toptec

IPP INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

# SELECTED APPLICATION RESULTS

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# TOPTEC INTRODUCTION

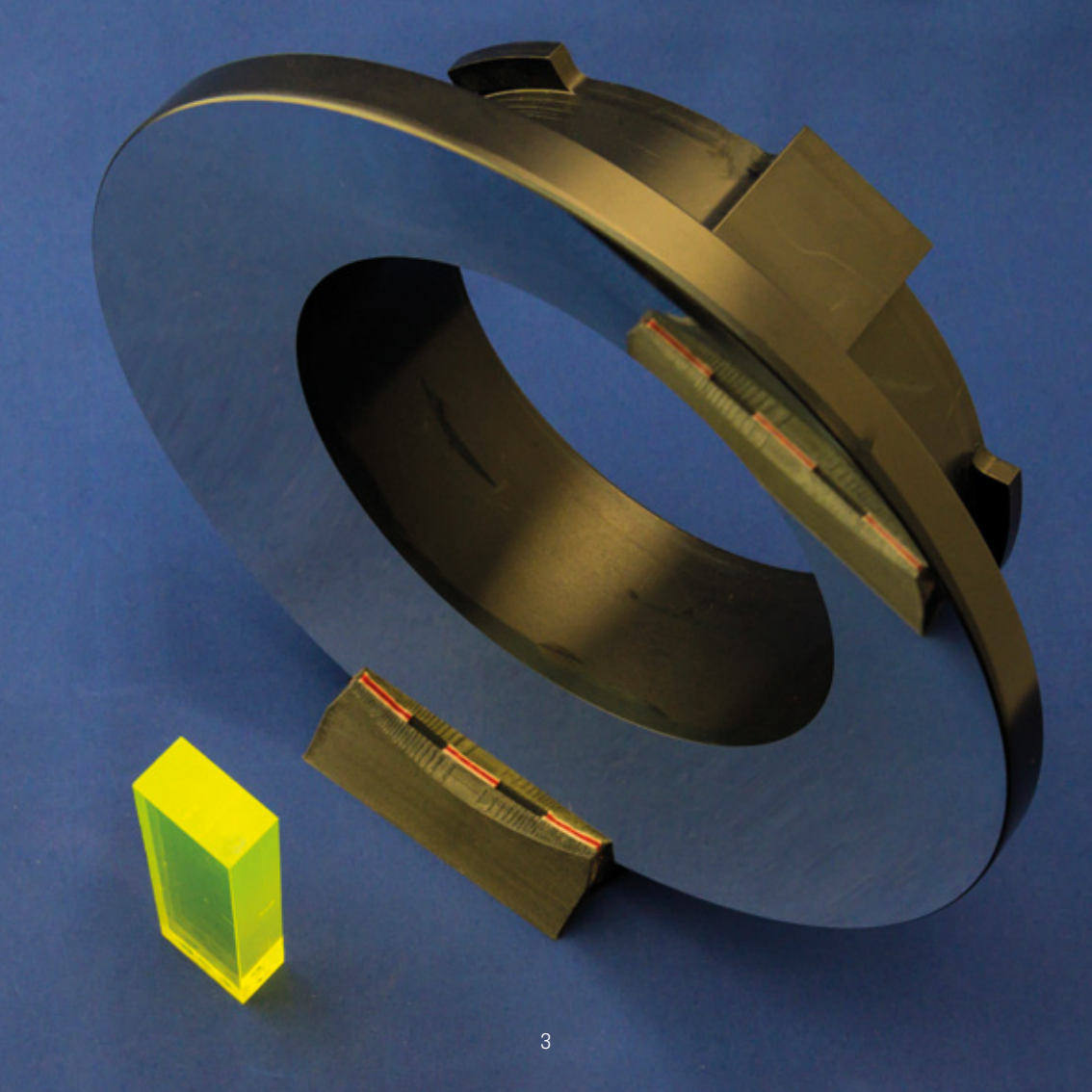
The main focus of our team's work is research into optics and optoelectronics, as well as development of applications associated with these topics. The TOPTEC research centre for special optics and optoelectronic systems is a department of the Institute of Plasma Physics of the Czech Academy of Sciences (CAS) and counts among the Academy's Application Centres. Our team consists of approximately 50 researchers and technicians. The scientific activities of TOPTEC involve the participation of a number of master's-degree and Ph.D. students.

At the very beginning, the team built on more than 40 years of tradition of optical research and development represented by the Optical Development Workshops of the CAS. Modernization and development of the Centre's capacities were facilitated by the support of Operational Programme Research and Development for Innovation (2010–2013), which helped transform TOPTEC into a state-of-the-art facility for research and development of optical element machining, thin-layer implementation and high-precision measurements. As a result, we are now capable of being a full-fledged member of consortia involved in international projects in the fields of metrology and optical system development for space research, both satellite and ground-based, or for high-performance laser development. Thanks to our cooperation with a whole range of industrial entities on the development of systems and devices for metrology,

automatization, or production control, we can efficiently link the academic and the industrial spheres.

As far as the evolution of the optical industry in Czechia is concerned, the Turnov area has played a significant role. Its importance has grown from the centuries-long ability to find and mine precious stones, which has led to the development of know-how in processing brittle crystalline materials.

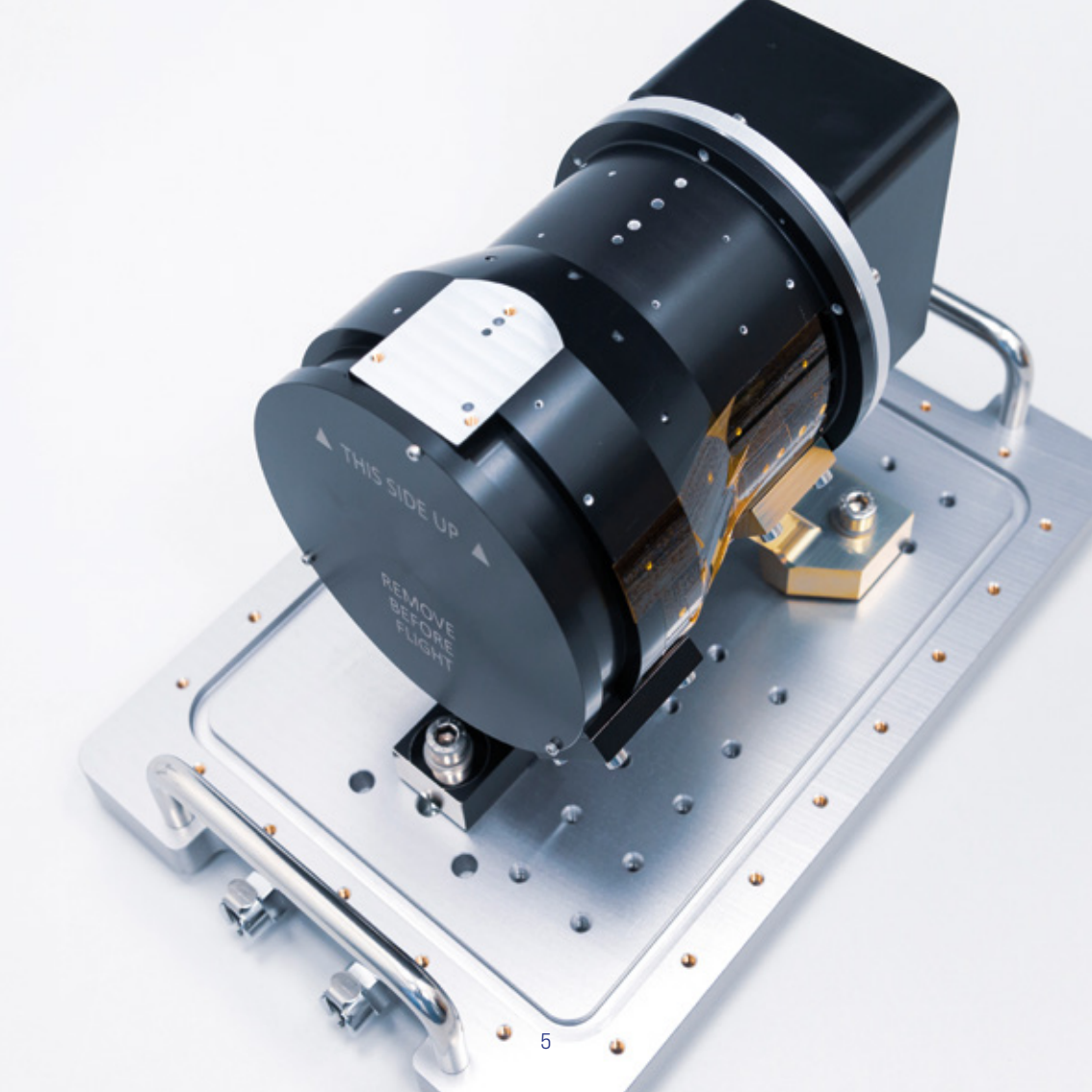
This local knowledge enabled the growth of the costume-jewellery industry in the Turnov and Jablonec regions from the 17th century. The 20th century saw a massive expansion of the costume-jewellery industry and the fields associated with the growing of artificial crystals and with ophthalmic optics. The Dioptra company was founded in Turnov and it specialized primarily in ophthalmic optics and optical instruments. A group dedicated to optical research evolved in Turnov as early as the 1950s and our team proudly continues its tradition. The long-honed expertise and skills counted among the prerequisites of TOPTEC's success in international-level research and development of optics. We currently cooperate with many academic and industrial entities in Czechia and worldwide.



# 1 THE MAIN ASPHERIC ANNULAR MIRRORS OF THE METIS CORONAGRAPH

The TOPTEC Centre team was responsible for the production of the two main aspheric mirrors (M1 and M2) as well as of the plane mirror (M3) of the telescope and the shield of the METIS coronagraph. All the flight and replacement parts were delivered to the Compagnia Generale per lo Spazio (OHB AG) company. Both the aspheric mirrors are annular and the optical surface of the mirrors is aspherical with a deviation of approximately 50 μm from the best-fit sphere. For this reason, their production required the development of unique sub-aperture grinding and polishing techniques combining CNC and conventional pitch-tool technology. The M1 mirror has an outer diameter of 218 mm and an inner diameter of 128 mm, while the M2 mirror features a 125-mm outer diameter and an 88-mm inner diameter.

A requirement which completely exceeds conventional standards for super-precision optical surfaces was to achieve surface shapes with a deviation below 120 nm PV and surface micro-roughness below 0.3 nm while maintaining the combined weight of both mirrors below 1 kg. The lightweight mirror structure was designed and optimized by the Centre's team using NASTRAN software; in the process, the team had to meet the double requirement that the mirrors be light and, simultaneously, sufficiently strong and rigid.

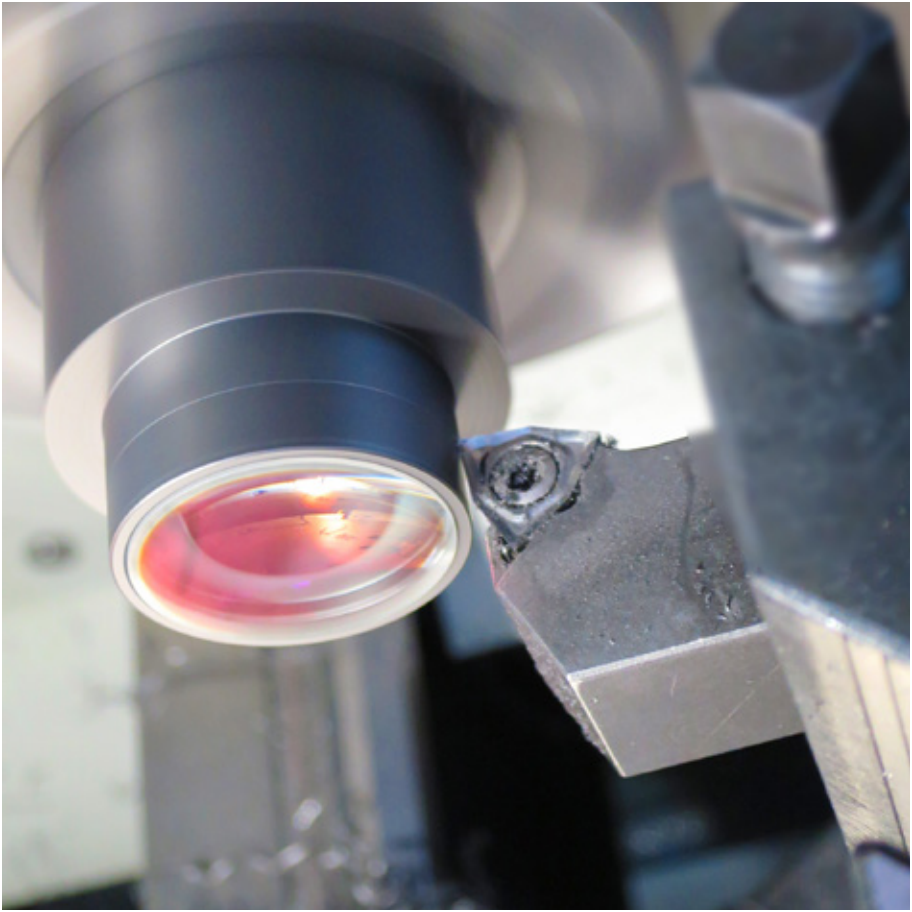

THIS SIDE UP
REMOVE
BEFORE
FLIGHT

# 2 FLEX SPECTROGRAPH TELESCOPE

The telescope consists of five high-precision 100 mm lenses that are manufactured with better than lambda/20 RMS shape accuracy and with micro-roughness below 0.3 nm. Only such precise elements will ensure that the signal originating from vegetation fluorescence during photosynthesis will be detectable from orbit on a sunny day.

Among other things, the optical elements must be housed in a tube whose individual components are manufactured at micrometre precision. It was necessary to ensure that the system would not be damaged or disturbed during the launch of the launch vehicle. Two of the optical elements are made of a $CaF_2$ material which is extremely fragile and therefore sensitive to vibrations. For that reason, TOPTEC has developed and implemented a special method of mounting the lenses based on an innovative bonding principle so that these vibrations are isolated.

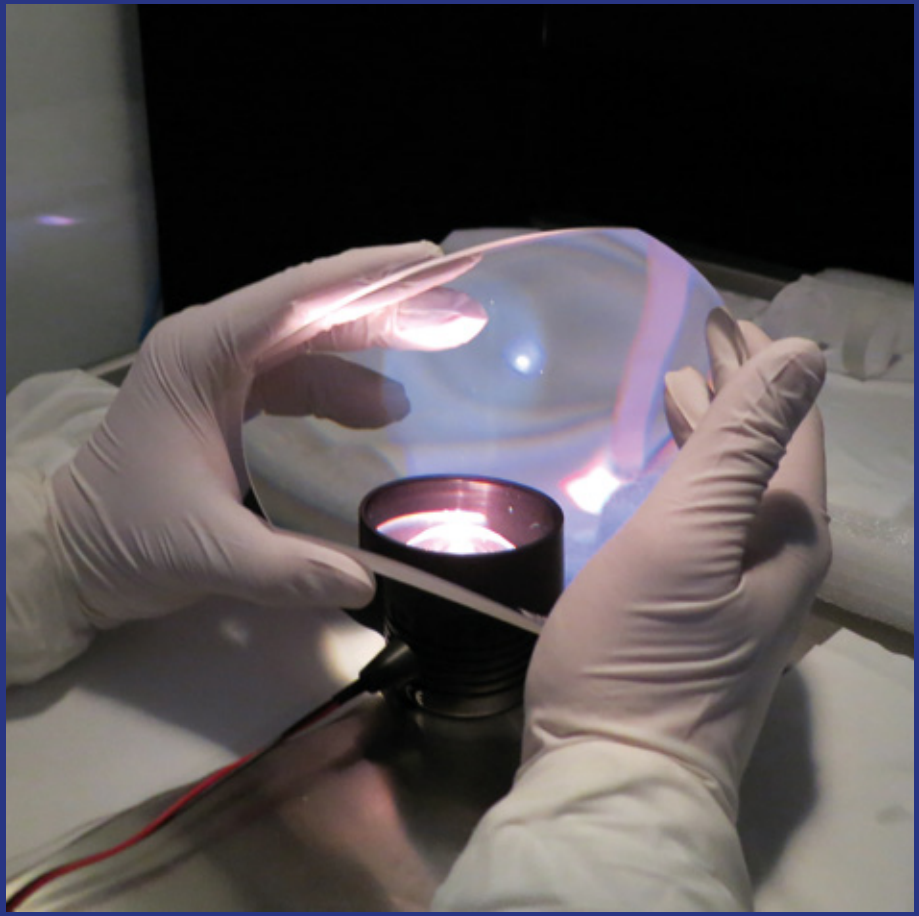
The TOPTEC team developed antireflective coatings with reflectivity below 0.3 % for high incidence angles to ensure extremely low intrinsic noise of the system. Alignment of the entire system would have been inconceivable without the involvement of a unique computer-assisted correction method, which enabled the system to achieve a performance almost identical to the theoretical maximum.



# 3 THE ASPIICS CORONAGRAPH OPTICAL SYSTEM

The TOPTEC Centre team handled the optical design, tolerance analyses and construction of the entire optical system and mechanical mounting. The fine-tuned optical system was delivered to the Belgian Centre Spatial de Liège, the main integrator of the coronagraph. The mission consists of two satellites which can take up a precise position where the satellite closer to the Sun forms a shield for the ASPIICS device mounted on the other satellite. The optical system is composed of two parts – the main lens and the relay optical system.

Both parts have been designed and optimized for maximum performance while maintaining a robust design (minor variations in optical and mechanical tolerances will not affect overall optical performance). The main lens – designed as a diffraction-limited doublet – was produced to achieve a minimum micro-roughness of 0.2 nm RMS, which was very challenging. The reason for this requirement was to achieve maximum signal-to-noise ratio and higher than the required micro-roughness would introduce unacceptable optical noise into the measurement. The relay optics system uses aspheric surfaces to reduce the total system mass, which is always a significant factor in satellite systems. The use of aspheric surfaces significantly reduces the number of optical elements but places high demands on the accuracy of the mechanical fit.



# 4 COMPENSATING OFF-AXIS ASPHERIC ELEMENTS AND TELESCOPE ADJUSTMENT SYSTEMS

The Near Earth Object Survey TELescope (NEOSTEL, also known as the Fly-Eye) is an astronomical reconnaissance and early warning system for detecting near -Earth objects 40 metres in size weeks before Earth impact. The project is a part of the Space Situational Awareness Near Earth programme.

