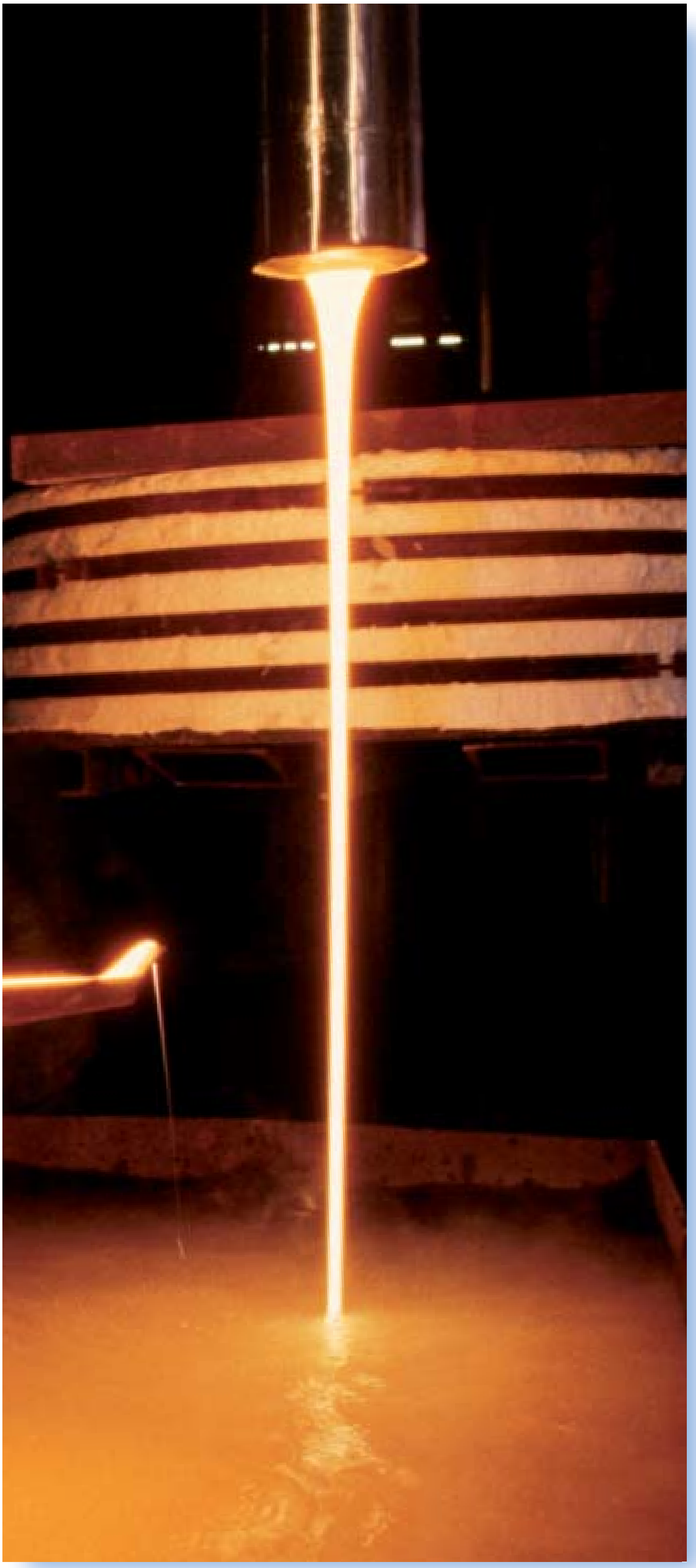
# ZERODUR® Glass Ceramic

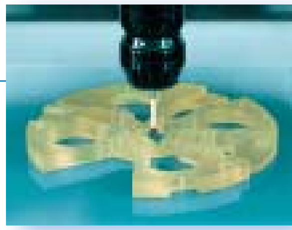
Temperature stable precision and quality in series

SCHOTT
glass made of ideas

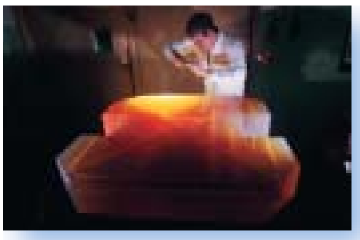


# Contents









# 1. ZERODUR has Extraordinary Properties

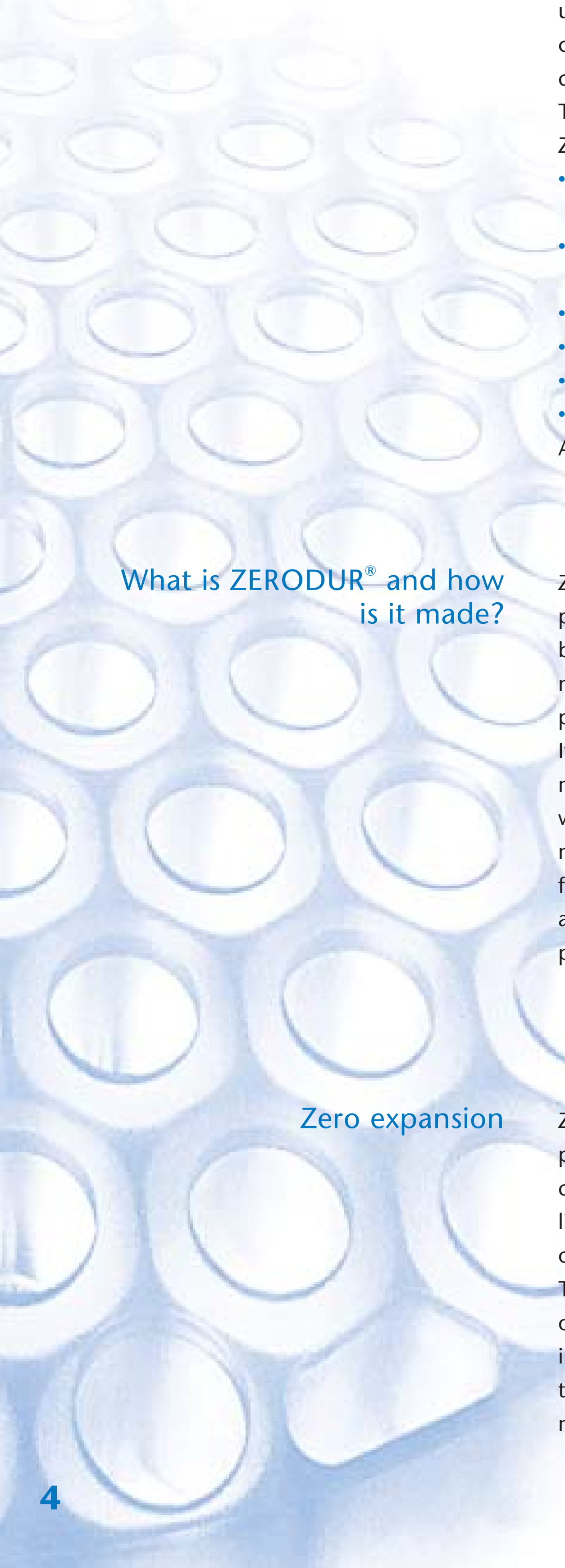
ZERODUR® is a zero expansion glass ceramic with extraordinary properties. It is widely used in applications where unavoidable temperature changes could influence critical size and distance accuracies.

The most important properties of ZERODUR® are:

- an extremely low thermal expansion coefficient
- excellent homogeneity of thermal expansion
- high internal quality
- good workability
- polishable to a high accuracy
- excellent chemical stability

All these properties can be realized in small components as well as in parts with weights of several tons with extraordinary reproducibility. Hence ZERODUR® has become a performance- and quality-determining factor in many spectacular applications within modern technology:

- Optical elements for lithography equipment
- High precision mechanical parts
- Mirror substrates for large astronomical telescopes
- Standards for precision measurement technology
- Mirror substrates for X-ray telescopes, weather satellites and comet probes



## What is ZERODUR® and how is it made?

ZERODUR® is an inorganic, non-porous glass ceramic, characterized by a phase of evenly distributed nano-crystals within a residual glass phase.

It is produced using methods common in modern glass technology, whereby suitable raw materials are molten, refined, homogenized and finally hot formed. After subsequent annealing, stress relaxation and first processing of the glassy blank a precise ceramization process follows, during which the glass is transformed into a glass ceramic through controlled volume crystallization. During this temperature treatment nuclei form within the glass and crystals subsequently grow at a somewhat higher temperature.

ZERODUR® owes its special properties to the exact balance of these glass and crystal phases.

## Zero expansion

ZERODUR® contains 70-78 weight percent crystalline phase with a high quartz structure. This has a negative linear thermal expansion, while that of the glass phase is positive.

The volumetric content and the size of the nano – crystallites is adjusted in such a way during the ceramization process that the positive thermal expansion of the remaining glassy phase and the negative thermal expansion of crystallites effectively neutralize each other.

This results in an extremely low thermal expansion behavior, which in certain temperature ranges varies around zero, depending on the ceramization sequence employed.

## Homogeneity and quality in large quantities

The ZERODUR® manufacturing sequence is based on established and proven methods used in the production of high homogeneity optical glasses. Therefore ZERODUR® itself is a material of the highest homogeneity, and even in large pieces with dimensions of several meters exhibits thermal and mechanical characteristics with nearly unmeasureable deviations. Optimized melting, casting and annealing procedures are the requirements to produce ZERODUR® in high quantities with reproducable excellent quality.

*A 2-meter mirror blank casting is transported into the annealing furnace.*

## ZERODUR®, unusual in its properties, easy to fabricate

ZERODUR® has a completely non-directional, isotropic structure, and possesses a non-porous surface. Crystalline and glass phases have chemical characteristics and hardness similar to those of optical glass so that ZERODUR® can be processed using the same machines and tools as optical and technical glasses (for example: cutting, grinding and polishing).

## ZERODUR® versatile in application

Mirror substrates and other important optical components of ZERODUR® allow precise imaging of structures in microlithography.
In mechanical applications, ZERODUR®'s unusual linear thermal stability allows precise adjustment of important components.
ZERODUR® is the ideal mirror substrate for astronomical telescope mirrors and x-ray telescopes of all sizes  where any lack of thermal stability would adversely influence image quality and system resolution.
ZERODUR® assures that better optical performance can be achieved using smaller and lighter mirrors.
In several 10 m-class telescope projects, SCHOTT has proven its ability to deliver high quantities of mirror blanks in the 1 to 2 m diameter range reliably and with a consistently high quality level. These are critical points for the construction of future extremely large telescopes with segmented mirrors of 20 to 100 m diameter.
For ring laser gyroscopes ZERODUR® forms the temperature-independent frame, whilst it's low helium permeability provides long life.

# 2. Thermal Properties

The most important and significant properties of the glass ceramic ZERODUR® are the extremely small coefficient of linear thermal expansion as well as the homogeneity of this coefficient throughout the entire piece.

## Mean coefficient of linear thermal expansion

Individual pieces of ZERODUR® can be supplied with a mean coefficient of linear thermal expansion α in the temperature range 0°C to 50°C in three expansion classes as follows:

| | |
|---|---|
| Expansion class 0 | $0 \pm 0.02 \cdot 10^{-6}$/K |
| Expansion class 1 | $0 \pm 0.05 \cdot 10^{-6}$/K |
| Expansion class 2 | $0 \pm 0.10 \cdot 10^{-6}$/K |

If not otherwise expressly specified, expansion class 2 material will be supplied. Closer tolerance will be supplied upon request.

Figure 1 illustrates the typical coefficient of linear thermal expansion α. ZERODUR® exhibits a very slight linear expansion over the entire temperature range. It is especially low near room temperature range.
The measurement accuracy for α in the temperature range of 0°C to 50°C is $\pm 0.01 \cdot 10^{-6}$/K, the repeatability of the single measurement is $\pm 0.005 \cdot 10^{-6}$/K (95% confidence level). Single measurements with increased repeatability can be carried out upon request.

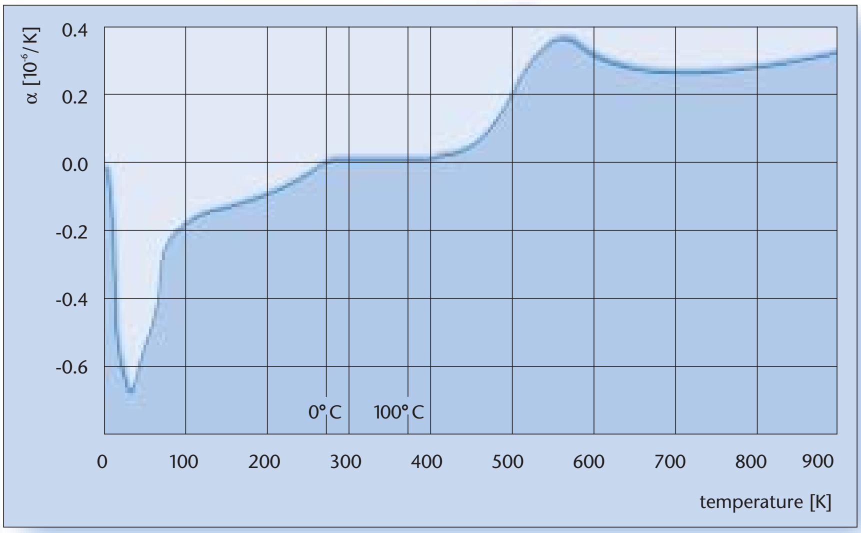



*Figure1: Curve of coefficient of linear thermal expansion of ZERODUR® as a function of temperature*

## Homogeneity of the coefficient of thermal expansion

Figure 2 shows an evaluation of the homogeneity of the coefficient of linear thermal expansion for more than 200 ZERODUR® mirror blanks. The diagram shows the frequency of the deviation of single measurements, taken evenly distributed on the mirror blanks, from the mean value of the blank. 95.5% of the single measurements are located in the range of $\pm 0.007 \cdot 10^{-6}$/K around the mean value. This range is only slightly larger compared to the range given by the repeatability of the single measurement. Therefore the actual homogeneity of ZERODUR® is in many cases better than the limits of the dilatometer measurement.

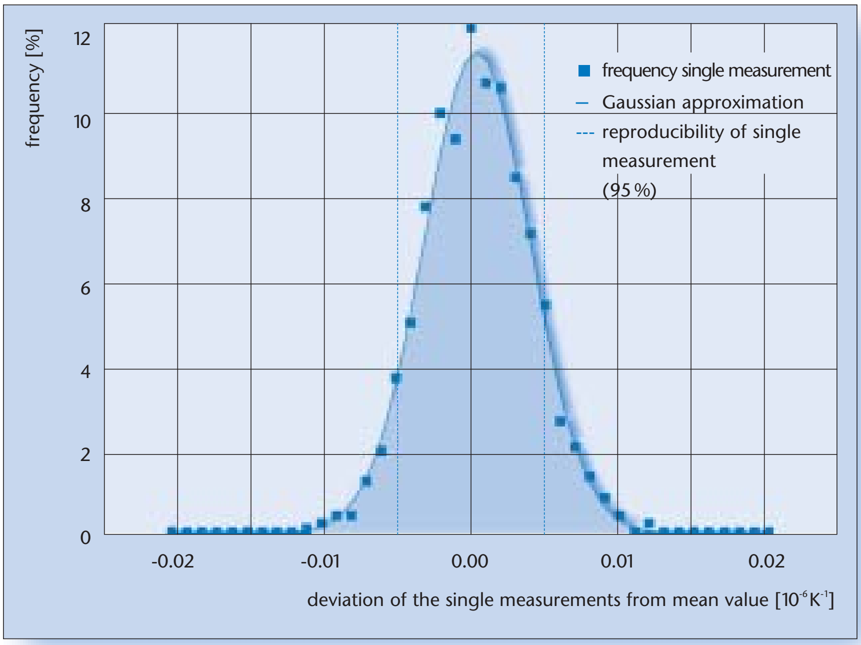



*Figure 2: Homogeneity of the linear thermal expansion coefficient: Single measurements of more than 200 mirror blanks with sizes from 1 to 2 m.*

The stated tolerances for homogeneity of linear expansion can be guaranteed in the following weight classes for each part, provided that the diameter of the part is at least twice its thickness:

| | |
|---|---|
| up to 18.0 tons | $\leq 0.03 \cdot 10^{-6}$/K |
| up to 6.0 tons | $\leq 0.02 \cdot 10^{-6}$/K |
| up to 0.3 tons | $\leq 0.01 \cdot 10^{-6}$/K |

## Total change of length is a specified temperature interval

In certain applications, the total change of length of a ZERODUR® part within a specified temperature interval is vital to its function (such as laser gyroscopes). In the region of -50°C to +100°C, the total change in length is usually smaller than $10 \cdot 10^{-6}$, based on the total length of the part.
Upon request, ZERODUR® can be supplied with smaller values. Figure 3 shows the typical relative expansion in length Δl/l of ZERODUR® relative to 0°C. The measurements were performed by CSIRO (National Measurement Laboratory in Sydney, Australia) in the temperature range 2 K to 125 K and made by Schott in the temperature range of 90 K to 900 K.

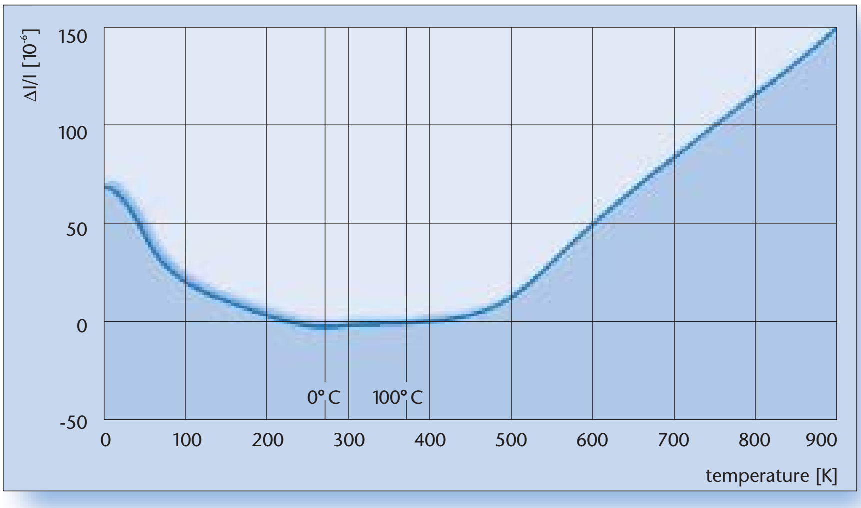



*Figure 3: Relative linear expansion Δl/l of ZERODUR®*

## Thermal conductivity

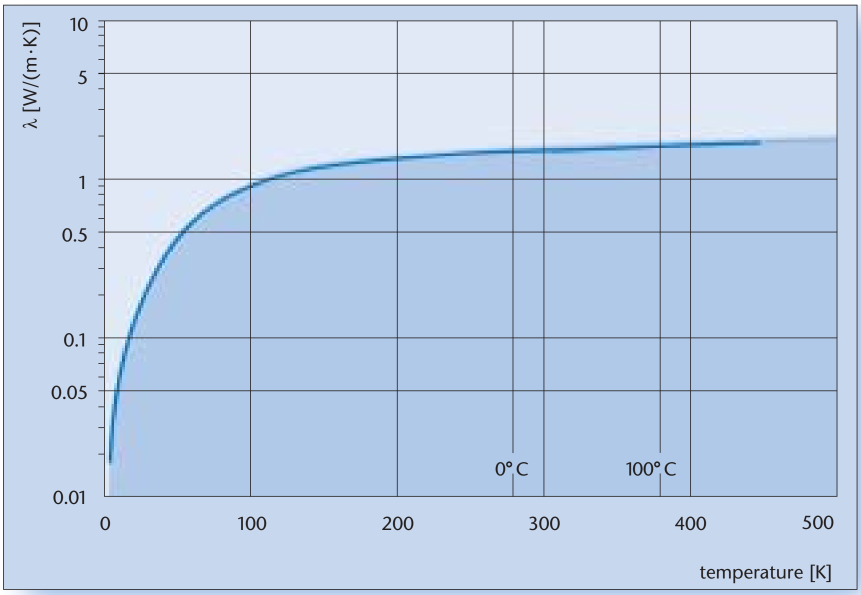



*Figure 4: Thermal conductivity of ZERODUR® as a function of temperature.*

| | |
|---|---|
| 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 |

## Specific heat capacity

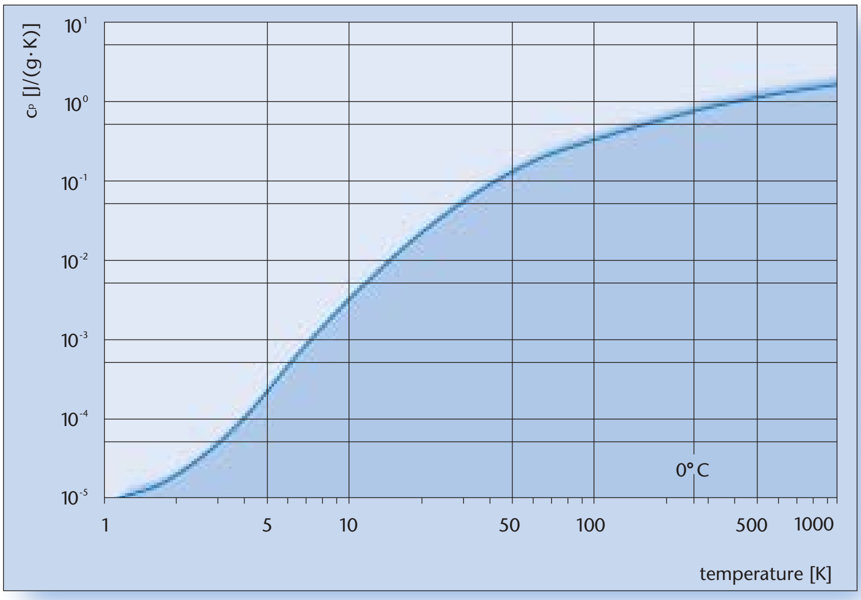
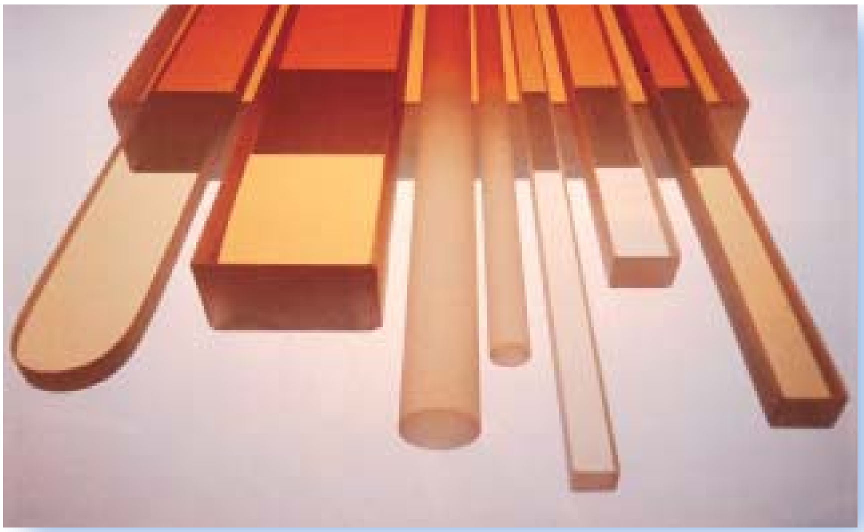



*Figure 5: Specific heat capacity of ZERODUR® as a function of temperature*

| | |
|---|---|
| Specific heat capacity $c_p$ at 20°C [J/(g·K)] | 0.80 |



*Different substrates for precision measurement applications*

## Maximum application temperature

ZERODUR® may be used as a mechanical component as well as a window at temperatures up to 600 °C.
Slight changes may arise in the linear thermal expansion coefficient α (0°C, 50°C) that can affect components of the highest optical precision, due to temperature treatments by the customer or user. If the final cooling rate $R_E$ differs from the initial cooling rate $R_P$, especially in the temperature range of 320°C to 130°C, the change of the linear thermal expansion coefficient α (0°C, 50°C) can be estimated by using the following equation:

$$\Delta\alpha(0°C, 50°C) = 0.025 \cdot \log_{10}\left\{\frac{R_E}{R_P}\right\} 10^{-6}/K$$

ZERODUR® is typically cooled during production at an initial cooling rate between 1°/h and 6°/h.
The linear thermal expansion coefficient does not change when cooling from temperatures above 320°C are carried out at the same rate as the initial cooling. The glass ceramic ZERODUR® can be subjected to temperature treatments up to 130°C without causing changes in the linear thermal expansion coefficient α (0°C, 50°C).

## ZERODUR® M

For highly precise thermal expansion requirements we strongly recommend the avoidance of cooling rates other than the above initial cooling rate in the critical temperature region during processing.
If a customer cannot influence the cooling rate, we recommend considering the use of ZERODUR® M, a material variation of ZERODUR®.

# 3. Internal Quality

The internal quality of ZERODUR® is essentially determined through

- Inclusions
- Bulk stress
- Striae

## Inclusions

Inclusions in ZERODUR® cannot be completely avoided. As a rule they are mainly bubbles and to some extent individual particles. They have no effect on the function of ZERODUR® as a substrate material for surfaces of the highest quality insofar as they lie completely within the volume. The probability that individual inclusions lie in the optically finished mirror surface is very low. Specifying the volume range in which the final functional surface lies can further reduce this slight risk. When stating this critical volume, ZERODUR® parts are selected and processed in such a way that more stringent requirements are met. During testing of ZERODUR® parts all inclusions with a diameter > 0.3 mm are considered. If an inclusion has a shape other than spherical, the average diameter is reported as the mean of the length and width.
Inclusions in ZERODUR® are distinguished by the designations "Standard" and Classes 0 to 4. The tolerances of these quality levels are listed in table 1:

| | Standard | 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 |

*Table 1: Quality levels for inclusions in ZERODUR®*

## Bulk stress

All ZERODUR® parts are subjected to precision optical annealing in order to achieve a permanent bulk stress, which is both low and symmetrically distributed.
Bulk stress causes optical birefringence which is measured and expressed as an optical path difference. The measurement of the path difference is performed in axial direction for discs and rods at 5% of the diameter from the edge. For rectangular plates, the measurement is performed in the middle of the longer side perpendicular to the plate's surface. The edge distance is 5% of the plate width.
Bulk stress is listed in two quality levels for different size classes of ZERODUR® parts in table 2.

| 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 |

*Table 2: Quality levels for bulk stress in ZERODUR®*

## Striae

Striae are local, very limited transparent regions with composition differing only slightly from the basic material. They are generally ribbon shaped (or often called bandlike), sometimes thread shaped.
The striae quality of ZERODUR® is tested by the stress optical method and is listed as an optical path difference in nm for thread-like striae.
The striae ranges listed in table 3 are maximum values for 5 quality levels for different dimensions and diagonals of ZERODUR® parts.
For ribbon-shaped striae, the optical path difference is given in nm/cm striae length and the quality levels in table 4 are valid.
For strict requirements, an extremely sensitive shadowgraph technique is used that allows fine visible striae to be found in the test direction.

| Stress birefringence caused by striae [nm/stria] 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* |

* Only applies to the critical volume in the area of the operating surfaces.
All others as with class 4 quality.

*Table 3: Quality levels for stress birefringence caused by striae in ZERODUR®*

| Stress birefringence caused by striae [nm/cm length of stria] for parts with diameters or diagonals | