SCHOTT
glass made of ideas

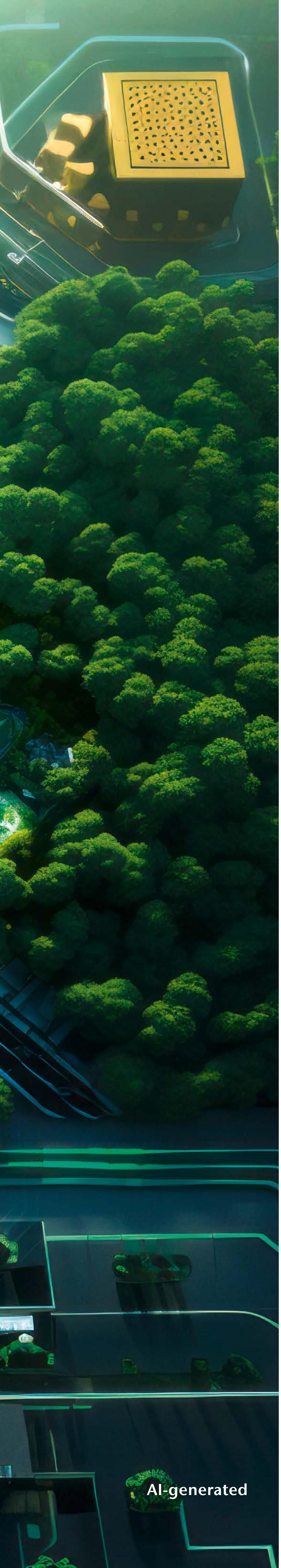
Thermal dimensional stability

ZERODUR® – glass-ceramic with near-zero thermal expansion. **A plus for you.**

A plus for our future

Are you interested in special materials enabling the future of imaging and digitalization? In this brochure, you will find information about ZERODUR® glass-ceramic, which is widely used in applications that require the highest thermal dimensional stability for high-resolution optics and precision engineering.

Dive into the world of ZERODUR® and learn more about how this glass-ceramic enables science and industry alike. For those starting to work on or specify their next product, we provide an overview of the material properties and processing possibilities. A hint regarding the future: Some of our pictures are marked “AI-generated.”



A plus for our future

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ZERODUR® is a glass-ceramic with near-zero thermal expansion over a wide temperature range. This extraordinary property means that applications requiring the highest precision can avoid geometrical shape and distance changes between parts even when exposed to temperature variances. On the following pages, we provide an overview of some applications in which ZERODUR® glass-ceramic is used to fulfill tight requirements. **Key properties of ZERODUR® are:**

Near-zero thermal expansion

The low net thermal expansion matches operating temperature ranges and achieves an accuracy of 0 ± 7 ppb/K.

Highly homogeneous properties

The low CTE and material properties are homogeneous throughout the entire volume up to 4.25 m.

CNC-customized 3D shapes

From a few centimeters up to 4 meters, large sophisticated shapes are available in bulk or light-weight configurations.

A plus in precision

Highest internal material quality

For stable results and excellent polishing behavior.

Reliability

High bending strength and life-time prediction enables impressive reliability.

Usable under extreme conditions

From Earth to space, dry to humid, pressure cells to vacuum, ZERODUR® withstands harsh conditions.

Low gas permeability

Allows for long-term stability for He-Ne laser applications in ring laser gyroscopes.

Annealing of a 4-m-class blank at SCHOTT AG

ZERODUR® material characteristics

ZERODUR® is an inorganic, non-porous lithium aluminum silicon oxide glass-ceramic characterized by evenly distributed nanocrystals within a residual glass phase.

For over 50 years, SCHOTT has produced ZERODUR® glass-ceramic at its headquarters in Mainz, Germany, using a two-step process: First, the carefully selected raw materials are melted, cast into molds, and annealed to obtain the glass phase. Second, a precise ceramization process transforms this glass phase into ZERODUR® glass-ceramic through controlled growth of nanocrystals. The negative linear thermal expansion coefficient of these crystals compensates for the positive expansion of the remaining glass phase.

The high homogeneity and internal quality of ZERODUR® can be attributed to the well-established melting and ceramization processes, which yield such excellent quality in high-volume ZERODUR® blanks up to 4.25 m in diameter. The technical specification part of this brochure provides detailed material characteristics to support your material specification.

Grinding of a 4-m-class raw blank on a three-point support, on a five-axis CNC machine

ZERODUR® processing

SCHOTT also has expertise in processing and delivering large quantities of monolithic and shaped blanks. We manufacture according to our customers' technical drawings with our grinding and polishing processes, and we can produce everything from single pieces up to series production.

For example, in 2024, we completed our on-time production of 949 mirror substrates for the European Southern Observatory's Extremely Large Telescope main mirror. The "processing" chapter provides you with useful data to support your technical specification process and ensure the feasibility of your product.

The most important properties of ZERODUR® glass-ceramic are summarized in this catalog, along with references to selected SCHOTT publications.

A complete list of these publications is available in the download section here:

schott.com/zerodur


AI-generated

A plus in safety

Commercial aircraft are equipped with advanced navigation systems that are essential for the safe operation of flights. These systems allow pilots to determine the aircraft's position with precision at any given moment, ensuring safe and timely arrivals.

CNC-shaped and double-side polished ZERODUR® blanks

The aerospace industry relies on navigation systems with accelerometers and gyroscopes that measure the linear acceleration and angular velocity in all three directions (x, y, z) to determine an aircraft's exact velocity and position. The integration of these instruments is vital for the complex maneuvers and navigation required in modern aviation.

One type of gyroscope technology makes use of the Sagnac effect, which describes the occurrence of a phase shift between two light beams travelling under rotation along a closed loop in opposite directions. This ring laser gyroscope is made from ZERODUR® glass-ceramic: The entire laser beamline is operated in a block of ZERODUR® called the body of the gyroscope. For the beamline control, ZERODUR® serves as substrate material for the highly reflective mirrors and a prism that is part of the detector optic.

Relying on ZERODUR® glass-ceramic with its low CTE results in an extraordinarily consistent beamline length. Furthermore, the glass-ceramic has a very low helium permeability, preventing the out-

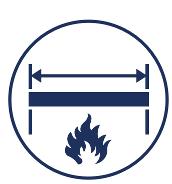
Did you know …

… ZERODUR® ring laser gyroscopes on board aircraft travel approximately 4,700 times the distance of the Earth’s circumference every day?

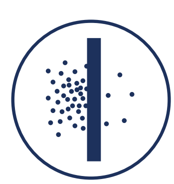
Pilots navigating an airplane

gassing of helium, which serves as a lasing medium. Both properties combined enable extremely precise position measurements (0.001°/h bias stability) and a very long operating life for ring laser gyroscopes (60,000 hrs).

Their high precision, reliability, and long operating life makes ring laser gyroscopes made of ZERODUR® glass-ceramic the perfect navigation hardware solution for safer air travel.



Near-zero thermal expansion

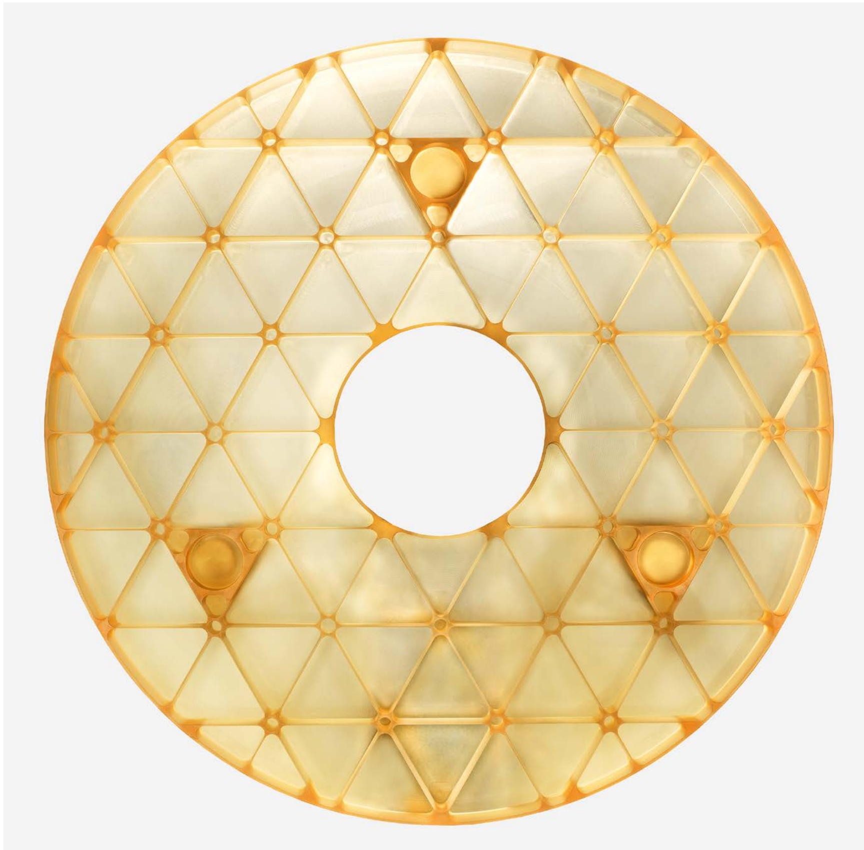


Low gas permeability

3D rendering

A plus in exploration

Space technologies increasingly provide benefits for life on Earth. Where early satellites focused on science and technology demonstrations, today's satellites provide high-resolution earth observation, telecommunications, navigation, internet from space and human space travel, among other applications.



A lightweight ZERODUR® mirror blank with a diameter of 1.2 m

Great space observatories, such as the Hubble Space Telescope or James Webb Space Telescope, have pushed the boundaries of technology for the advancement of science. These telescopes require extremely stable materials to create high-resolution images of faraway space objects, e.g., picometer stability. But also, high-resolution earth observation optics need thermally and mechanically stable components that survive launch conditions and the harsh environment in space. This thermal stability needs to be maintained throughout the orbit's trajectory, which induces thermal gradients on the optics. Additionally, satellite optics need to be as light as possible without any loss in performance or stability.

Mirror substrates from ZERODUR® exhibit near-zero thermal expansion over a wide temperature range that can be tailored to a space mission's operational temperature. Combined with its single-digit ppb/K CTE homogeneity over the entire volume of the material, ZERODUR® provides excellent thermal stability on each orbit.

ZERODUR® mirror substrates for space optics are typically lightweight thanks to CNC grinding methods, which can reduce its mass by more than 90 %. In addition to its design, the mirror substrate's mechanical stability depends on its surface quality, which is enhanced by sophisticated etching technologies to survive launches.

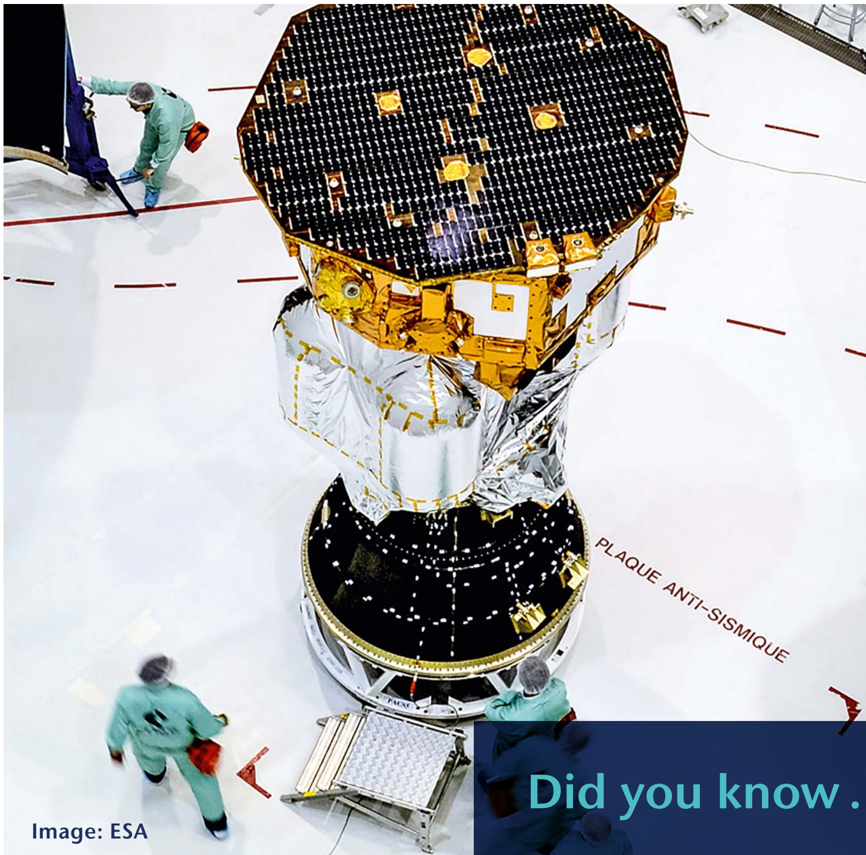


Image: ESA

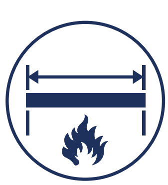
Integration of the LISA Pathfinder payload into the Vega launcher

Did you know …

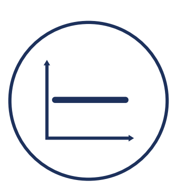
… the first image from the Chandra X-ray Observatory shows a neutron star in the supernova Cassiopeia A? Chandra was placed on its observation orbit in 1999 and has flown on an elliptical orbit between 16,000 and 133,000 km from Earth since then. In its most recent missions, Chandra has been exploring medium-sized black holes that it identifies by pointing at three x-ray sources near their locations.

SCHOTT offers processing and precision grinding of ZERODUR® blanks with fine grain sizes and narrow form tolerances on optical surfaces that enable direct fine-tool polishing and save polishing time during the optical fabrication process.

Lightweight ZERODUR® mirror substrates and components provide the high thermal stability to enable high-resolution imaging in harsh space environments.



Near-zero thermal expansion



Highly homogeneous properties

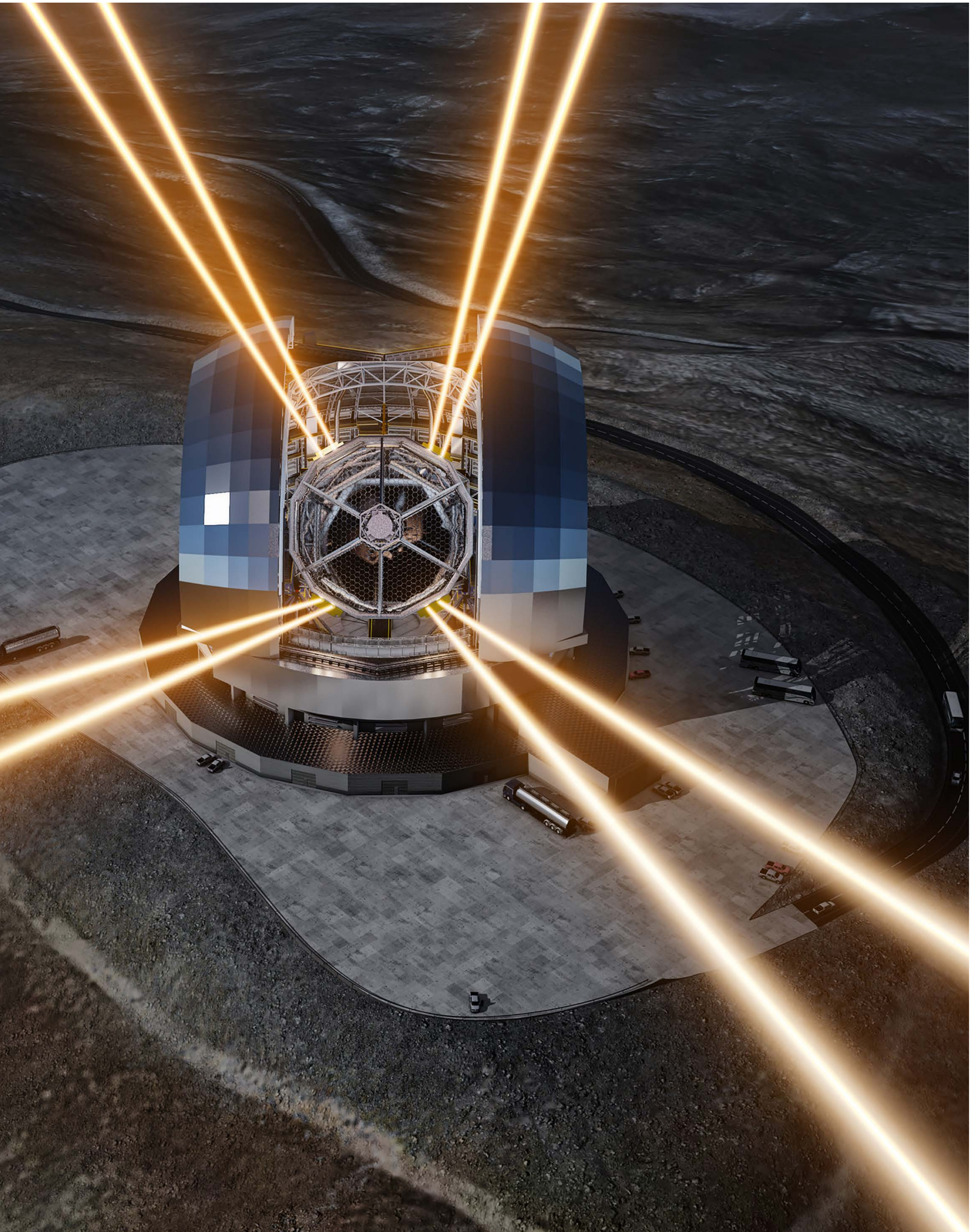
Reliability

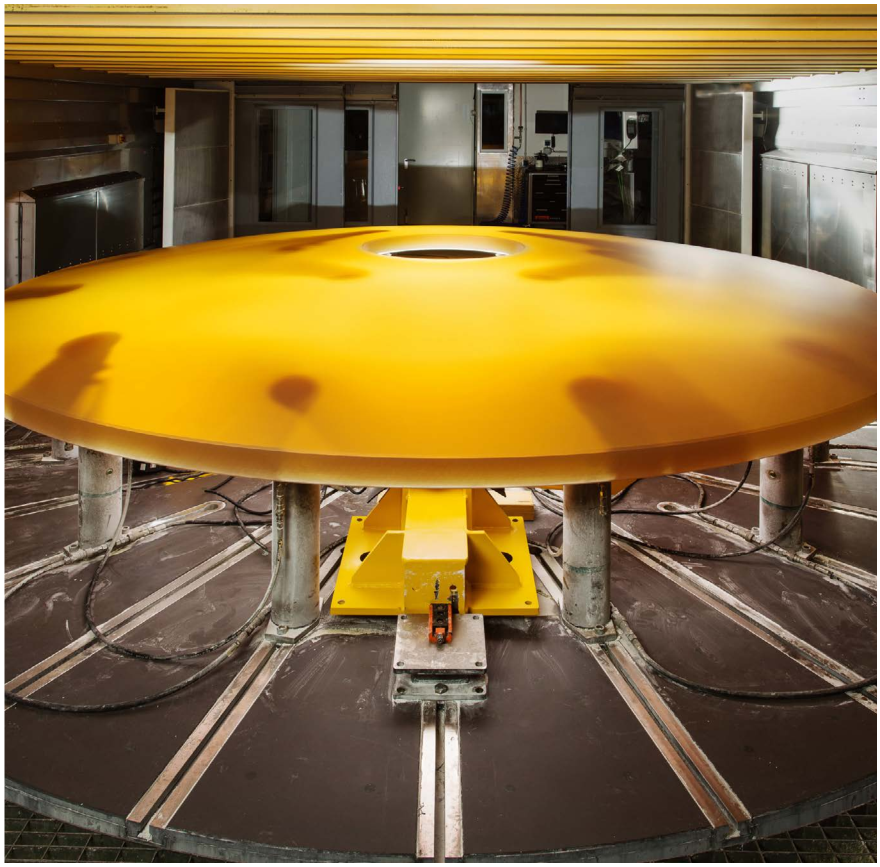
Usable under extreme conditions

A plus in discovery

Astronomy seeks to reveal the secrets of our universe. Observing at different wavelengths as far back as a few moments after the big bang, astronomers collect data to support, challenge, and certainly improve our current physics model basis to understand our universe.

Image: ESO





4-m-class ZERODUR® secondary mirror substrate for the Extremely Large Telescope

To accomplish that, astronomers need powerful telescopes that count as some of the most sophisticated machines humans have ever built.

Key to observing astronomical objects in deep space is collecting enough photons and avoiding or mitigating image disturbances from Earth's atmosphere. For this reason, the telescope design with its materials, components, and detectors needs to support large and precisely aligned apertures so that they do not lose any photons during observation. The temperature changes through 24 h at the telescope's site influence the observation and thus require extreme thermal stability for the optics, especially the mirrors.

To overcome these challenges, ZERODUR® glass-ceramic was selected as mirror substrate for the Calar Alto Observatory, even though the glass-ceramic had just been developed a few years earlier. The near-zero thermal expansion of it's tiny samples convinced the astronomers at the Max Planck Institute of Astronomy in Heidelberg to choose this new material. Their order of 12 blanks from 0.3 m to 3.6 m in diameter is considered as the day of the commercialization of the glass-ceramic ZERODUR®. The largest ZERODUR® blanks ever made – measuring 8 m in diameter – serve as the primary mirrors of European Southern Observatory's (ESO) Very Large Telescope (VLT). Today, SCHOTT regularly manufactures blanks in sizes up to 4.25 m in diameter.

Today, many of the world's greatest observatories rely on ZERODUR® mirror substrates. For ESO's Extremely Large Telescope (ELT), SCHOTT produced 949 mirror blanks in series. They exhibit single-digit ppb/K CTE homogeneity not only on the


Image: ESO

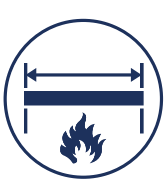
The ESO's VLT relies on an 8-m primary mirror made of ZERODUR®

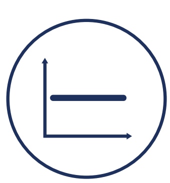
Did you know …

… in 2008, scenes from the James Bond film "Quantum of Solace" starring Daniel Craig were filmed at ESO's Paranal Residencia Hotel close to the VLT site? The subterranean hotel is an award-winning building housing ESO visitors on the Cerro Paranal mountain.

entire volume of one substrate. From substrate to substrate the achieved CTE distribution of +/- 20 ppb/K exceeds specification and reflects the excellent reproducibility of material properties achieved by perfecting the manufacturing process over many years.

ZERODUR® glass-ceramic has been the mirror substrate material of choice for many ground-based stellar and solar observatories for more than 50 years.


Near-zero thermal expansion


Highly homogeneous properties

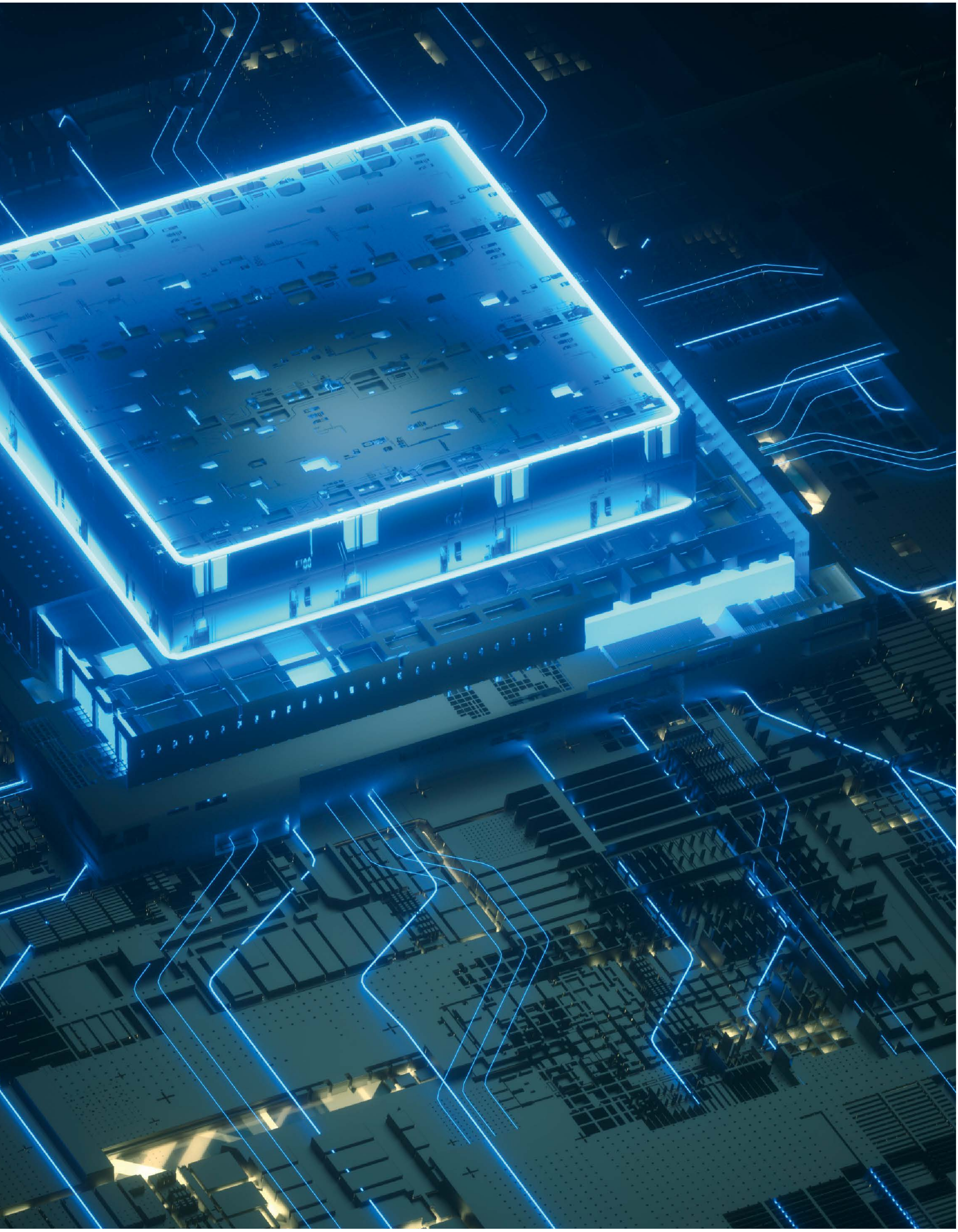

CNC-customized 3D shapes

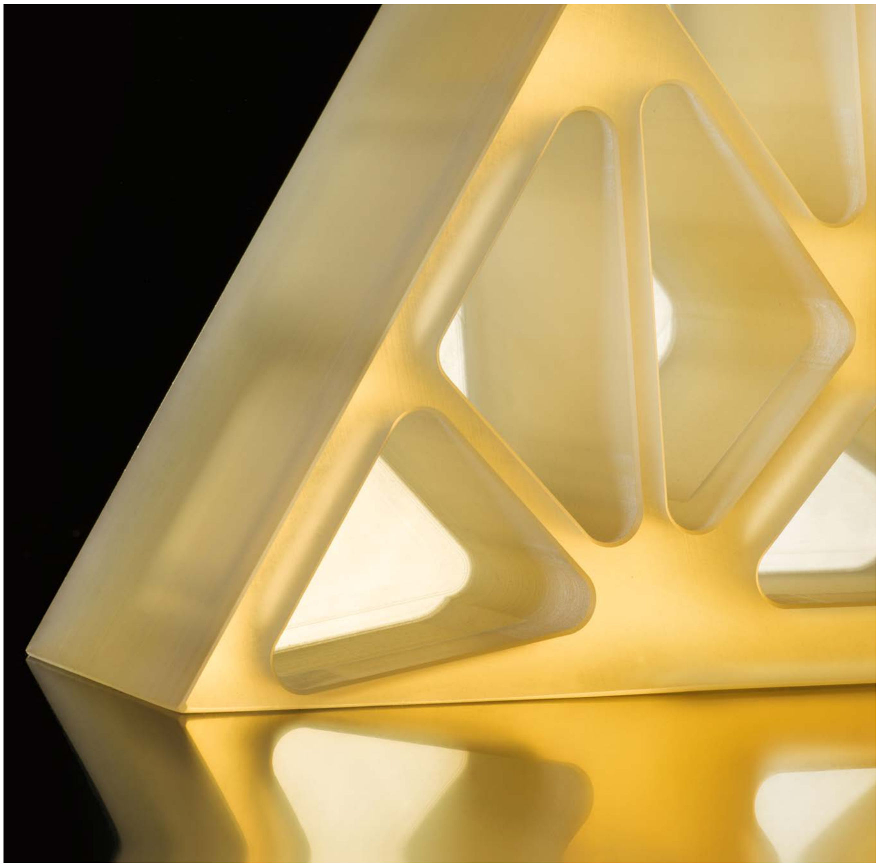

Usable under extreme conditions

A plus in digitalization

Microchips play an important role in our lives, which is even more apparent with emerging technologies like Internet of Things, autonomous driving, and artificial intelligence. We rely on microchips to be available and to perform reliably for these technologies.