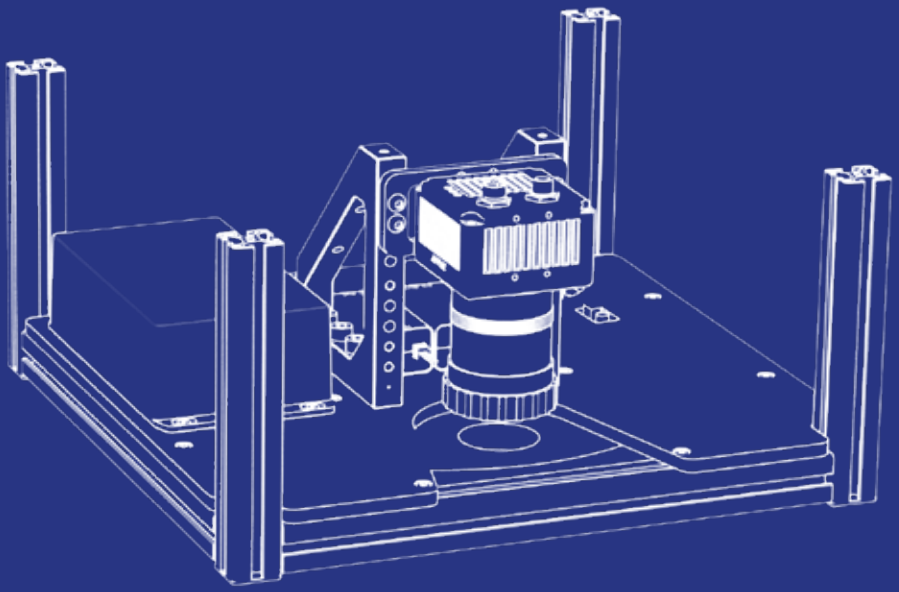
A brand-new concept, the so-called Fly-Eye, has been adopted for the construction of the telescope. This type of telescope features a wide field of view (45°) with a resolution of 1.5 arc seconds per pixel over the whole FOV (a tennis ball at LEO). It consists of a primary mirror 1.6 m in diameter, followed by a beam splitter, which splits the captured image among 16 cameras.

The TOPTEC team has realized the compensating off-axis aspheric elements which are situated over 16-megapixel detectors ensuring a super-wide field of view. They have also produced a range of adjustment tools, such as the alignment aid – a device for the rough alignment of individual optical paths of the telescope's 16 channels. Last but not least, TOPTEC has also supplied a giant autocollimator designed as an off-axis compact telescope with an active optical system and beam divergence below 3 arc seconds. The autocollimator produces a beam over 600 mm in diameter.

# 5 MODERNIZATION OF THE PEREK TELESCOPE (2 METRES)

The Perek Telescope remains, despite its age, the largest telescope in the Czech Republic. Its primary mirror is 2 metres in diameter. The telescope is situated in the giant dome of the Astronomical Institute of the Czech Academy of Sciences in Ondřejov. Following thorough analyses of possibilities and requirements, performed by a team consisting of the Astronomical Institute and TOPTEC experts, a modernization of the telescope was undertaken in 2020.

The modernization was managed and implemented by the TOPTEC Centre team. During a unique and demanding operation, the mirrors were removed from the optical path leading to the spectrographs, to be replaced by state-of-the art octagonal optical fibres. This change has led to a multiple increase in the number of photons entering the spectrographs and CCD cameras. The improvement in the optical system throughput is so large compared to the original configuration that it has enabled observation of previously unobservable objects. The acquired spectra are significantly less affected by noise. The telescope has been equipped with a modern CMOS camera enabling the acquisition of direct images of space objects, which was not possible in the previous configuration as our largest telescope previously served merely as a front-end optics piece for the spectrographs. This upgrade has opened new options for the utilization of the telescope for exoplanet observation.



# 6 DEVELOPMENT AND PRODUCTION OF A MULTICHROMATIC IMAGING SYSTEM INCLUDING A SYSTEM WITH IR BANDPASS FILTERS

For research in the field of aerosol contamination of surfaces, TOPTEC has developed a 10-channel multispectral imaging system in the long-wave infrared (LWIR) region. The system displays an area of approximately 25×25 $cm^2$ from a distance of 1 m and is designed to be mounted on the wall of a wind tunnel.

The contaminated surface shows a change in spectral emissivity and reflectance. This allows the observation of the evolution of the aerosol state on the monitored surface under changing model weather conditions. The system is based on the IRCA-3 camera developed by APPLIC s.r.o. and a set of bandpass spectral filters in a motorized filter wheel.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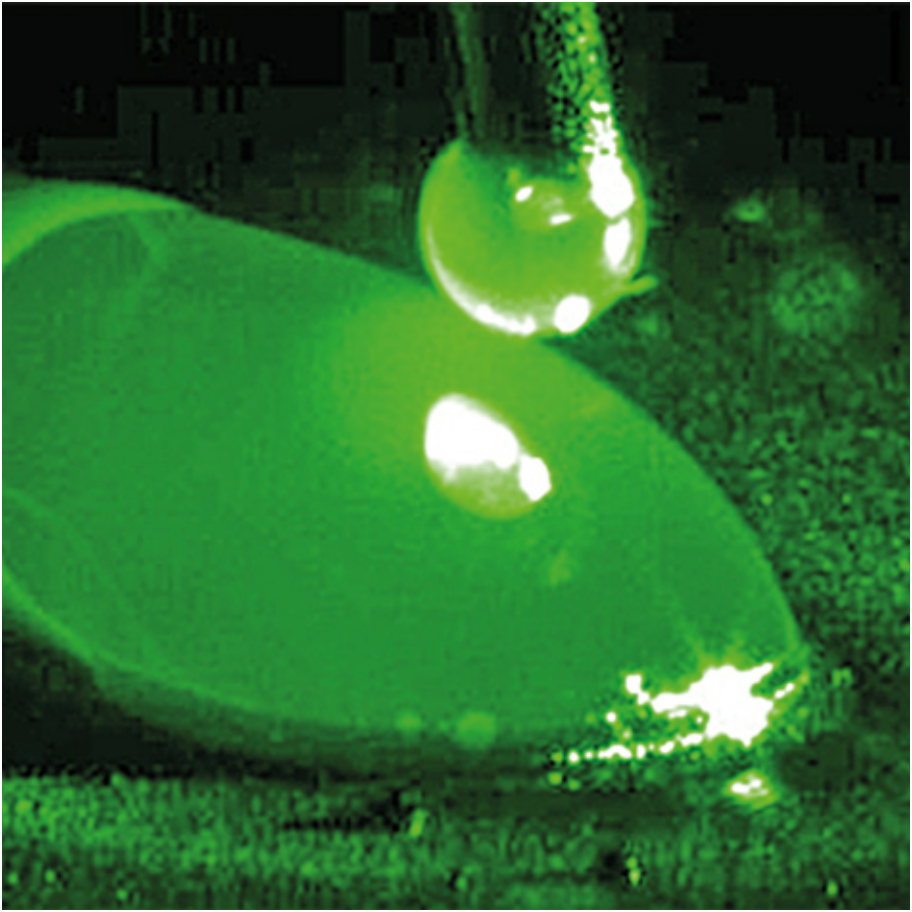
# 7 DEVELOPMENT AND PRODUCTION OF AN ABSOLUTE ILLUMINATION SYSTEM; CONSTRUCTION OF A CALIBRATION DEVICE

New generation automobile headlights equipped with LED sources require perfect control of the radiation characteristics during production. The headlight output control must ensure that the headlight meets luminance and luminous flux parameters without exceeding them. It is vital to measure these parameters with metrological traceability.

