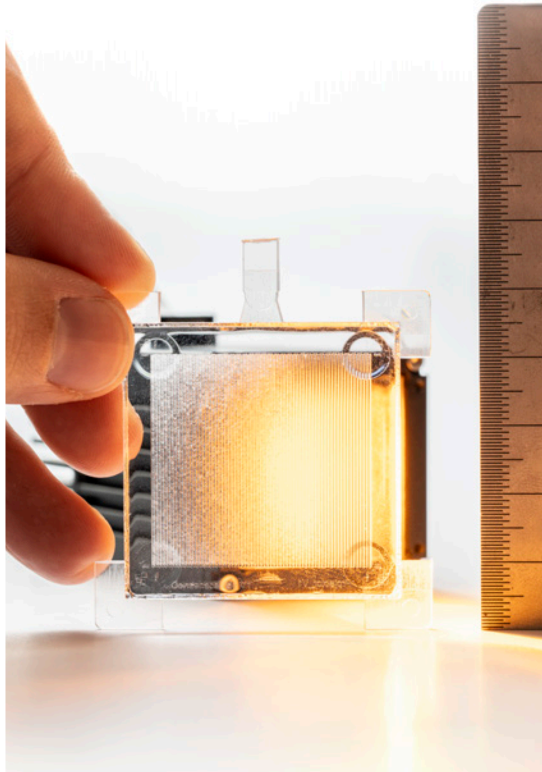
Miniaturized projection systems

Fraunhofer IOF has developed a miniaturized micro-optical array-projection-technology enabling projection onto tilted and curved screens with brightness up to 3000 lux. Continuous innovation has led to displays which are even visible in full daylight. These systems serve as warning indicators for cyclists or as animated graphics to open and close the trunk by waving the foot under the rear bumper.

Projecting logos via signature lighting is a sophisticated feature for brand identification. This technology can be integrated into existing lighting systems e.g., in backlights.

Expertise in the automotive field

Automobile manufacturers have already integrated this feature into their high-end vehicles, such as the Welcome Light Carpet in current BMW models.



Left: BMW 7 series with array projector developed by Fraunhofer IOF.

Right: Maskless Micro-Optics for Automotive Applications.

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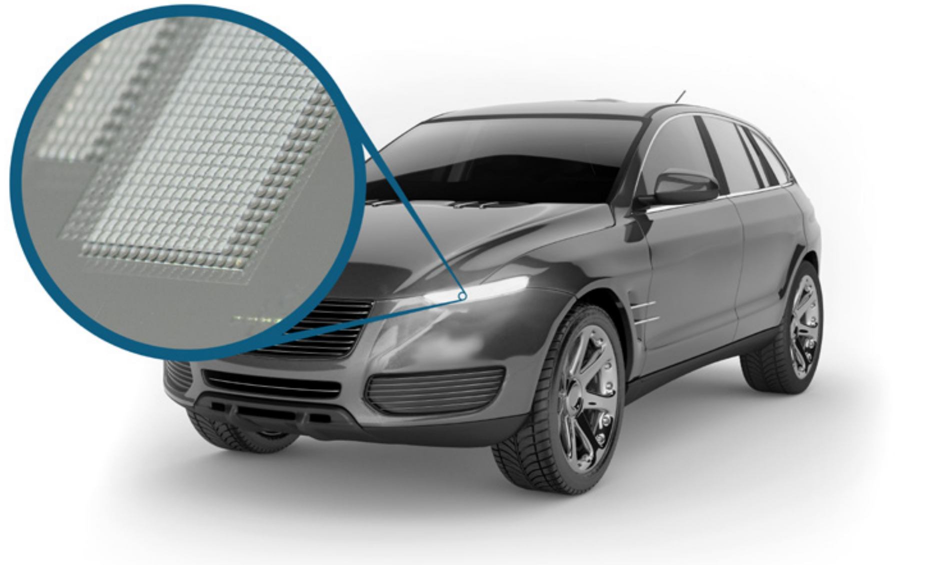
Headlamp / Adaptive lighting system

Adaptive driving beam (ADB) systems provide a comfortable driving experience by enhancing both illumination distance and road safety. With individually addressable beam segments, these systems prevent glare for oncoming and preceding traffic while ensuring clear visibility.