3D rendering



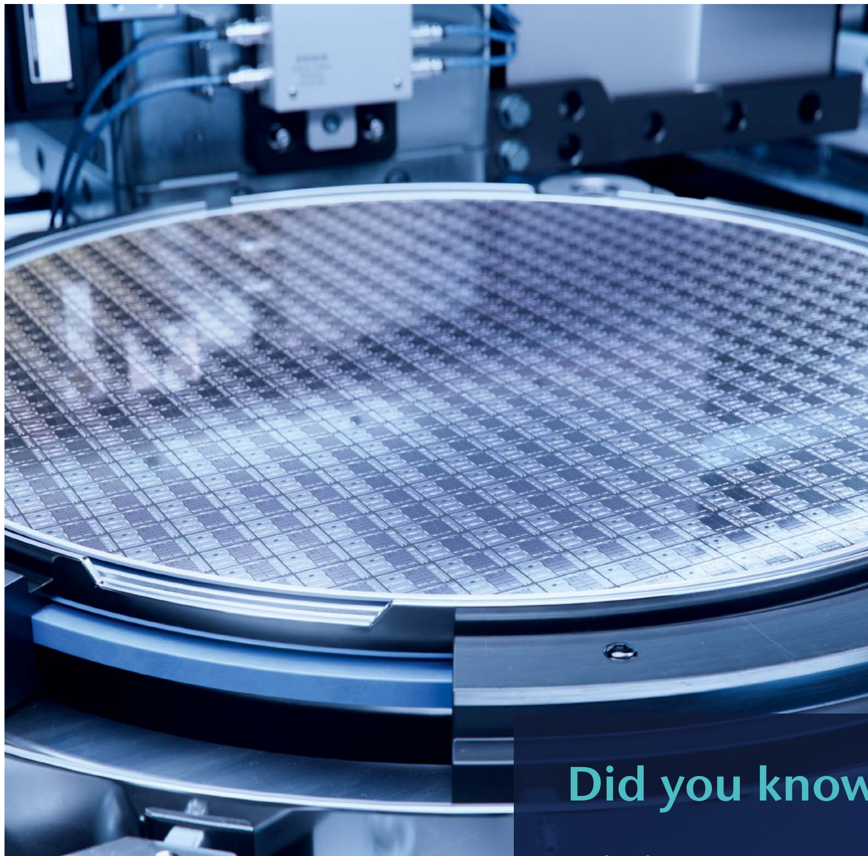


A lightweight ZERODUR® structure with pocket geometries

Although microchips have not increased in size, the number of transistors on chips have increased by a factor in the order of magnitude of 1000 over the past two decades in line with Moore's Law.

Improved chip performance thanks to higher transistor densities is achieved by finer structures down to nanometer sizes. To realize this, a sophisticated positioning system needs to align the microchip substrates, i.e., wafers, with respect to the photo mask blank to provide the structure information with nanometer precision and accuracy. Materials used in this and other systems in semiconductor lithography require extreme thermal stability: that's why they need to have an extremely low coefficient of thermal expansion to support precise alignment. Furthermore, this stability has to be guaranteed over the entire volume of the components, which can be up to several hundred millimeters in dimension. ZERODUR® glass-ceramic enables the highest precision in chip production. The extremely small structures of modern integrated circuits in computers and smartphones are produced using ZERODUR® glass-ceramic components.

With its near-zero thermal expansion, ZERODUR® is the material of choice to support positioning systems. Its CTE can even be tailored to application temperatures around room temperature for photolithographic structuring of microchips.



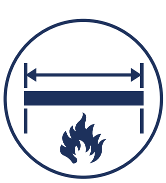
Silicon wafer production

The single-digit ppb/K CTE homogeneity of ZERODUR® maintains thermal stability even as local temperature gradients arise. Furthermore, ZERODUR® can be shaped according to customers' designs by processes like CNC grinding.

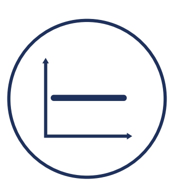
ZERODUR® components help in photolithography machines to accurately position the wafers for exposure.

Did you know …

… the first transistor was about the size of a human hand? It was introduced by John Bardeen, Walter Brattain, and William Shockley, scientists at Bell Labs, in 1947. Today, the smallest transistor consists of only one silver atom and is being researched at Germany's Karlsruhe Institute of Technology (KIT).



Near-zero thermal expansion



Highly homogeneous properties

CNC-customized 3D shapes

Usable under extreme conditions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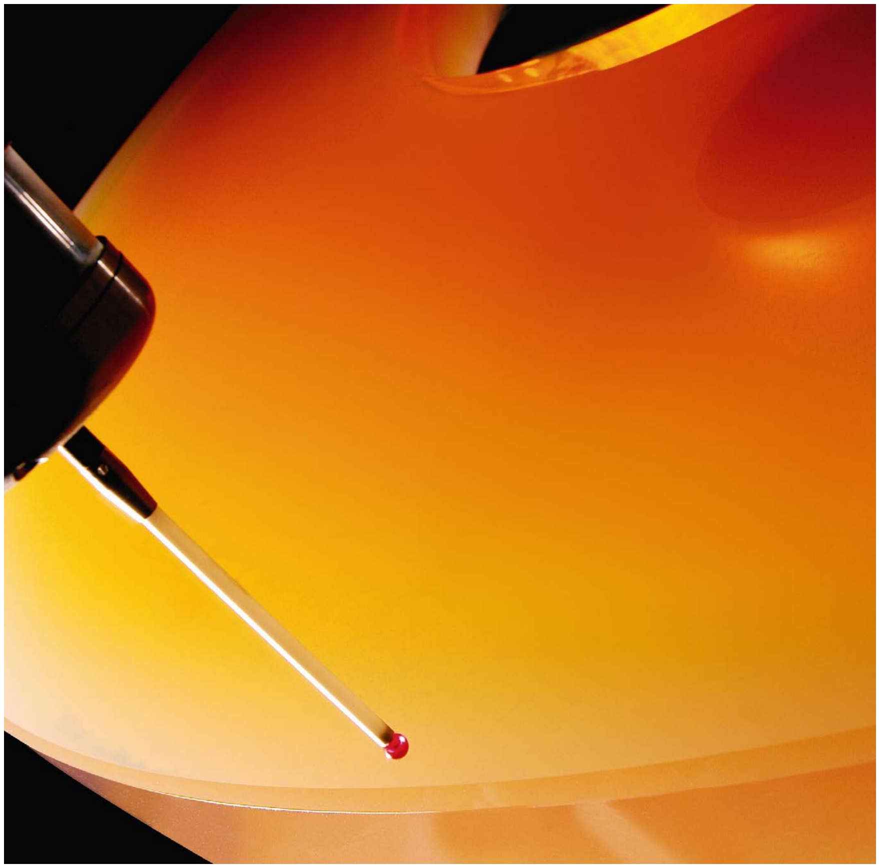
AI-generated

A plus in brilliance

Displays have become an integral part of our lives. They connect us to the world, are essential to our daily work, and deliver us crystal-clear pictures and bright colors.

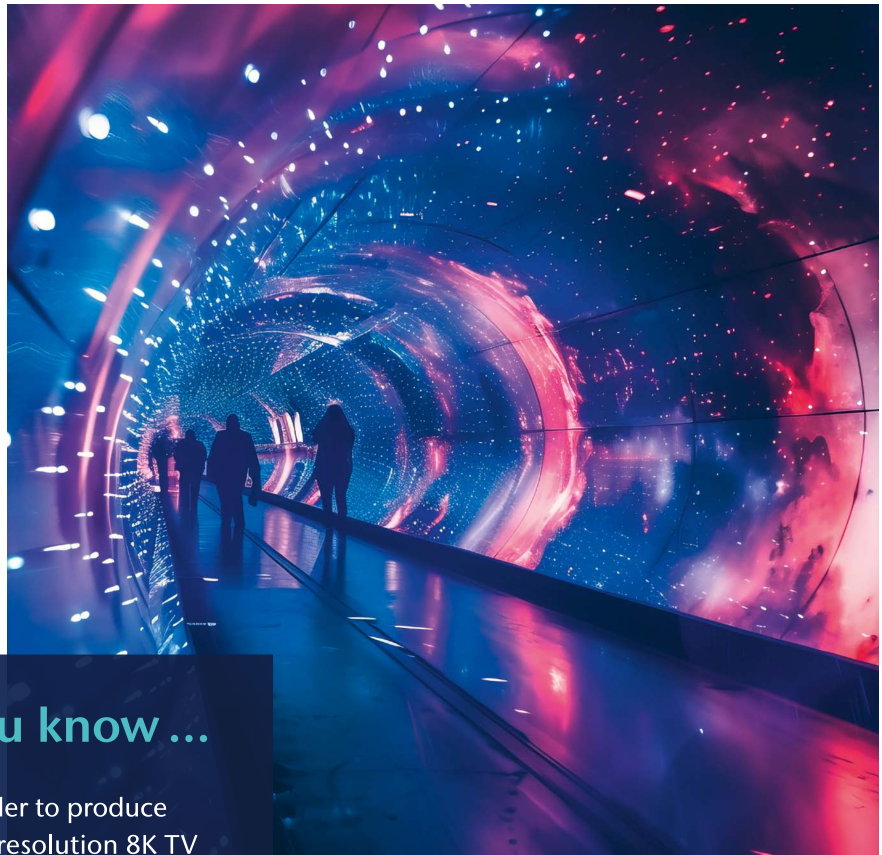


Large monolithic ZERODUR® blank

Flat panel displays are produced using photolithographic methods like those used in microchip production. This requires large optics that allow for increased pixel density while reducing the pixel pitch to close to one micrometer.

That's why the extremely low thermal expansion and excellent polishing properties make ZERODUR® glass-ceramic an optimal mirror substrate material in these optics. Furthermore, the ability to produce ZERODUR® blanks in large dimensions while maintaining its properties homogeneously throughout its entire volume enables the imaging of the photomask pattern in 2.0 μm resolution.

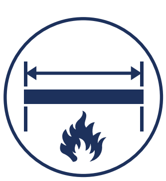
Large ZERODUR® substrates can be found in the vast majority of flat panel display lithography devices thanks to the glass-ceramic's low CTE over its entire volume and its excellent polishability.



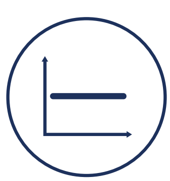
Display tunnel
for trade shows
and events

Did you know …

… that in order to produce the highest-resolution 8K TV currently available, a structure of almost 100 million transistors must be printed on the display's glass sheet?



Near-zero
thermal expansion



Highly homogeneous
properties

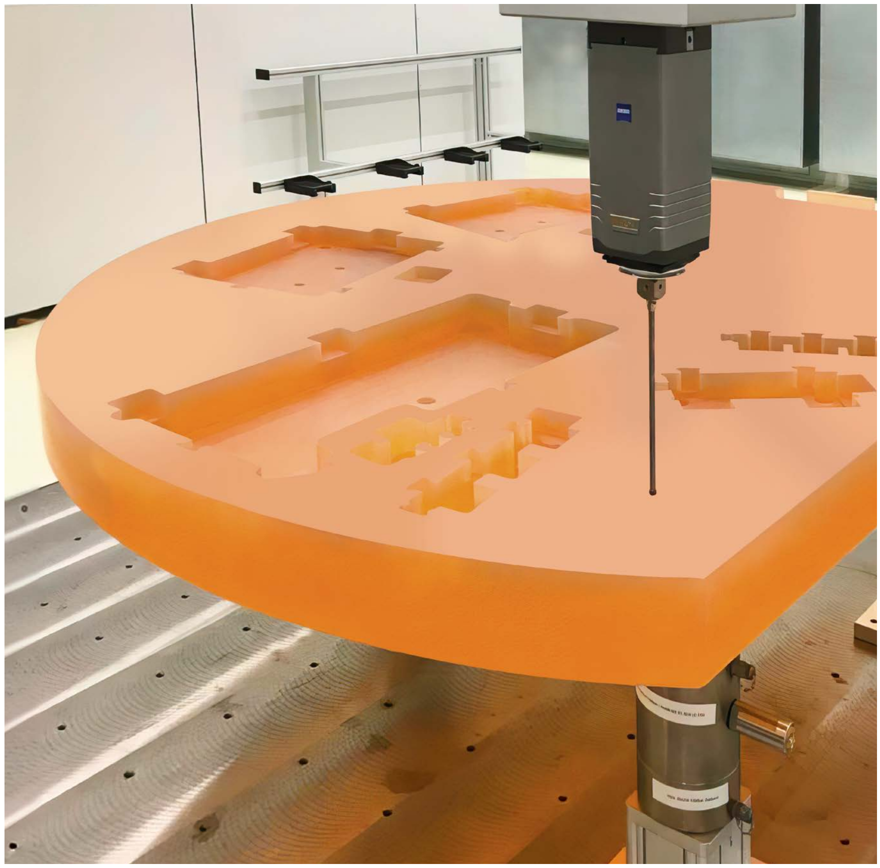
CNC-customized
3D shapes

Usable under
extreme conditions


AI-generated

A plus in accuracy

In the manufacturing industry, reliable production processes and high throughputs of the highest quality are required. Metrology is essential to precisely align products on the line during each processing step or during quality checks and iterative manufacturing.