The TOPTEC team in cooperation with ELCOM, a.s. designed and produced a special measuring device that can re-image the beam coming out of the reflector and measure the required spatial and angular characteristics by a camera calibrated system.
The measured data are evaluated by a custom-developed software, whose development the TOPTEC team participated in.

In addition, we have designed and delivered a calibrated metrologically traceable light source for absolute luminous flux measurement. Another challenge was the development of an aspherized doublet with a large diameter (greater than 250 mm) necessary to reimage headlight beam. Apart from the unusually wide field of view (26°), the doublet was optimized for extremely low internal reflections and the formation of so-called ghosting (reimaged internal reflections).

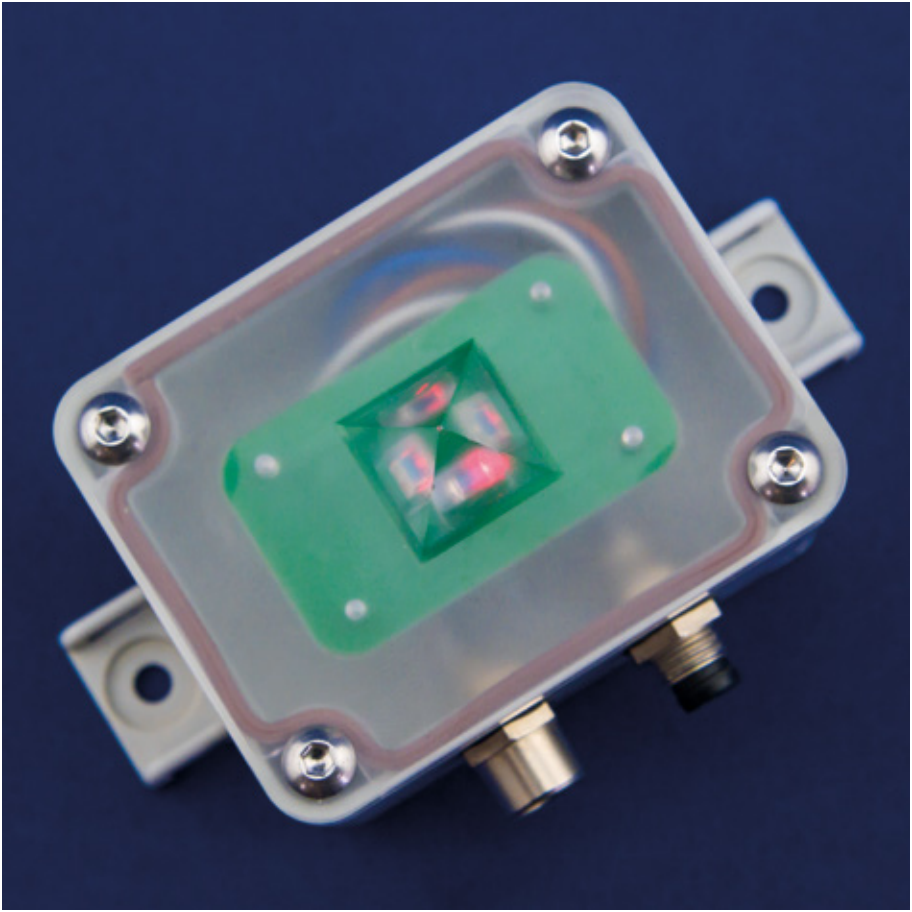


# 8 DEVELOPMENT OF A LASER ILLUMINATOR FOR WELDING PROCESS RESEARCH

Based on AIR Products s. r. o requirements, the TOPTEC team developed and delivered an imaging system for the monitoring and imaging of the welding process in real time with high temporal resolution.

Understanding welding process behaviour is crucial particularly in the development of welding of new materials. Visual observation of the welding process is not possible under normal conditions as the electric arc produces an enormous amount of radiation in the visible, infrared, as well as UV regions. It was necessary to develop a system which can suppress the arc's own radiation by a factor of approximately 10,000 while allowing the light from the illumination source to pass through.

TOPTEC designed a filtering optical system with a very narrow bandpass which was identical to the central wavelength of the laser source. The laser illuminator designed by TOPTEC delivers 15 W of monochromatic light in a narrow beam. This achieved a significantly higher signal-to-noise ratio than under normal conditions and allowed the weld area and the entire welding process to be imaged with sufficient contrast to allow the process to be recorded by a digital high-speed camera with a frame rate of several thousand frames per second.



# 9 DEVELOPMENT OF A DIFFUSER FOR A SOLAR DETECTOR

The project, carried out in cooperation with one of our industrial partners, the Solar Monitor s.r.o. company, focused on the development of a new type of solar irradiance measurement sensor applicable without additional modification for a very wide range of latitudes. A number of requirements had to be met regarding robustness, size, as well as cost of the sensor.

The TOPTEC team concentrated on an original smart solution, which uses a highly optimized diffuser. The diffuser scatters solar radiation incident from almost any angle of the upper hemisphere in the same way. This eliminates the need to electronically, or in subsequent processing, compensate the data for different sensor sensitivities for different incidence angles. This seemingly simple principle ensures the high robustness of the solar radiation sensor. The actual optimization was very challenging and resulted in a non-trivial internal design of the diffuser.