Left: A high beam module is positioned between low beam modules, creating a customizable solid-state headlamp system.

Headlamp / Adaptive lighting system

Recent advancements of Fraunhofer IOF in micro-optical beam shaping technology have made it possible to build a solid-state ADB system. By using an LED array and precisely controlling channel cross-talk, ADB systems achieve high performance and safety on the road.



Ultra-compact high beam and low beam

Fraunhofer IOF's innovative solid-state lighting system enables the realization of an adaptive high beam and an efficient low beam. Both lighting units can be seamlessly integrated into a vehicle's design language with a high degree of freedom while occupying minimal space.

The maskless irregular micro-optics offer an effective solution for low beam shaping, eliminating the need for absorbing elements. This allows for up to 75 % system transmission with a remarkably slim profile.

Top: Micro optic headlight for narrow front lights on car.

Left: Testing the high beam module's adaptability to prevent blinding other road users under real-world conditions.

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Car2X communication – Highly visible animated projected blinker

Our researchers at Fraunhofer IOF have further developed their array projection system, which is already established in the automotive industry. The new maskless design of the projection optics is particularly suitable for traffic situations where high visibility is an advantage to increase the safety of all road users.

Simplified optical design enables low manufacturing costs

To increase the brightness of the projection and simplify production, the absorbent film mask was removed. As a result, the lens can be manufactured using the conventional injection molding process while maintaining the optical quality of the projection.

Maskless approach allows design freedom

Based on this maskless approach we developed an animated projected blinker that projects a sequence of 3 chevrons on the road surface. The entrance lenslet apertures are chevron shaped and arranged in a space-filling array We realize a projected brightness of 7 klx on the road surface. The projector module is 40 × 40 × 45 mm³ in size. Additionally, the micro-optics have been realised by injection molding, offering large-scale low-cost manufacturing.

Top: Dynamic projection of chevrons on road using maskless MLA.

Bottom: Maskless MLA for projected blinker with housing for dynamic automotive blinker application.

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Car2X communication by dynamic ground projection

The directed communication of vehicles with other road users via ground projection can increase safety considerably. But daylight visible systems require brightness levels that rule out LED sources for a full-dynamic projection.

Visualization of the design possibilities of a multi-channel dynamic projection system.

Laser projection system for increased visibility

Holographic energy redistribution is the key for ultra-bright projection to be visible at daylight condition, when utilizing laser sources and redistribute their energy via digital phase modulation (SLM). To achieve a large projected area while maintaining high brightnesses, a multi-channel approach has been demonstrated. It enables to generate situation dependent, dynamic intensity distributions from a small sized projector.