ZERODUR® optical bench for the W. M. Keck Observatory's Keck Planet Finder instrument

Alignment systems can be as simple as scale bars with sophisticated encoding systems to position products to micro- and nanometer precision. At such low margins, the thermal expansion of the alignment systems influences its accuracy if temperature gradients cannot fully be avoided.

Length scales made from ZERODUR® glass-ceramic allow for high-precision positioning within the nanometer range due to its near-zero thermal expansion over large temperature ranges (0°C–50°C) around room temperature. For use in controlled temperature environments, the ability to tailor the coefficient of thermal expansion to a specific temperature range results in even higher thermal stability.

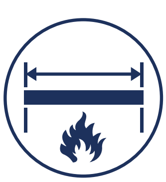
Metrology applications use ZERODUR® glass-ceramic because its near-zero thermal expansion allows for measurements with nanometer accuracy.

Image: HEIDENHAIN

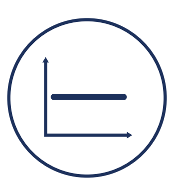
The exposed HEIDENHAIN LIP 200 linear encoder enables measuring steps of 31.25 pm

Did you know …

… that ZERODUR® glass-ceramic allow for measurement resolution that is 2 million times smaller than the thickness of a human hair?



Near-zero thermal expansion



Highly homogeneous properties

CNC-customized 3D shapes

Usable under extreme conditions

A plus for you

With over 50 years of expertise in ZERODUR® material research and processing, we are a team of scientists, engineers, and project managers who love to work with this fascinating material.

With our capabilities and ZERODUR® glass-ceramic expertise, we work closely with our customers to make their high-precision applications possible. As a strong and reliable partner, we offer:

- Outstanding material expertise through ongoing research with more than 100 technical papers published on ZERODUR®
- Material availability with our capacities serving current and future market demand for ZERODUR®
- Processing capability in a new manufacturing center to realize complex shapes and tolerances
- Engineering consulting and design-to-cost for your technical specifications
- Finite element analysis to simulate first eigenfrequencies of complex parts
- The most precise coordinate measurement machines and metrology required to realize your tolerances
- Acid etching of ZERODUR® at various partner companies in Germany to remove sub-surface damage and increase surface strength
- Packaging design to safely ship your ZERODUR® part, even up to 4.2 m in diameter
- State-of-the-art project management to meet your project requirements
- Local sales representatives and after-sales service, including on-site support
- Integrated quality, environmental, and safety management system according to ISO 9001 and ISO 14001

We are an accredited testing laboratory for many glass properties and a certification laboratory for glass-ceramic reference samples for expansion characteristics in accordance with DIN EN ISO/IEC 17025.

We are dedicated to realizing projects.

Let us know how we can support you further and add a plus to your mission.

Challenge glass. Challenge us!
https://www.schott.com/opportunity-lab-inquiry

Near-zero thermal expansion

Mean coefficient of linear thermal expansion

ZERODUR® glass-ceramic is supplied with a mean coefficient of linear thermal expansion (CTE) in the temperature range 0°C to 50°C in six expansion classes as follows:

Table1
Coefficient of thermal expansion tolerance classes available at SCHOTT

CTE (0°C; 50°C) specification tolerances	
Expansion Class 2	0 ± 0.100 ppm/K
Expansion Class 1	0 ± 0.050 ppm/K
Expansion Class 0	0 ± 0.020 ppm/K
Expansion Class 0 Special	0 ± 0.010 ppm/K
Expansion Class 0 Extreme	0 ± 0.007 ppm/K

CTE optimized for application temperature profiles	
ZERODUR® TAILORED	0± 0.020 ppm/K (± 0.010 ppm/K upon request)

ZERODUR® SPECIAL and EXTREME

Our SPECIAL and EXTREME grades are achieved through optimized production control and using a statistical measurement procedure that employs advanced CTE metrology equipment while maintaining all other material properties and outstanding quality.

ZERODUR® TAILORED

ZERODUR® TAILORED optimizes the thermal expansion behavior of components for individual customer application temperature profiles. It is based on a physical material model that takes into account structural relaxation effects.[1]

Figure 1 shows the example of ZERODUR® TAILORED material for use as the mirror substrate in the Extremely Large Telescope. The temperature range at the building site in Cerro Armazones, Chile, varies between 0°C and 14°C during a 100 h period. ZERODUR® EXTREME exhibits a relative change of length Δ l/l of 0.5 ppm, while ZERODUR® TAILORED limits the length change to only 0.08 ppm for these temperatures.

To order ZERODUR® TAILORED, please specify your application temperature range and temperature change rate (°C/h).

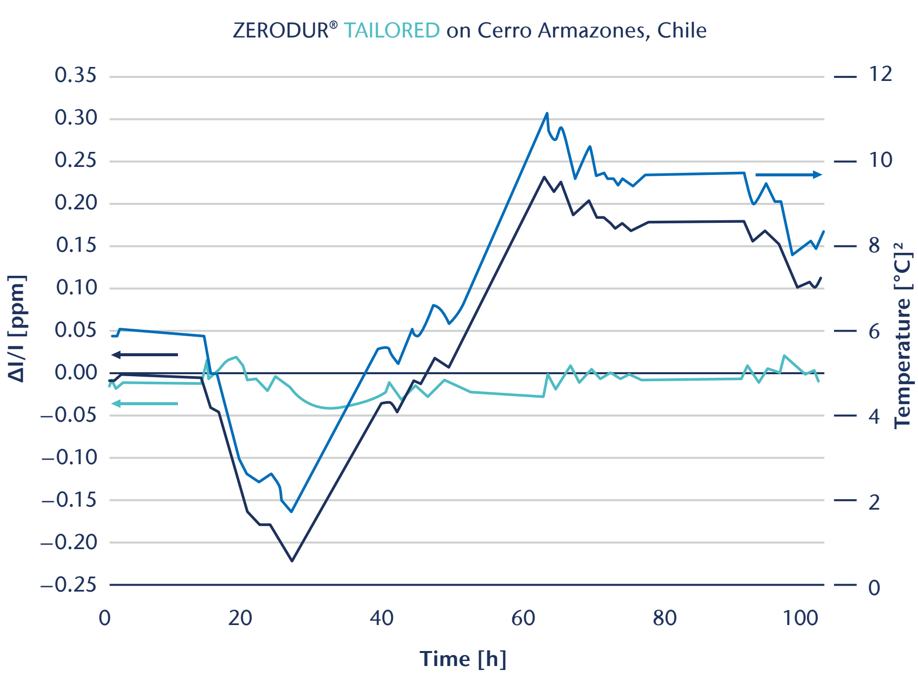


Figure 1
Thermal expansion of ZERODUR® TAILORED for a typical temperature profile on the top of the Cerro Armazones mountain, the site for the ESO's Extremely Large Telescope in the Atacama Desert of Chile

[1] Ralf Jedamzik, Thoralf Johansson, and Thomas Westerhoff, Modeling of the thermal expansion behaviour of ZERODUR® at arbitrary temperature profiles, in "Proc. SPIE 7739", 2010; **https://doi.org/10.1117/12.855980**

[2] Temperature data from: Public Database Server: **http://sitedata.tmt.org/** from June 1 and 4, 2008, air-conditioned during the day

ZERODUR® TAILORED Cryo

The thermal expansion behavior of ZERODUR® glass-ceramic can be optimized within the cryo temperature range. A thermal expansion of less than 0 +/- 0.1 ppm/K can be achieved for temperatures down to approximately 90 K.[1]

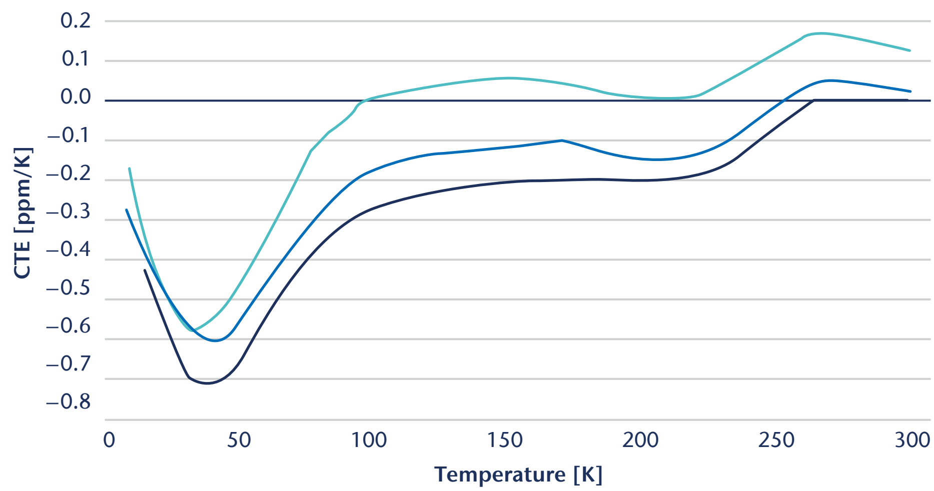


Figure 2
Coefficient of thermal expansion of ZERODUR® TAILORED Cryo compared with two non-tailored ZERODUR® samples, measured by the Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

CTE measurement accuracy

The CTE measurements are performed using a standardized, highly accurate, and reproducible measurement procedure based on dilatometry and are proprietary to SCHOTT AG.[2]

In the 0°C to 50°C temperature range, the measurement setup yields the accuracy and repeatability in Table 2.

Table 2
Coefficient of thermal expansion measurement accuracy and repeatability

	Accuracy	Repeatability (95%)
Standard	± 0.010 ppm/K	± 0.005 ppm/K
Advanced	± 0.003 ppm/K	± 0.001 ppm/K

Figure 3 below shows the typical relative expansion in length Δl/l and CTE of ZERODUR® TAILORED during heating from –50°C to +100°C.

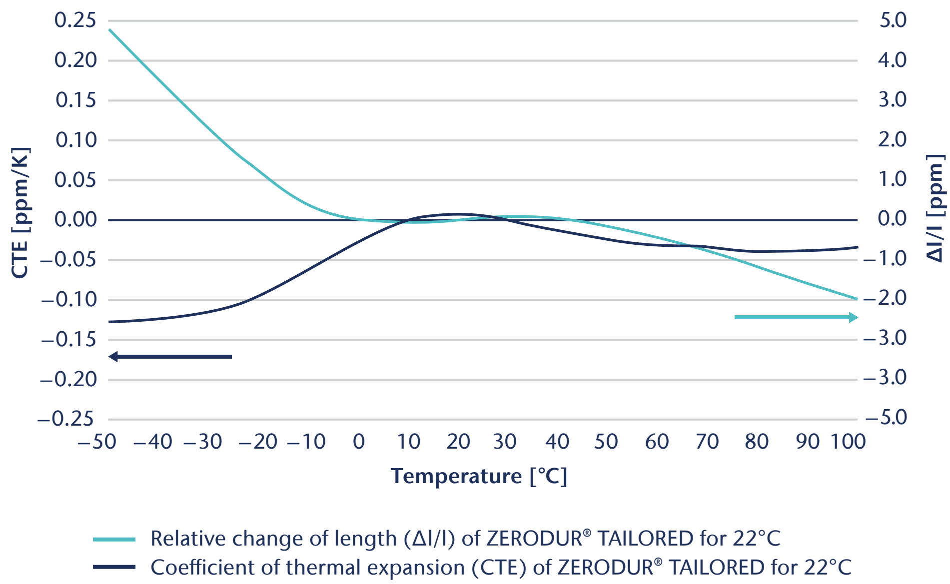


Figure 3
Coefficient of thermal expansion (left axis, light blue) and relative change of length (right axis, dark blue) as a function of temperature between -50°C and +100°C

Total change of length between -50°C and +100°C

< 10 ppm

[1] Jedamzik, Westerhoff, ZERODUR TAILORED for cryogenic application in "Proc. SPIE 9151", 2014, **https://doi.org/10.1117/12.2055086**

[2] Jedamzik, Westerhoff, Homogeneity of the coefficient of linear thermal expansion of ZERODUR: a review of a decade of evaluations in "Proc. SPIE 10401", 2017, **https://doi.org/10.1117/12.2272902**

Homogeneity of the coefficient of thermal expansion

Single-digit
CTE homogeneity over the entire volume

The CTE homogeneity is typically evaluated by extracting samples from the circumferential area of the used volume. Figure 4 displays a homogeneity evaluation of a blank sacrificially cut to samples for statistical evaluation. The difference in CTE between the highest and the lowest value measured are calculated. The homogeneity of linear expansion is ensured in the size classes specified. The CTE homogeneity is expressed in ppb/K.

Table 3
CTE homogeneity tolerances

CTE (0°C; 50°C) homogeneity tolerances (peak to valley)	
up to 4.0 m diameter	≤ 20 ppb/K
up to 2.5 m diameter	≤ 15 ppb/K
up to 1.5 m diameter	≤ 10 ppb/K

Tighter tolerances on request.

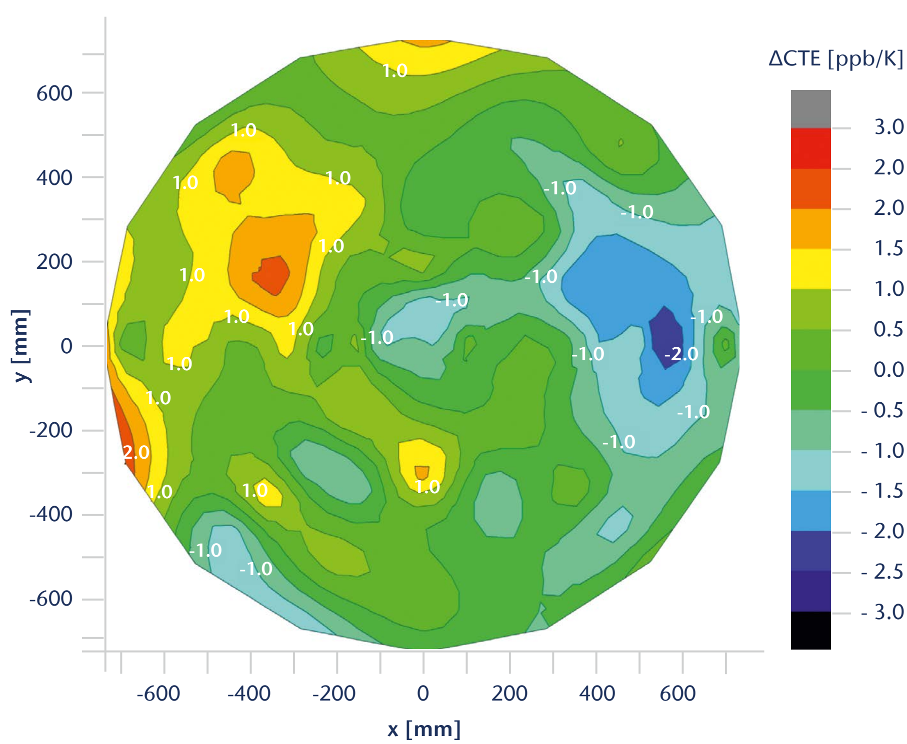


Figure 4
CTE distribution of a 1.5-m-diameter blank with a determined to CTE homogeneity of 5 ppb/K

Recommended application temperature cooling rates between 130°C and 320°C

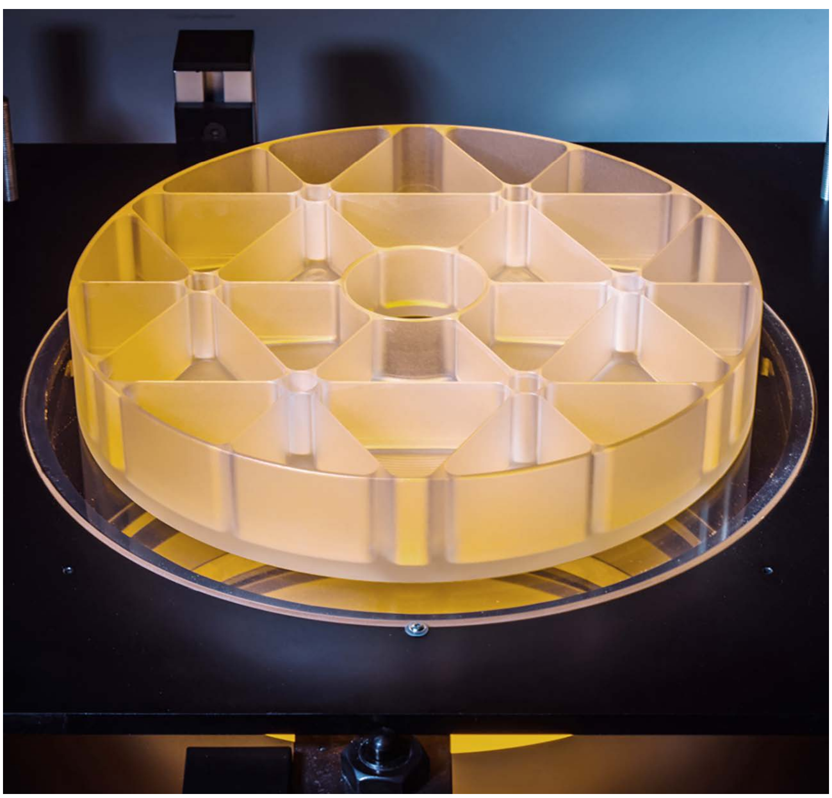
The standard and tailored CTE profiles as shown in previous sections are assuming temperatures exposures up to 100°C. Changes may occur if ZERODUR® glass-ceramic is cooled down from application temperatures between 130°C and 320°C to room temperature with a rate that differs from the initial cooling rate.

The initial cooling rate is 3°C/h. Each factor of 10 difference between application and initial cooling rate can lead to a permanent CTE change of 25 ppb/K.[1]

Maximum application temperature

600°C

Note that the CTE specifications are effected by using ZERODUR® above 100°C and not properly cooling it down.



300-mm-diameter lightweight ZERODUR® mirror blank

Length stability over time

Gauge blocks with a length of 400 mm made from ZERODUR® glass-ceramic have been connected interferometrically to a wavelength standard at the Physikalisch-Technische Bundesanstalt or PTB, Germany's national metrology institute. The rods that were maintained at 20°C showed shrinkage over time. However, the shrinkage rate was hardly measurable and decreased exponentially over time. For most applications, shrinkage is irrelevant.

[1] Jedamzik, Westerhoff, Advice for the use of ZERODUR® at higher temperatures, in "Proc. SPIE 10706", 2018, **https://doi.org/10.1117/12.2311648**

Internal quality

Bubbles and inclusions

Inclusions in ZERODUR® blanks are mainly bubbles with gaseous content or solid inclusions. For optical surfaces, a critical volume can be defined by setting stricter requirements. During inspection of ZERODUR® parts, all inclusions with a diameter > 0.3 mm are taken into consideration. If an inclusion has an irregular shape other than spherical, the average diameter is reported as the mean of the length and width.

	Stand.	Class 4	Class 3	Class 2	Class 1	Class 0
Average number of inclusions per 100 cm^3	5.0	5.0	4.0	3.0	2.0	1.0
Maximum diameter of individual inclusions in mm for different diameters or diagonals of the ZERODUR® part						
In the critical volume:						
< 500 mm	1.4	1.2	1.0	0.8	0.6	0.4
< 2000 mm	2.0	1.8	1.6	1.5	1.2	1.0
< 4000 mm	3.0	2.5	2.0	1.8	1.6	1.5
In the uncritical volume:						
< 500 mm	3.0	2.0	1.5	1.0	0.8	0.6
< 2000 mm	6.0	5.0	4.0	3.0	3.0	3.0
< 4000 mm	10.0	8.0	6.0	6.0	6.0	6.0

Individual specifications available on request.

Table 4
Quality levels for inclusions in ZERODUR®

On average only **one** inclusion sized **0.4 mm** per 100 cm^3 for blanks smaller than 500 mm

Bulk stress

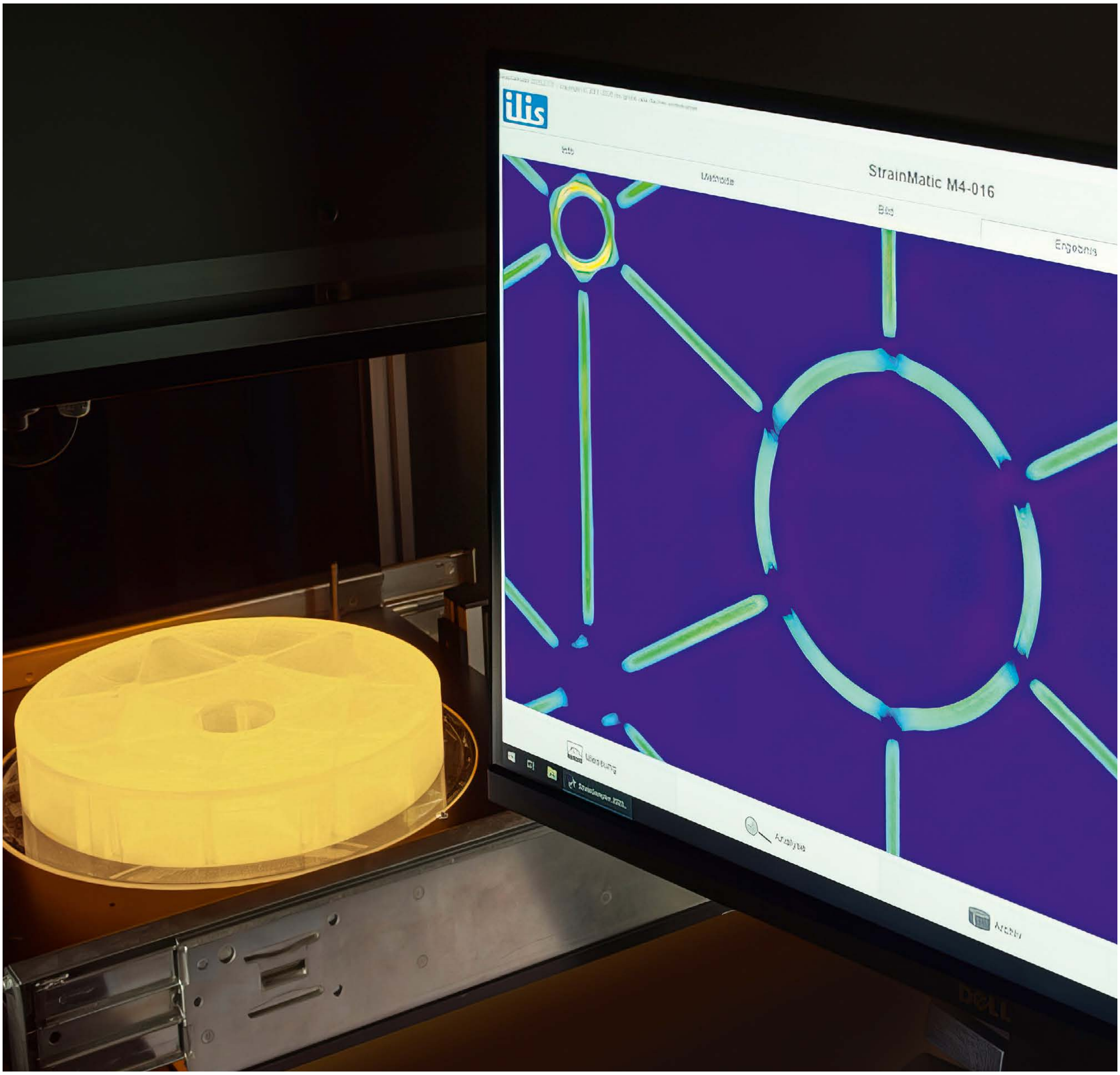
All ZERODUR® parts are precision-annealed to achieve low and symmetrically distributed permanent bulk stress. The bulk-stress-induced birefringence is measured in axial direction for discs and rods at positions 5 % of the diameter from the edge. For rectangular plates, the measurement is performed at positions in the middle of the longer side perpendicular to the plate's surface.

It is recorded in path difference per thickness in inspection direction. Industrial high-resolution imaging polarimeter systems are used for the measurement.

Bulk stress birefringence [nm/cm] for parts with diameters or diagonals	Standard	Class 4
< 500 mm	6	4
< 2000 mm	12	10
< 4000 mm	15	12

Individual specifications available on request.

Table 5
Quality levels for bulk stress in ZERODUR®



Imaging polarimeter for high-accuracy stress birefringence measurement in ZERODUR® products

Striae

Striae are locally confined transparent regions with compositions that differ from the basic material only very slightly. They are generally ribbon-shaped (or often called band-like), but are occasionally thread-shaped. The stress birefringence of striae is measured as a path difference in nm as listed in Table 6.