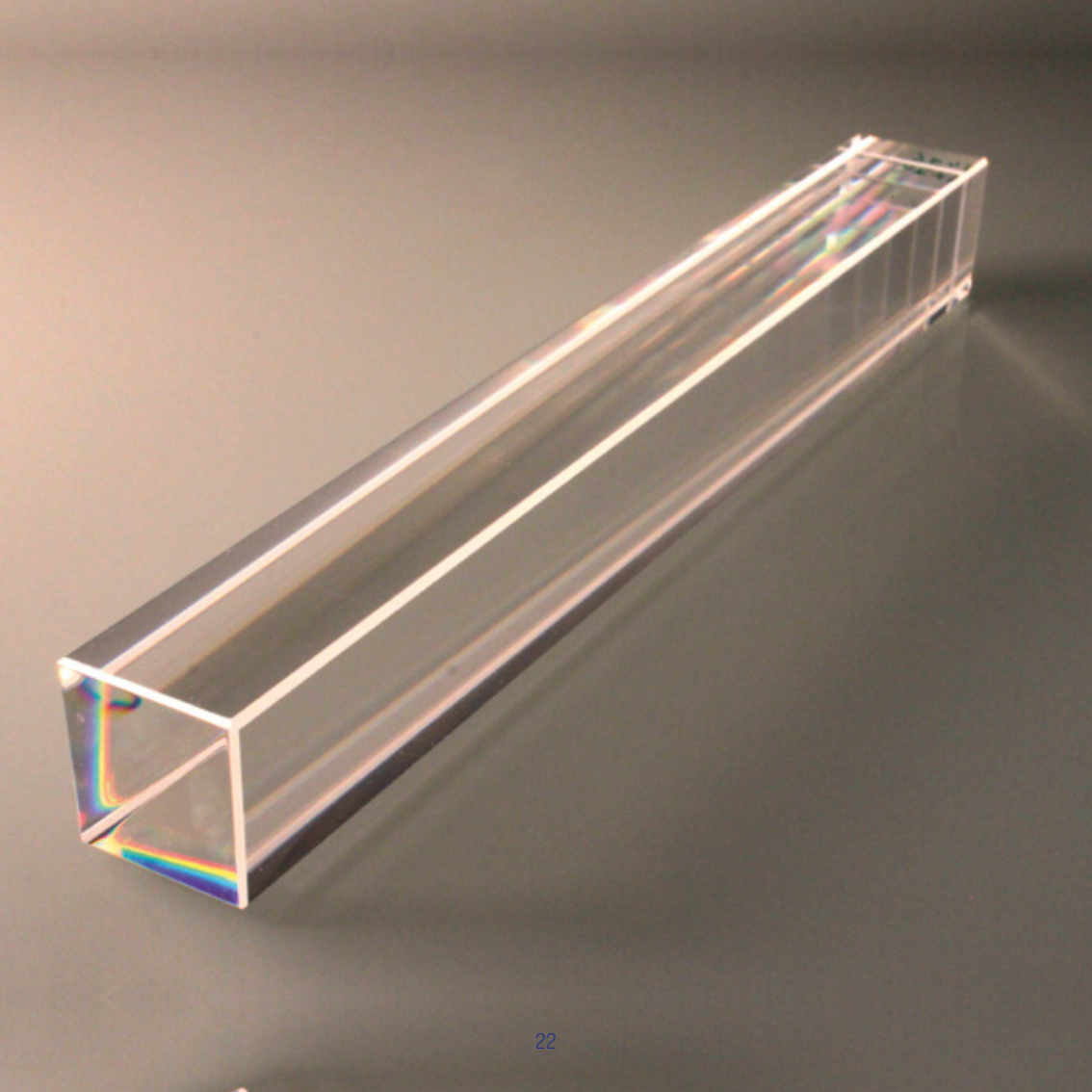
The result of the project is a newly-designed hemispherical diffuser, which can be used to monitor solar radiation for photovoltaic power plants or for meteorological stations.

# 10 DEVELOPMENT AND OPTIMIZATION OF A TECHNOLOGY FOR THE MACHINING OF PBWO3 CRYSTALLINE MATERIAL

The industrial partner CRYTUR, spol. s r.o. has developed a new type of highly efficient scintillator for the construction of muon calorimeters. The material has excellent properties, but from the point of view of machinability it is highly problematic due to its brittleness, cleavage and overall softness.

Together with CRYTUR, TOPTEC solved a development task aimed at attaining a productive machining technology leading to high surface quality and low scrap rates, thereby reducing material cost. Based on extensive research, the TOPTEC team selected several promising directions in both coarse and fine machining. Extensive experiments were carried out and the analysis of the results gave rise to an optimal multi-step production process with a minimum of necessary intermediate checks and iterations.

For a successful design of the calorimeters, it was necessary to achieve a close prismatic shape in which none of the angles were trivial 90°. Special mechanical fixtures were designed and supplied for this purpose.

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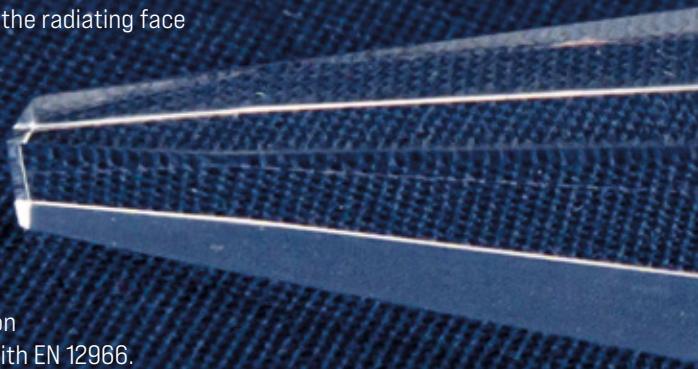
# 11 MIRRORS FOR MICROWAVE SPECTROGRAPH RESONATOR

The TOPTEC team designed and implemented giant metal resonator mirrors for the unique emission Fourier transform microwave spectrometer constructed at the University of Chemistry and Technology, Prague. The spectrometer is designed for the analysis of, e.g., odorous substances, pheromones or complex organic molecules. The mirrors are made of aluminium alloy and form a variable path length resonator. The production of the atypical mirrors was challenging due to their size and shape. The requirements of the scientific team at the University of Chemistry and Technology led to spherical mirrors with a diameter of 930 mm and a radius of curvature of 930 mm. Sufficient rigidity and low weight of the mirrors had to be achieved. The micro-roughness requirements were not critical due to the wavelengths analysed.