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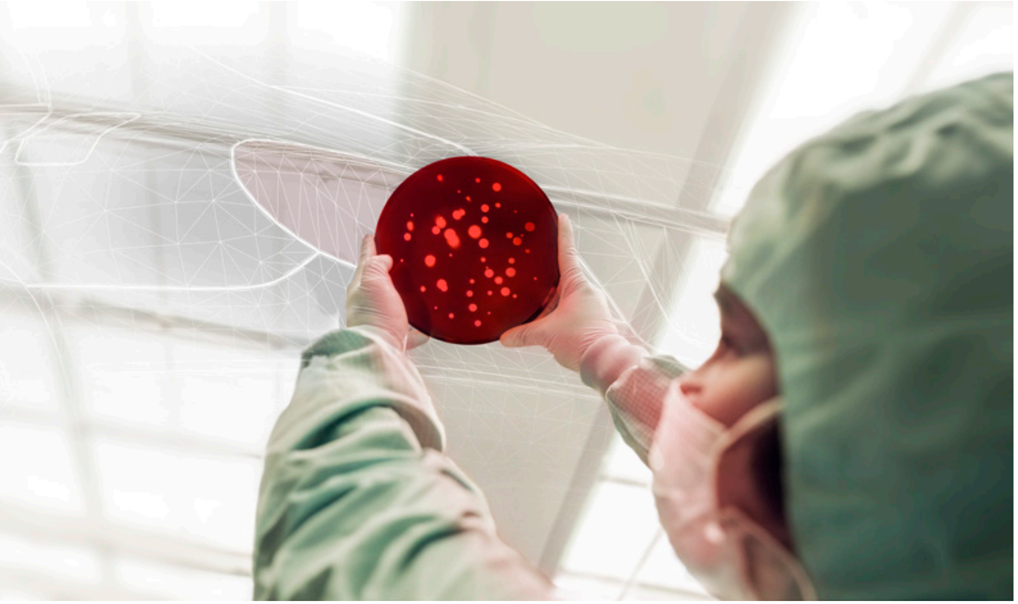
Tailored LED backlights

Newly developed light field displays by Fraunhofer IOF enable a revolutionary approach to rear light design. Large-format 3D effects can be created on an ultra-thin surface, providing vehicles with a unique nighttime appearance.

We developed a technology to realize a 3D rear lamp. The slim size of the display optics (ca. 3 mm) allows compact construction without the need of facetted mirrors to give a 3D impression. The lightfield display is based on multi-aperture micro-optics to display icons, symbols, with a 'floating-in-space' quasi 3D effect. The displays generate a field of view of 20°…40°. Tiny microlenses of diameter 300 µm together with individually shaped and decentered array of slide mask structures generate eye-catching patterns and motifs. Combination of lightfield displays with tailored diffusors offer even more creative freedoms to generate unique rear lighting concepts. Additional application of such lightfield displays could be for display of icons, branding, or more.



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Left: The image projected on the light field display appears to float in space.

Right: Lightfield display consisting of a microlens array with an object mask array.

Head-up displays

Head Up Displays project vehicle's status information via the windscreen into the driver's eye box. Providing service data (i.e. speed and navigation) in an overlay while keeping the view on the track ahead, these complex optical systems contribute increased safety and elevated driver experience. However, it is challenging to combine wide field of view, comfortable eye-box size, and compact unit space in these complex optical systems, while making high demands on resolution and high-fidelity projection.

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The in-house developed 5-axis direct-writing lithography tool allows the production of innovative head-up display elements.

Tailored systems

Micro- and nano-optical structures help to overcome such limits. Waveguide-based pupil expander principles request for highly efficient RGB coupling gratings. We master those by electron-beam lithography in large area using the concept of metastructures. These are well-suited for cost-efficient nano-imprint-replication.

Tailored-light diffuser elements, which are utilized as intermediate image screen for the picture-generating unit, exhibit deterministic scattering functionality. Combining achromatic scattering, focusing, and deflection in a single optical enable efficient redirection into the projection path and compact system architectures at the same time.

Enhancing LiDAR applications

Light detection and ranging (LiDAR) laser systems in vehicles supporting advanced driver assistance systems (ADAS) and are going to play a key role in autonomous and assisted driving. Micro-optical solutions enable compact, lightweight, and cost-efficient systems.

Wafer with SPAD-sensors and MLA.

Improving sensitivity

Fraunhofer IOF has a strong competence in the design and manufacturing of wafer-level optical meta-structures for high-efficiency laser beam shaping for ultra wide-angle scenery illumination.

Wafer-level integrated micro-optical solutions can also help improve the sensitivity of time-of-flight (ToF) camera sensors, which are an integral part of the LiDAR-package. Those, however, often suffer from a low filling factor of the light sensitive areas due to extensive space for complex read-out electronics. IOF-fabricated Microlens arrays, which are adapted to the primary imaging optics, molded directly on top of the CMOS wafer substrates improved the sensitivity of SPAD sensors by nearly an order of magnitude.