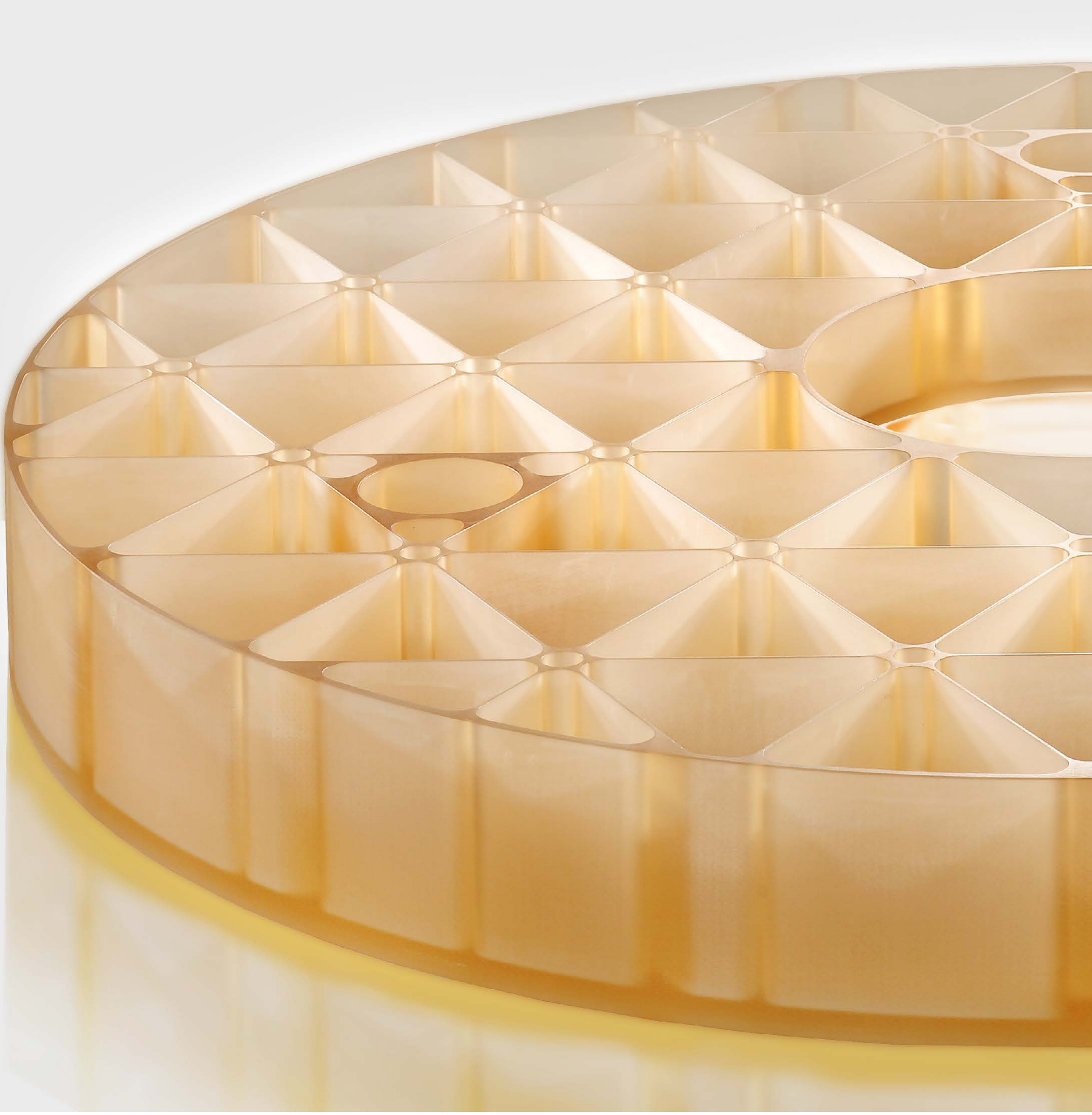
In parts with thicknesses of more than 250 mm, the path difference is expressed in nm/cm striae length and is specified on an individual basis. SCHOTT uses industrial high-resolution imaging polarimeter systems for the measurement.

Stress birefringence caused by striae [nm/striae] for parts with diameters or diagonals	Standard	Class 4	Class 3	Class 2	Class 1
< 500 mm	60	45	30	5	/
< 2000 mm	60	45	30	30	5
< 4000 mm	60	45	30	30	30

Table 6
Quality levels for stress birefringence caused by striae in ZERODUR®

Individual specifications available on request.

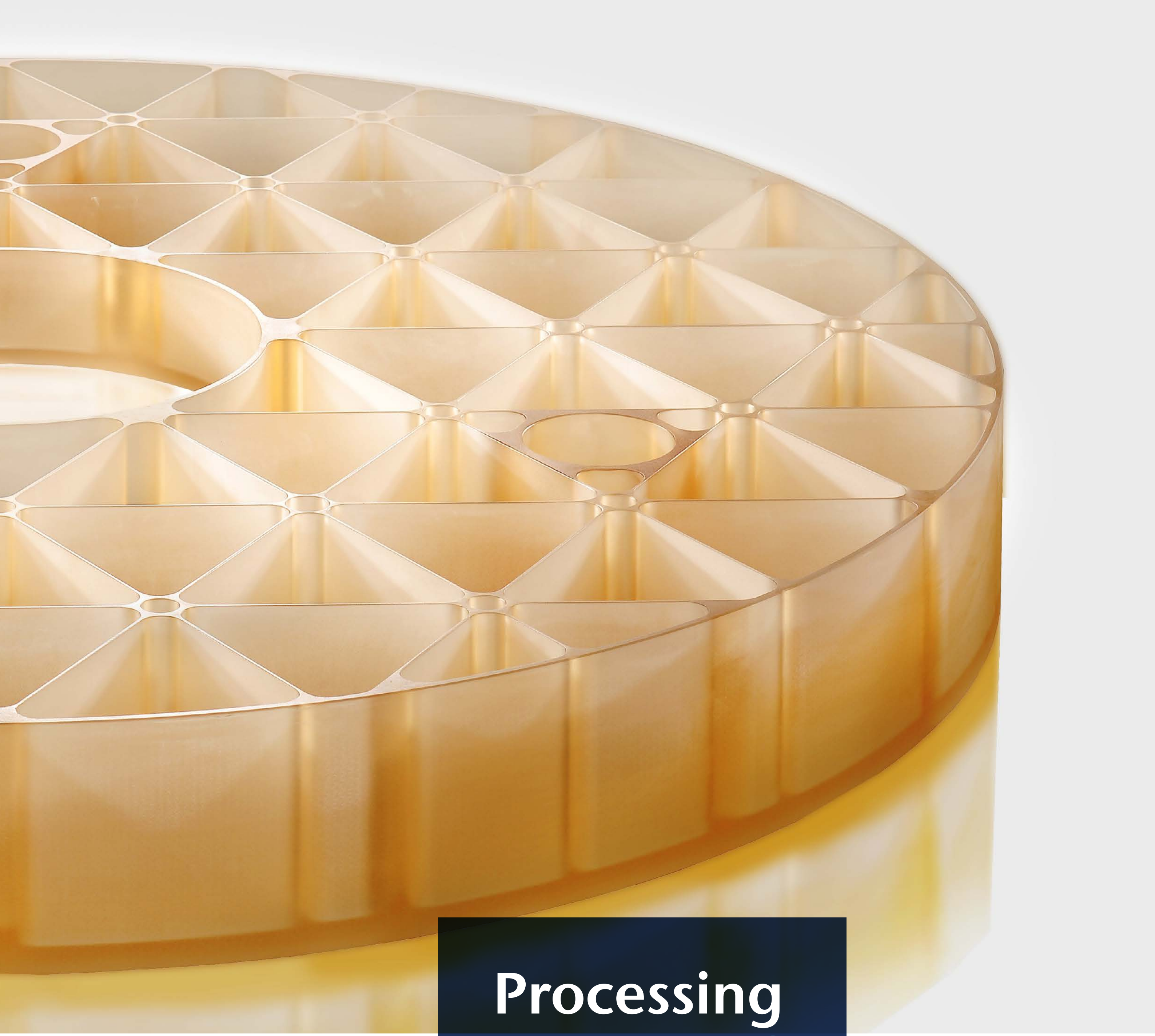
Feel free to send us inquiries on requirements that go beyond the inclusions, striae, and bulk stress specifications mentioned. If no quality is specified in an order, SCHOTT will supply ZERODUR® in standard quality.



SCHOTT provides customized structures according to your technical specifications.

Since production costs can be highly influenced during the design phase, this is the time when SCHOTT's application engineers draw on their long-term expertise in machining ZERODUR®.

The capabilities of the Processing Competence Center enable production of ZERODUR® structures ranging from a few millimeters up to 4.2 meters in diameter.

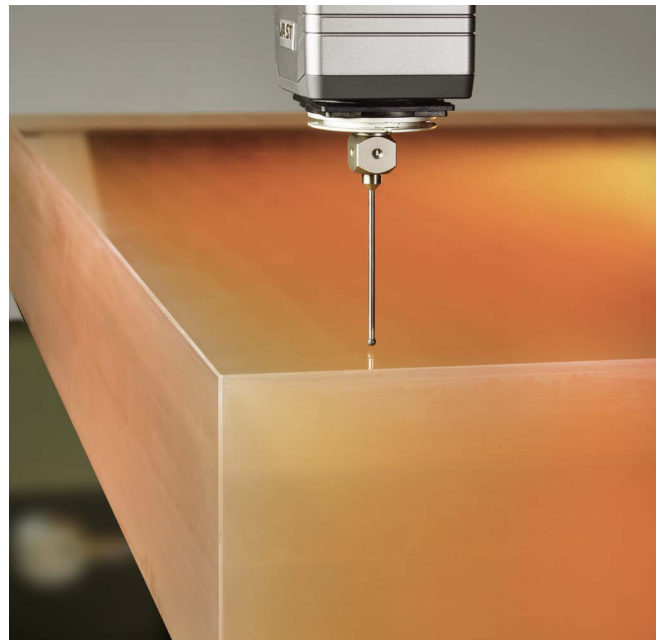


Processing ZERODUR®

SCHOTT's modern machine park consists of over 20 CNC machines with three or more axes that facilitate a wide range of customer requirements (see next page). Our standard diamond grain tools are between D20 and D151, typically resulting in mean surface roughness of Ra < 3.5 µm. Smoother roughness of Ra < 1 µm can be realized with finer grains and different processing parameters upon customer request or based on in-house or external lapping processes.

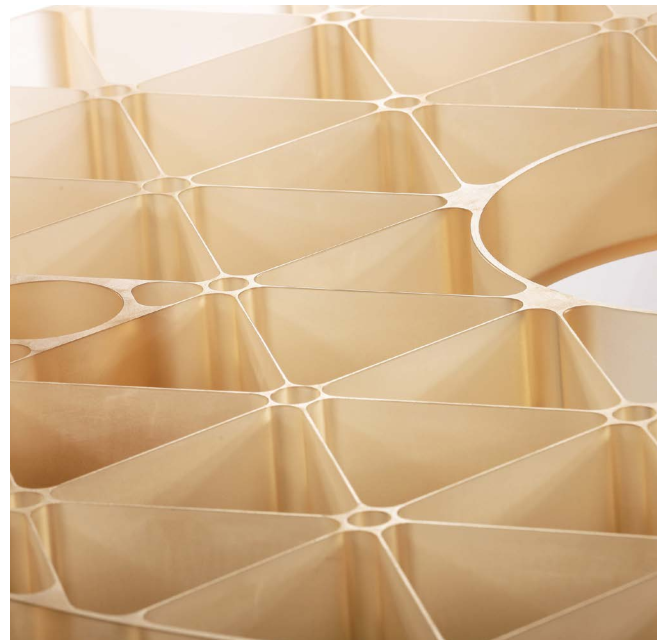
CNC machine capabilities and products for grinding at SCHOTT

With its modern CNC machines, SCHOTT can produce ZERODUR® products in a large variety of different geometrical shapes including holes, blind holes, semi-closed holes, and even free-form surfaces. The realizable tolerances are highly dependent on the geometry and size of the parts.



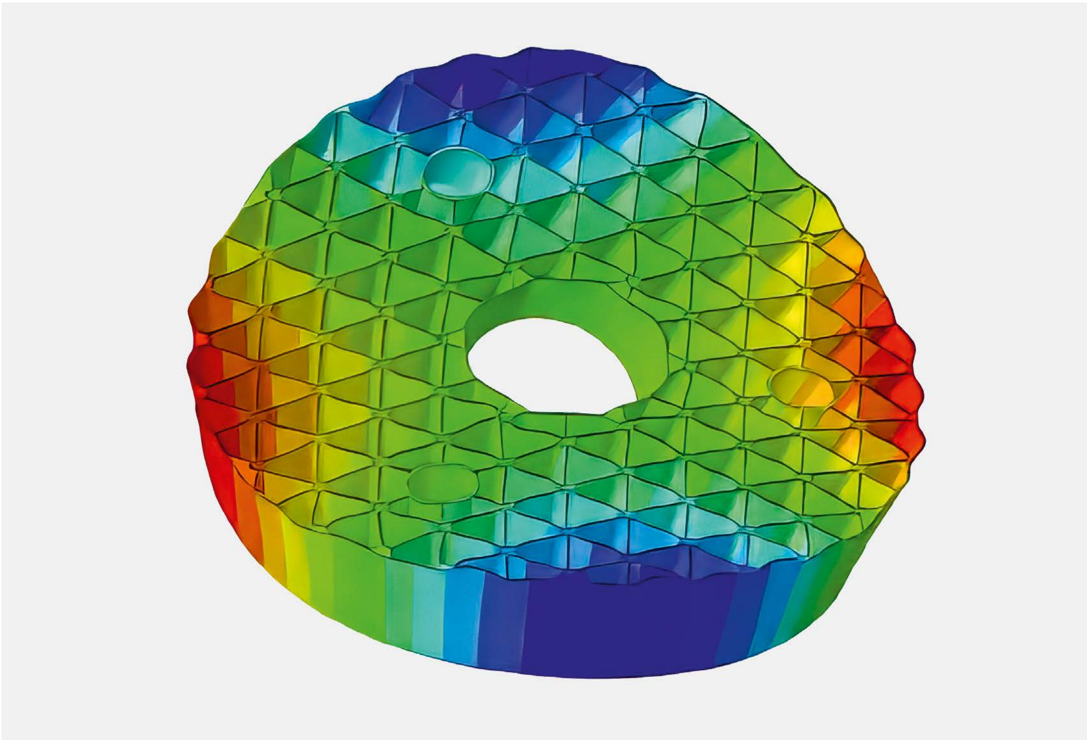
Large and customized parts
5-axis machining center
Traveling distance (L × W × H): 4,500 × 6,000 × 1,300 mm^3
Max. workpiece diameter: 5,000 mm
Max. workpiece weight: 40 t
Tool spindle | Max. spindle speed: 14,000 rpm
Machine control system: Siemens 840D
3-axis positioning accuracy: 0.04 mm
Features: inner and outer cooling, mechanical and vacuum clamping, rotary table