# 12 OPTICAL DESIGN OF SPECIAL FREE-FORM ELEMENTS FOR B3 AND B4 CLASS USED IN MOTORWAY INFORMATION PANELS

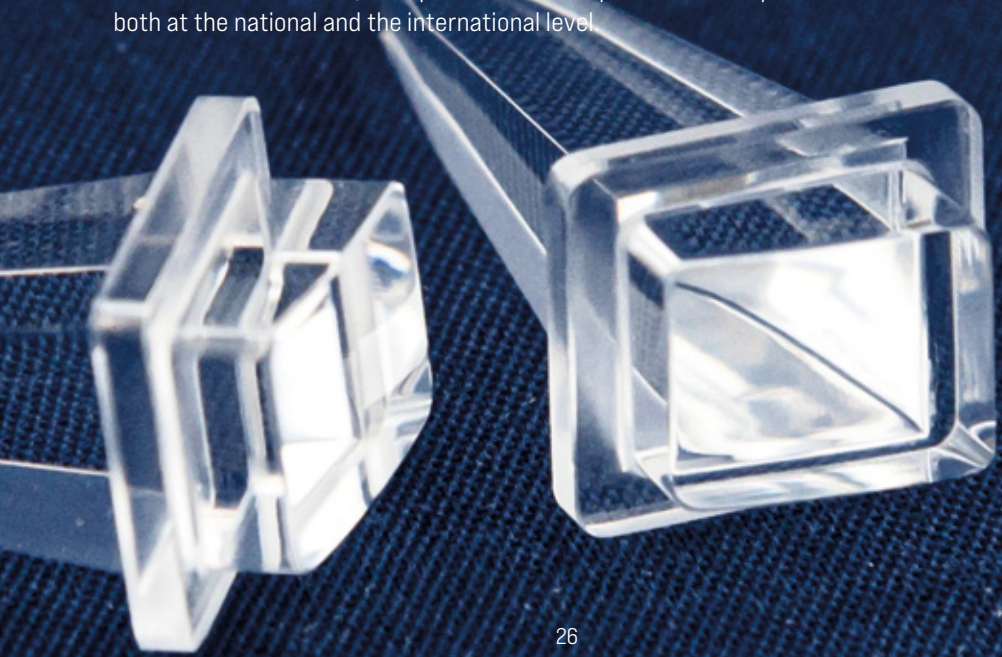
The project, completed in cooperation with ELTODO, a.s., focused on the development of optical elements of new-generation information panels, moulded from the PMMA material. Optical elements have to perform a number of functions and their multi-criteria optimization required the construction of a highly complex merit function. TOPTEC provided the 64-core computing cluster needed for the computation of the time-consuming design iterations.

The element has to thoroughly mix light from the three RGB chips of the high-efficiency colour LED. In addition, the element must ensure the best possible light transport from the LED to the radiating face of the element. The shape of the radiating face is a free form designed to achieve the required angular characteristics, where each class has its own specific criteria, which are strictly checked by the Homologation Authority. The designed solution achieves perfect compliance with EN 12966.



This solution improves road safety by providing drivers with colour information on road signs. Furthermore, it significantly increases the environmental friendliness of the panels due to its high efficiency. The efficient usage of light decreases the energy consumption of the panels while extending their lifespan as they need not be run at the highest power level for most of the day.

The panels tend to have tens of thousands of light elements. The last optimization criterion was high resistance of the elements to false optical signals arising when the panels are illuminated at an unsuitable angle by direct sunlight. As far as economic benefits are concerned, the optical element improves the competitiveness of the client both at the national and the international level.

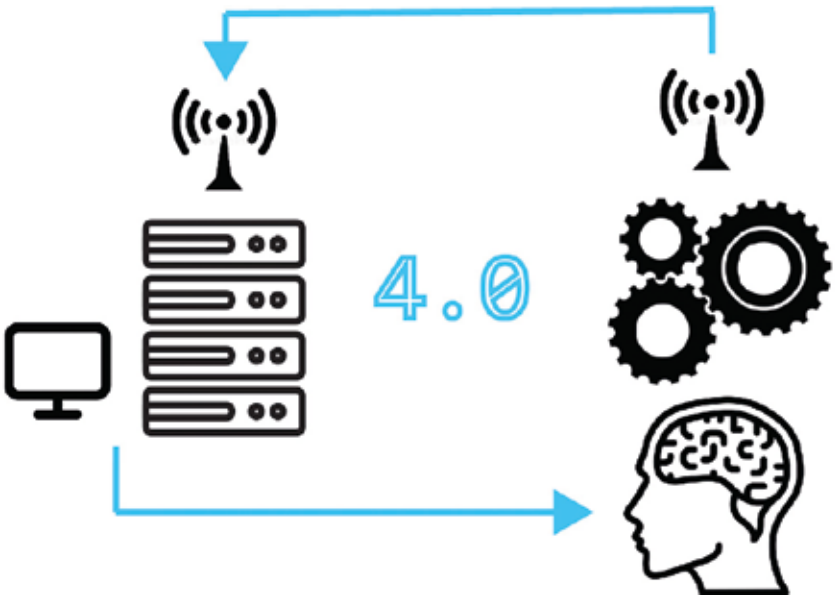


# 13 OPTICAL LAYOUT AND LENS ILLUMINATION DESIGN FOR OptoNS DEVICES

For a detailed study of the processes accompanying nanofiber formation in an industrial Nanospider machine, ELMARCO s.r.o. requested the development of an optical imaging system which can display the formation of a Taylor cone in sufficient detail from a long distance in order to minimize the risk of contamination of the optics and the risk of damage to the camera due to electrical charge accumulation on the system.

With the available commercial systems, it was possible to project the stream from the polymer cylinder onto 3 to 5 camera pixels, which was insufficient to measure the stream shape and diameter well enough.

A suitable imaging system has to achieve a magnification up to 3.3 times higher, i.e., a re-imaging of the mean sized stream to 10–17 pixels for a correct diameter analysis. The optical system was therefore designed as a front lens to the Nikon AF Nikkor 200mm f/4 IF-ED commercial lens in doublet, triplet and quadruplet versions. All the optical designs were optimized to minimize the optical defects of the system and to achieve maximum light throughput of the whole system.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# 14 SYSTEM FOR MONITORING THE REAL OPERATING TIME OF CNC OPTICAL MACHINES

The TOPTEC team participated in the analysis of the design and implementation of a computer system for monitoring the real operating time and operating parameters of a group of CNC machine tools of different classes. The system is designed in accordance with Industry 4.0 principles.

The action of saving a record to the database is initiated directly by the machine and not by the parent control system. Non-trivial general-purpose methods for detecting the start of a process and readout and storing the monitored data have been proposed and implemented. Furthermore, an optimum data structure for storing a heterogeneous data set was designed.