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Panoramic interior camera for autonomous driving

The monitoring of the vehicle interior using camera systems is essential for observing the driver's attention and readiness level to take over in critical situations as well as allowing new interactive user interfaces and support further safety features.

The miniaturized wide-angle 3D camera is shown here disassembled into its individual optical components.

Live feed for monitoring vehicle interiors when required in semi-autonomous driving.

An ultra-compact wide-angle camera including Time-of-flight (ToF) sensor for 3D-measurement is developed to realized high compactness (<10 mm lens height) and large diagonal 180° field-of-view (FoV) with low optical distortion. This is achieved by utilizing a hybrid multi-aperture imaging approach combined with prisms tiling the overall field of view. Injection molded glass and wafer-scale polymer-on-glass elements enable temperature stability required for high automotive standards. A suited time-of-flight sensor enables additional 3D-measurement capabilities.

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Compact wide-angle thermal camera for autonomous driving

Identifying the surrounding of cars equipped with camera systems is necessary for pedestrians and bicycles recognition in future automotives. But in harsh environments like fog, rain, night or sun glare, classical systems may fail and require more reliable sensor information.


Compact wide-angle thermal camera for autonomous driving

Multi-channel catadioptric thermal imaging is the key

The catadioptric system based on mirrors and thin silicon correction plates manufactured in cost-effective and parallelized wafer-scale technology achieves a 12.5° single diagonal field-of-view (FoV) at low F/1.1 and high transmission. To achieve a large overall FoV, a multi-channel approach with silicon prisms for deflection has been demonstrated while utilizing several low-resolution uncooled micro-bolometer cameras (resolution: 160 × 120 pixels at 12 µm pixel pitch) behind the optics module. The currently configured 2 × 4-channel thermal camera has an optical system's track length smaller than 18 mm and a lateral size of 70 × 35 mm² featuring an overall 36° diagonal FoV (image format 1:2.5) with an angular resolution of 16 pixels/degree.

Top: Trial of the compact thermal imaging system at night.

Left: Individual wafer-level components of the thermal camera system.

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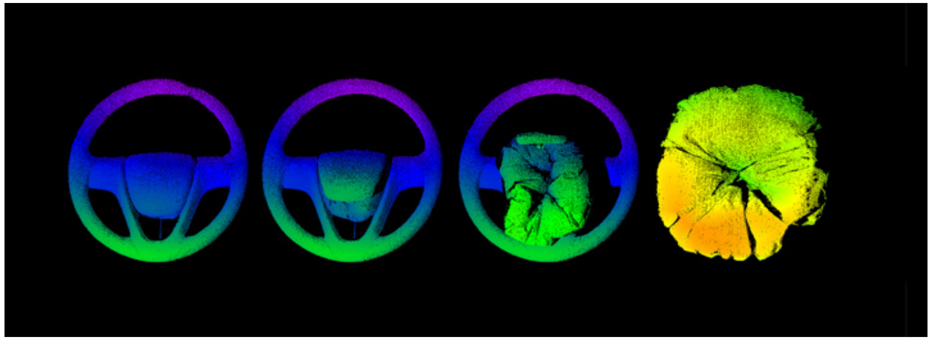
Ultrafast 3D capturing

Optical 3D measurement technology is a versatile tool that is employed in many areas of industry and research. Especially highly dynamic processes like the inflation of an airbag require high-speed technology to examine and evaluate these moving objects in full 3D.



High resolution at high speed

Researchers at Fraunhofer IOF have developed projection, acquisition, and evaluation technologies with multi-kilohertz frame rates by using high-speed camera systems in conjunction with gobo-projection and parallelized data processing. This enables us to capture and evaluate up to 1,500 3D-frames per second with each frame composed of 1 million 3D-pixels, or even 50,000 3D-frames per second with each frame composed of 250,000 3D-pixels.