Machining center for medium-sized parts
5-axis machining center
Traveling distance (L × W × H): 2,200 × 2,200 × 1,600 mm^3
Max. workpiece diameter: 2,000 mm (2,600 mm upon request)
Max. workpiece weight: 5 t
Tool spindle | Max. spindle speed: 10,000 rpm
Machine control system: Heidenhain TNC 640
3-axis positioning accuracy: 0.01 mm
Features: inner and outer cooling, mechanical and vacuum clamping, linear table



Small parts processing
3-axis machining center
Traveling distance (L × W × H): 1,100 × 560 x 510 mm^3
Max. workpiece range (L × W × H): 1,000 × 470 × 300 mm
Max. workpiece weight: 50 kg
Tool spindle | Max. spindle speed: 10,000 rpm
Machine control system: Siemens 840D
3-axis positioning accuracy: 0.01 mm
Features: inner and outer cooling, mechanical and vacuum clamping, linear table

Highly precise grinding operations
5-axis machining center
Traveling distance (L × W × H): 1,310 ×1,250 × 600 mm^3
Max. workpiece range (L × W × H): 1,250 × 1,200 × 600 mm
Max. workpiece weight: 2.5 t
Tool spindle | Max. spindle speed: 12,000 rpm
Machine control system: Heidenhain TNC 640
3-axis positioning accuracy: 0.01 mm
Features: inner and outer cooling, mechanical and vacuum clamping, swiveling & rotary table



FEM eigenfrequency simulation of a typical lightweight design (left)

The ZEISS MMZ-G coordinate measurement machine with a reference mirror for internal standard measurement (right)

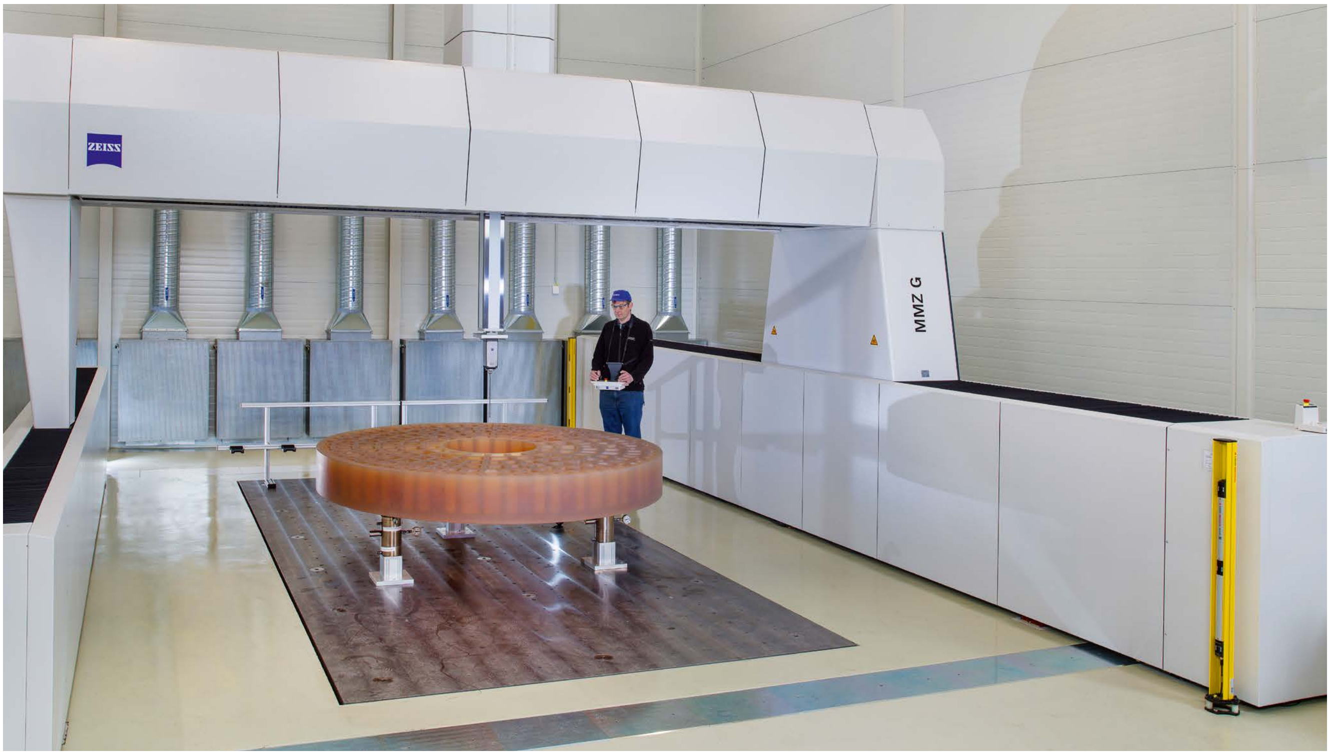
ZERODUR® lightweighting

One of SCHOTT's key capabilities is producing lightweight structures, which is particularly useful in large mirror substrates for space applications. SCHOTT is continuously improving in terms of ZERODUR® processing, which also allows to achieve challenging aspect ratios of pocket height to rib thickness. This results in high robustness while meeting the mass requirements of the customers. Lightweighting factors above 90% are possible, and application engineers support the design of the mirror substrates using the finite element analysis (FEA).

All parts are supplied with bevels on all sharp edges to prevent edge damage. SCHOTT offers acid-etching of the the lightweight structures using a well-established process of removing sub-surface damage. Areas that should not be etched, like optical surfaces, can be masked during the process.

Given the material's brittleness it is not feasible to create threads directly within it. Instead, it is recommended to bond threaded metal inserts into the ZERODUR® component.

In addition to CAD/CAM assistance, SCHOTT's application engineers also support the design and manufacturing of transport boxes and ZERODUR® handling tools.



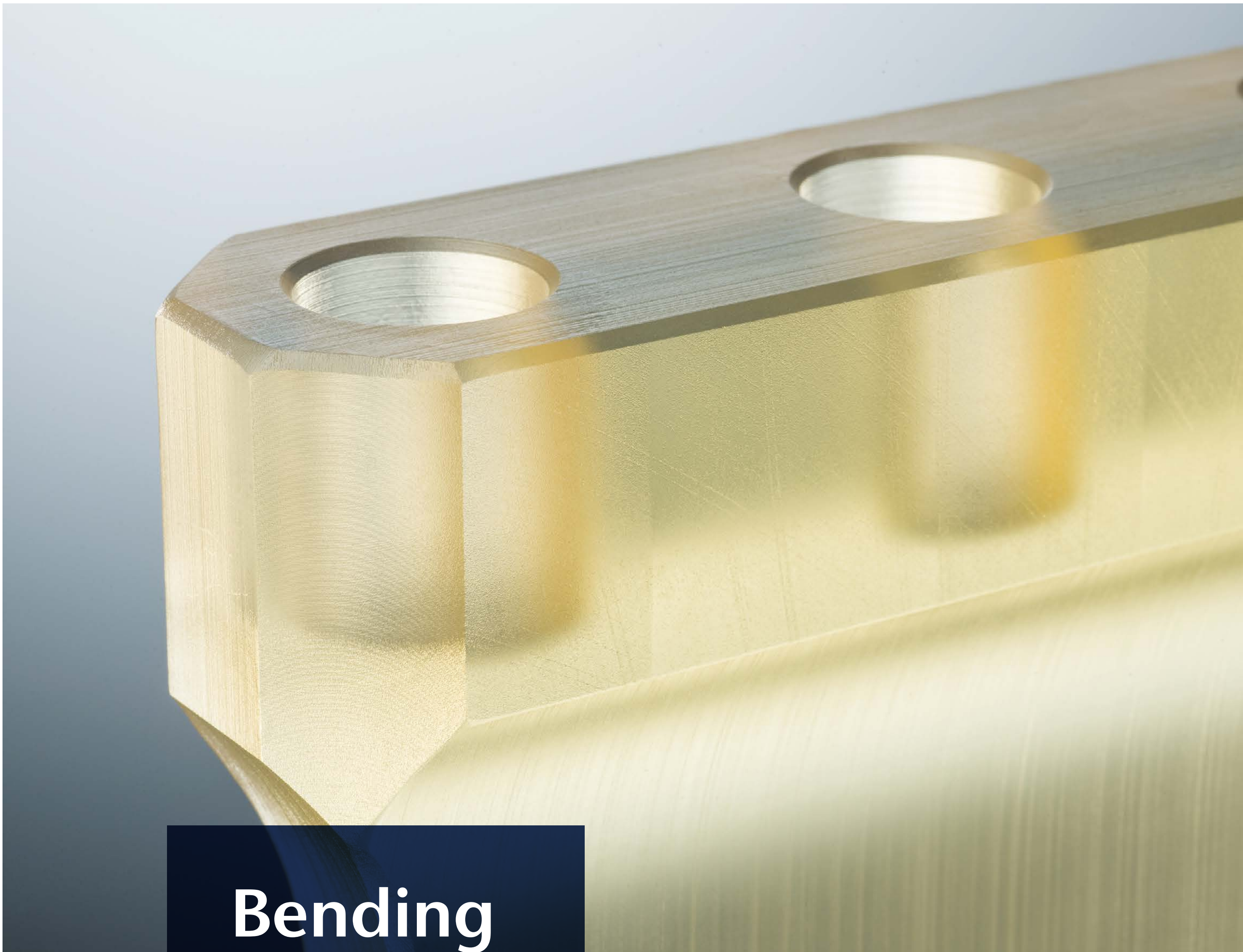
High-precision CMM measurements:

SCHOTT's extensive CMM capabilities can verify geometrical product specifications in a wide range. In addition to several ZEISS PRISMO systems for smaller geometries, large volume parts can be measured with a ZEISS MMZ-G and a Leica mobile laser tracker.

The ZEISS MMZ-G has a travel distance of 5 × 6 × 2 m (X × Y × Z). All measuring tasks are programmed and performed by the universal software ZEISS CALYPSO.

Extremely precise tactile measurement with length tolerance

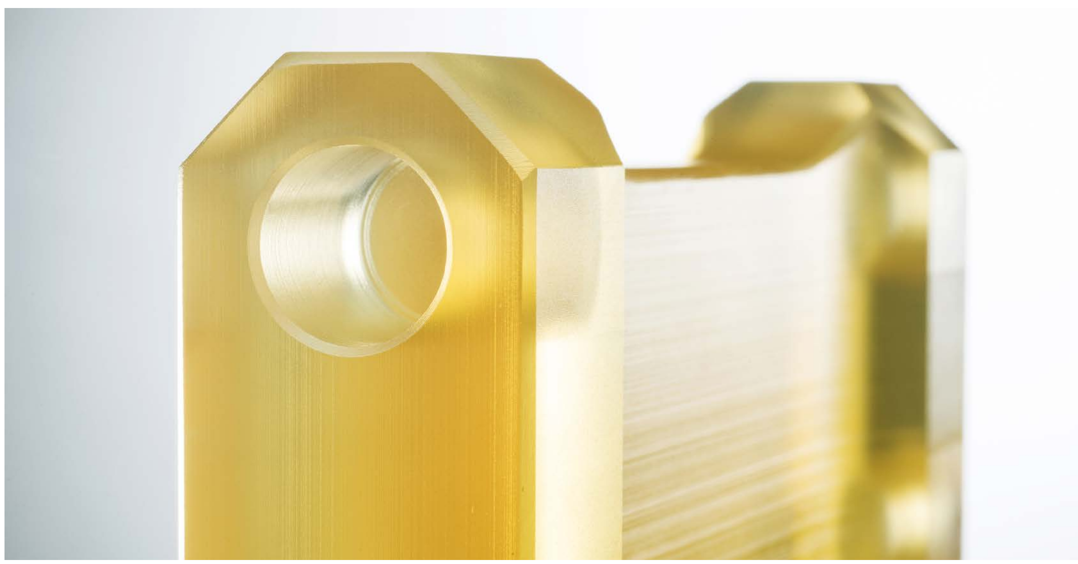
≤ 1.0 µm + L/1500 mm



Bending strength

Extensive data on the strength of ZERODUR® glass-ceramic

The bending strength of glass and glass-ceramic is not a material constant. It mainly depends on the amount of sub-surface damage after surface finishing, the loading geometry, and the environmental conditions of the specific part in its intended application. The maximum sub-surface damage depth determines the load that a specific part can endure in regions of tensile stress. This is reflected in the probabilistic approach of the Weibull distribution determining a breakage stress threshold.

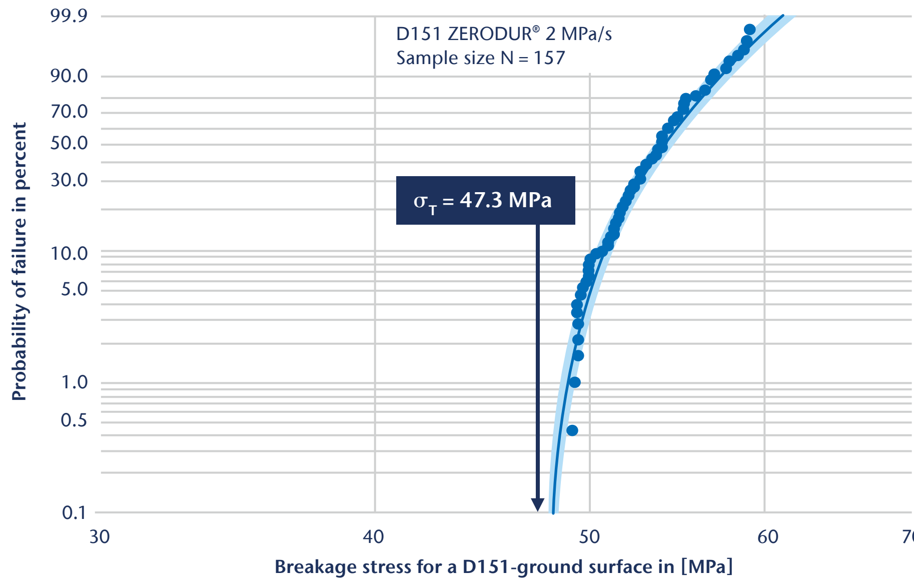


The breakage stress results for the investigated ZERODUR® samples follow the statistical three-parameter Weibull distribution. Below the threshold stress, failure probability approaches zero. The Weibull parameters for different surface conditions prepared with SCHOTT grinding processes and further information on the bending strength of ZERODUR® glass-ceramic can be found in the literature[1].