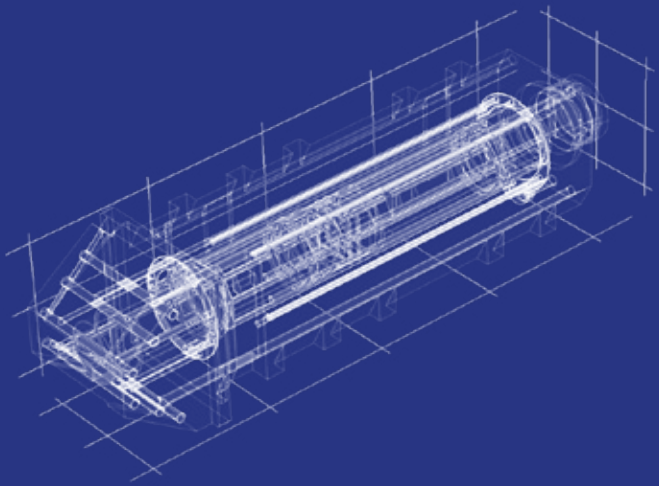
The system was developed and tested in cooperation with asphericon s.r.o. The first version of the system is fully functional and deployed by the industrial partner. A higher version of the system is still under development with the aim of achieving the extraction and storage of a wide range of process parameters, so that these data sets can later be analysed to optimize complex machining processes.

# 15 MODELING AND OPTIMIZATION OF A SYSTEM OF NON-CONTACT MEASUREMENT OF ASPHALT SURFACE BY THE OPTICAL TRACING METHOD

The FUTTEC a.s. company has developed a new method of repairing asphalt pavement by means of microwave heating technology. The technology uses a large-scale matrix microwave source, which heats the edges and the centre of a pothole at different power levels depending on the specifications, so that, after heating, the optimum temperature for adhesion of the asphalt mix is achieved in all areas.

When repairing asphalt, all areas need to be heated to a temperature of 140 ± 5 °C to properly bond the old and new asphalt.

The TOPTEC team was approached with a brief to create very robust temperature sensors that can measure surface temperatures repeatedly and accurately under a variety of conditions from a distance of tens of centimetres. TOPTEC developed



a complex mathematical and physical model of the problem, whose analysis revealed critical points which could not be identified by a conventional approach, as at least two of them are completely non-intuitive influences. The biggest problem turned out to be the actual IR radiation of the optics and the sensor tube.

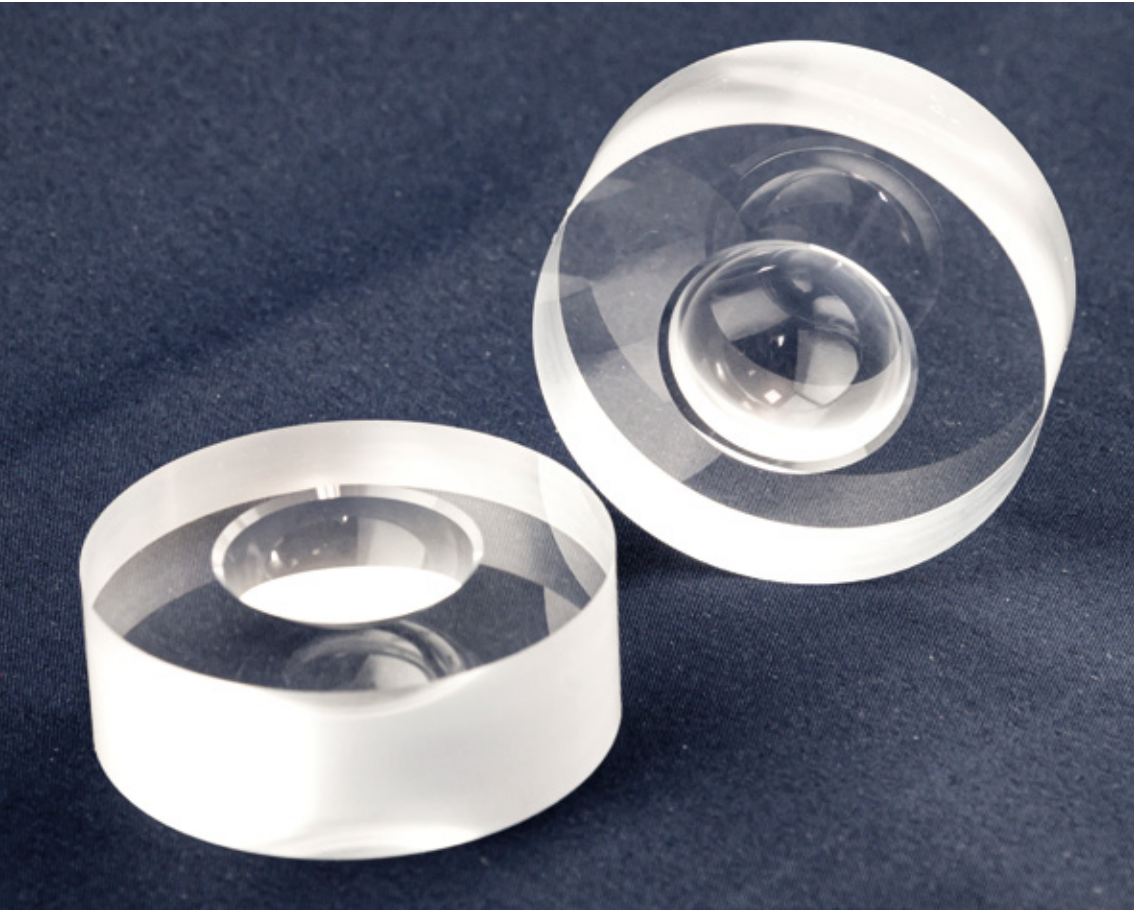
A sensor design was then devised which partially or completely eliminated the problems and which is able to measure the asphalt temperature to within ± 5 °C. This achieves the necessary temperature to properly heat the asphalt at the point of failure (pothole).

This technology is suitable for repairing small holes and especially for preventative maintenance – ideally as soon as the problem starts to manifest itself. In addition, without the need to mill the road, the consumption of asphalt is significantly reduced.

# 16 ACETABULUM SOCKETS

The aim of the project was to produce atypical optical measuring elements in the form of plano-concave optical elements, where the concave surface reached the shape of a full hemisphere. Accomplishing a precise, optical quality hemisphere is, due to its shape, a very demanding operation in optical manufacturing, both in terms of production technology and the subsequent evaluation of the surface quality.

The elements find application in experiments with joint implants, where they simulate the acetabulum socket. Through the planar back surface of the element and optically transparent environment, it was possible to continuously evaluate element wear and thus adjust the experimental conditions to minimize the wear and thereby achieve greater implant durability.



# SELECTED PATENTS

- Interferometric measurement device for aspheric surfaces
- Optical element for marking boards
- Mechanism for clamping and positioning of optical elements
- Device for monitoring the quality of moving linear textile material at an operating unit
- Focusing lens of a system for hyperspectral display
- Optical element 2G25 varG
- Optical system for producing an optical structured beam

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