Expertise in the automotive field

We have already transferred this innovative technology to our customers. One of these systems can capture the crash test of a complete car; another system was optimized to capture a crash test from inside the car – withstanding the strong negative acceleration during the crash.

Top: Demonstration of an airbag deployment: 3D data at four different time points.

Left: High-speed 3D measurement system.

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Inline production control

Many industrial production plants demand 100 percent inspection of the manufactured goods for quality assurance. To guarantee this at high production rates, inline measurement solutions are vital for an efficient production.

Tailored optical 3D measurement systems

We develop customer-specific, fully automatic, robot-based,non-contact, optical 3D measuring inline inspection systems. These systems can measure areas from only a few square millimeters up to several square meters with rates in the millisecond range.

We use specially developed optical systems and parallelized 3D algorithms based on multi-processor systems. The full-surface measurement can detect and interpret local deformations and defects simultaneously. The 3D measurement accuracy is in the range of 10^{-4} of the measurement field diagonal.

Expertise in the automotive field

We have already integrated systems into the quality control of casted motor blocks, large industrial catalysts, aircraft engines, and more. The resulting data is compatible with common CAD systems.

Your ideas or projects can be realized based on our experience in 3D metrology of more than 25 years. Please contact us.

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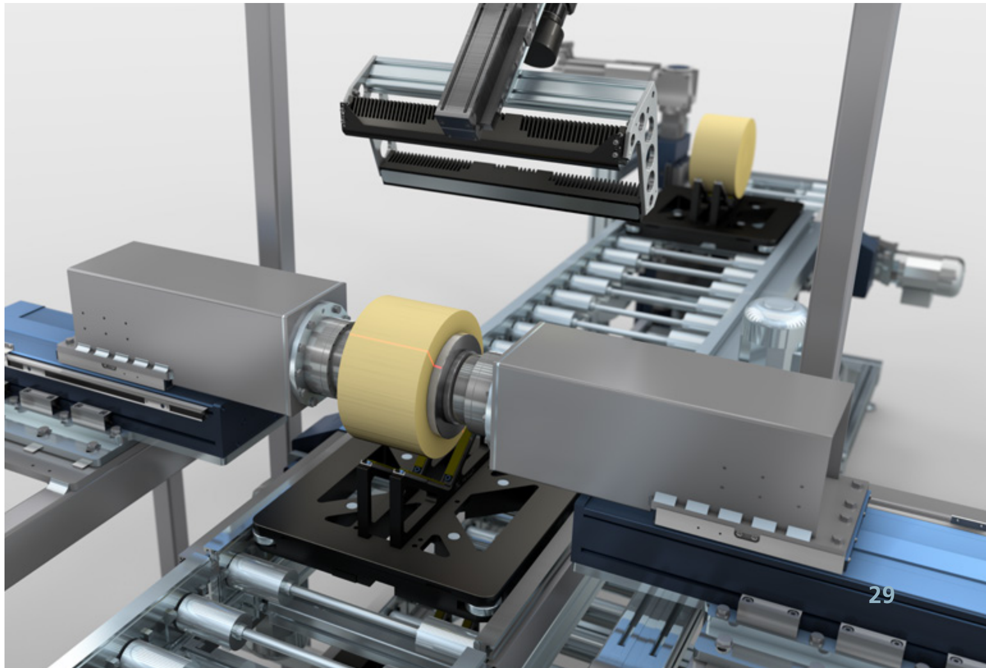
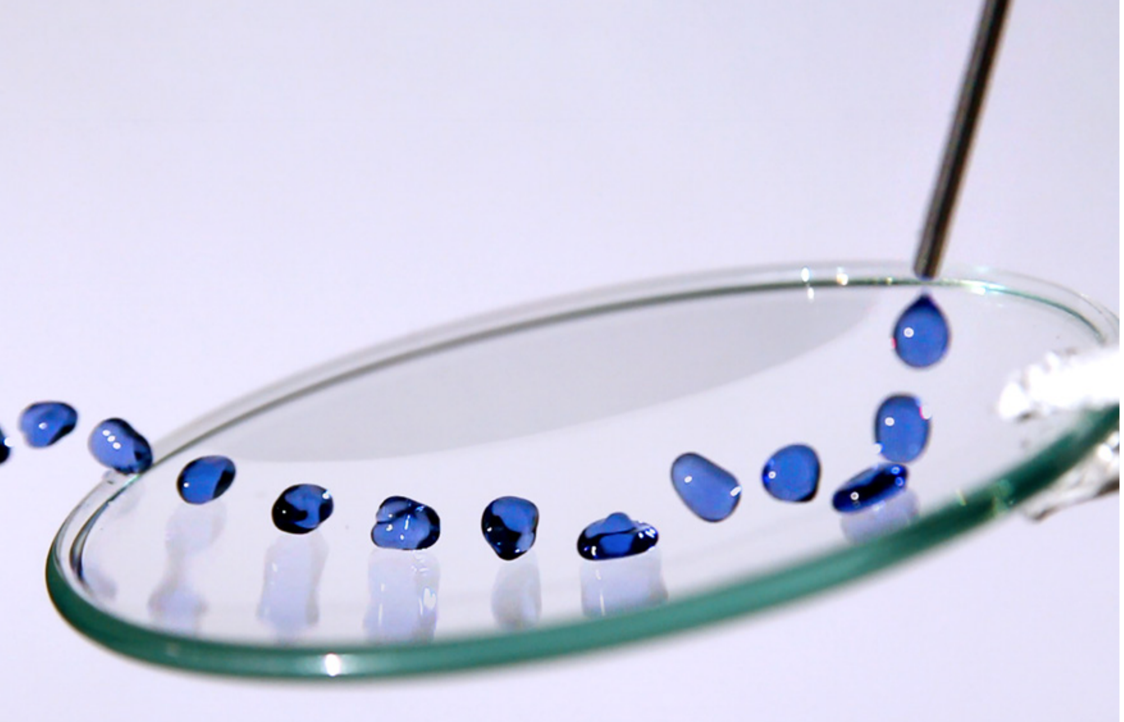
Left: Gesture-controlled 3D sensor platform for autonomous component measurement.