[1] Hartmann, Minimum lifetime of ZERODUR® structures based on the breakage stress threshold model: a review, in “Optical Engineering Vol. 58 Issue 2”, 2019, https://doi.org/10.1117/1.OE.58.2.020902

For a D151-ground surface, the breakage stress threshold is 47.3 MPa according to the three-parameter Weibull fit (Figure 5). Finer grinding and etching an appropriate thickness of surface layer increases the threshold significantly.

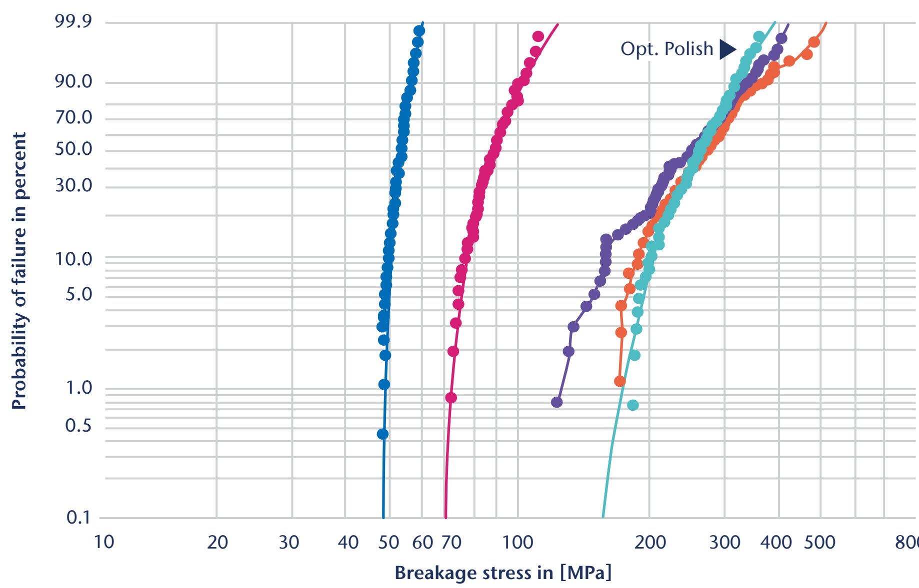
Figure 5
Breakage stress investigations: Probability of failure as a function of breakage stress when 2 MPa/s are applied



For surfaces ground with diamond grain sizes between D151 (coarse grain, dark blue) and D25 (fine grain, pink), a threshold value can be found between 40 to 70 MPa (Figure 6, left side of the diagram). The right side of the diagram shows the distribution of D151- and D64-ground and subsequently acid-etched: The EXX denotes a layer of XX µm etched off. Taking off a layer of 83 µm thickness per surface increases the strength to above 100 MPa. For more details, please refer to the literature.[1]

Figure 6
D64 and D151 are diamond grain size distributions; the E-value delineates the µm etched off

Sample	N	Min.	Max.
D151	157	49.1	59.2
D25	86	70.7	112.0
D151 E83	91	124.7	405.8
D64 E73	65	172.9	486.5
Opt. polish	93	185.5	364.4



The fatigue impact of subcritical microcrack growth is defined by the stress corrosion constant, which is reliably known for ZERODUR® under key environmental conditions such as normal humidity, dry, and extremely dry. The availability of data from breakage stress samples enables the calculation of lifetime, taking into account the fatigue effect.

Employing the threshold stress allows for the calculation of minimum lifetimes, disregarding any premature failures. This is applicable for surfaces devoid of extra scratches or defects, which are not characteristic of the surface preparation process. The validity of this minimum life-time calculation method is backed by long-term measurement data.

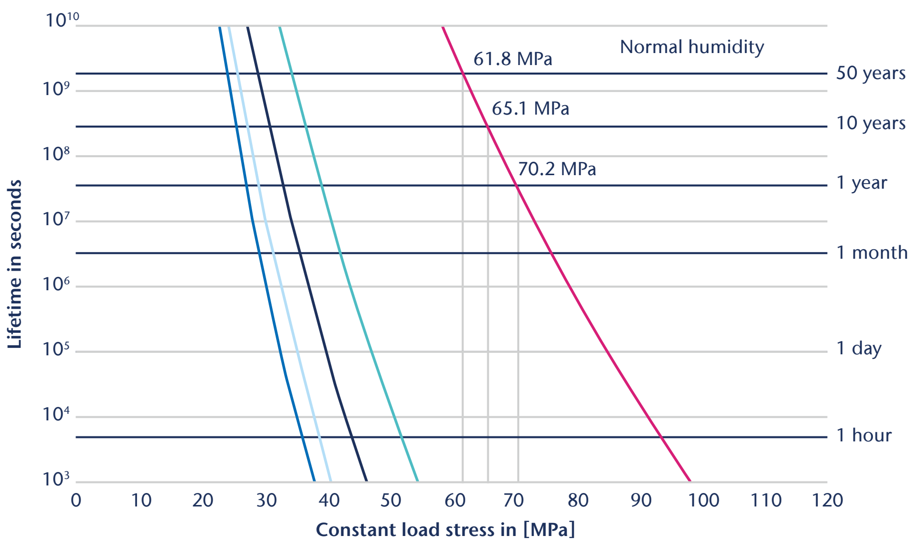
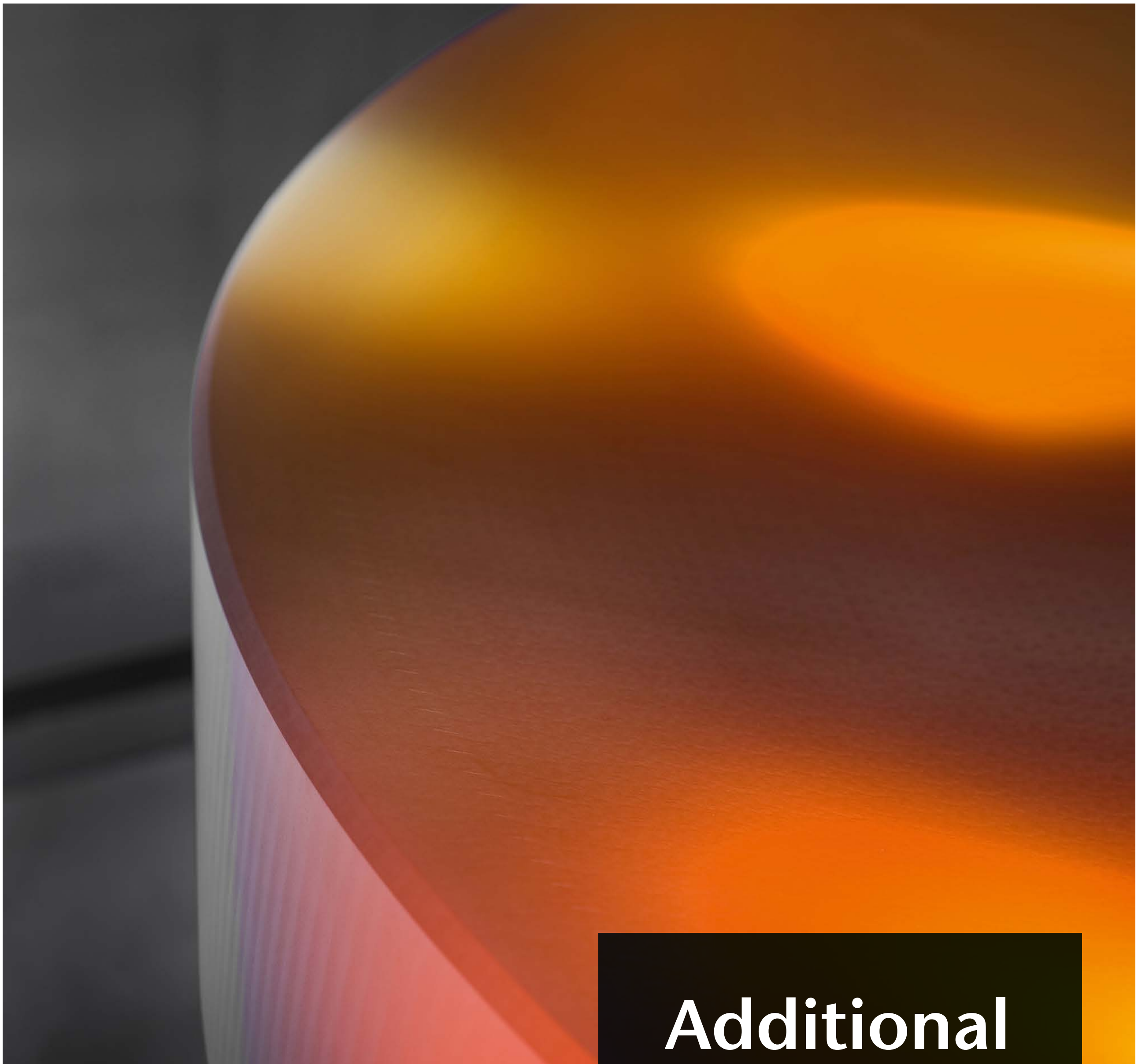


Figure 7
Durability under conditions of normal humidity of ZERODUR® components, processed using four distinct grinding tools (D151, D46, D35, D25), and subsequently ground and etched

D151 = 47.3 MPa
D46 = 51.0 MPa
D35 = 57.4 MPa
D25 = 67.7 MPa
Etched = 120.0 MPa

[1] Hartmann, Minimum lifetime of ZERODUR® structures based on the breakage stress threshold model: a review, in "Optical Engineering Vol. 58 Issue 2", 2019, https://doi.org/10.1117/1.OE.58.2.020902



Additional properties

Inertness

At ambient temperature, ZERODUR® surfaces remain unaffected by acids (except hydrofluoric acid), alkalis, salts, and dye solutions, leaving no residual traces after a duration of 170 hours. However, concentrated sulfuric acid can damage the material at elevated temperatures. Building and insulation materials such as mica, chamotte, MgO, and SiO_2 exhibit negligible reaction with ZERODUR® even at temperatures up to 600°C after a period of 5 hours.

Coatings

Substrates of ZERODUR® can be coated with metals and dielectric materials, among others. Owing to its robust chemical resistance, the mirror coating can be repeatedly stripped off. The polished surface is amenable to cleaning and re-coating.

Mechanical, optical, and chemical properties

Table 7
Mechanical, optical, and chemical properties of ZERODUR®

	ZERODUR®
Thermal conductivity λ at 20°C [W/(m · K)]	1.46
Thermal diffusivity index a at 20°C [10^{-6} m^2/s]	0.72
Heat capacity cp at 20°C [J/(g · K)]	0.80
Young's modulus E at 20°C [GPa]-mean value	90.3
Poisson's ratio	0.24
Density [g/cm^3]	2.53
Knoop Hardness HK 0,1/20 (ISO9385)	620
Refractive index n_d	1.5424
Abbe number ν_d	56.1
Internal transmittance at 580 nm	
5 mm thickness	0.95
10 mm thickness	0.90
Stress optical coefficient K at λ = 589.3 nm [10^{-6} MPa^{-1}]	3.0
Hydrolytic resistance class (ISO 719)	HGB 1
Acid resistance class (ISO 8424)	1.0
Alkali resistance class (ISO 10629)	1.0
Climate resistance	Class 1
Stain resistance	Class 0
Electrical resistivity ρ at 20°C [Ω · cm]	$2.6 \cdot 10^{13}$
T_{k100} [°C], Temperature for ρ = 108 [Ω · cm]	178
Helium permeability [atoms/(cm · s · bar)]	
at 20°C	$1.6 \cdot 10^{6}$
at 100°C	$5.0 \cdot 10^{7}$
at 200°C	$7.2 \cdot 10^{8}$

A plus in sustainability

Environmental protection has been one of SCHOTT's key corporate goals for decades. Time and again, we have set new sustainability standards in the glass industry.

Shaping a sustainable future

We know that shared responsibility and close collaboration produce innovative solutions. As a foundation company, we are aware of our influence on sustainable development. As early as 1896, our founders Otto Schott and Ernst Abbe made responsibility for our employees and their families, for our society, and for science an integral part of our corporate culture.

We are committed to this task with conviction. We are already thinking about tomorrow today. As a global innovative Group in the field of materials technology, we find new ways to shape a better future – for our partner companies, and society.

WINNER
German Sustainability Award Company 2024

GOLD 2023 ecovadis Sustainability Rating

ENERGY EFFICIENCY AWARD 2022 by dena
WINNER
Concepts for a climate-neutral future

Clear commitment to the goals of the UN

We are committed to the United Nations' 17 global Sustainable Development Goals (SDGs). They cover social, environmental, and economic aspects that the global community wants to achieve by 2030 for a more sustainable and peaceful future. We are focusing on four goals in which we can make the greatest contribution:

3 GOOD HEALTH AND WELL-BEING

5 GENDER EQUALITY

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

Would you like to learn more about our commitment to sustainability? Visit our website: **schott.com**

Contact us!

Let us know how we can be a plus for your future.

Technical publications

All of our technical information, certifications, datasheets, and publications are also available on our website. Please scan the QR code or find them at **schott.com**!

ZERODUR® homepage

Scan our codes to find an overview!

Safety datasheets

Contact

If you have any questions, please contact us at **+49 (0)6131/66-1812** or via email **info.optics@schott.com**

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