Right: Inline measuring system for quality assurance in production operations with optical 3D and 2D sensor technology.





Functional coatings enhance your automotive applications

In the optical industry, surface coatings play a crucial role in creating tailored surfaces for various applications. At Fraunhofer IOF, we specialize in developing surface functionalization and multi-functional optical coating systems.

Our expertise extends to working with plastics, glass, and metal, and we have successfully transferred these technologies to production and high-volume manufacturing. With our in-depth knowledge and advanced technologies, we excel in designing and simulating optical layer systems, developing coating processes, and characterizing surfaces and coatings.

Our capabilities cover a wide range of surface coatings, including:

- Ultra-broadband antireflective coatings
- Scratch-resistant coatings on plastics
- Additional functionalities like anti-fog and self-cleaning
- Durable metal-dielectric coatings
- Transparent conductive coatings

In addition we offer exhaustive testing procedures such as environmental tests, mechanical testing, and evaluation of optical properties. We also specialize in coating failure analysis and lifetime studies. Furthermore, we are equipped to measure light scattering and appearance, providing accurate and reliable data for your specific requirements.

Whether you need special coatings or assistance with a challenge at hand, our team is ready to support you. Contact us to discuss your surface coating needs and benefit from our specialized expertise.

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Left: Hydrophobic surface with self-cleaning effect.

Bottom: Antireflective coating for automotive ligthing systems.

Editorial notes

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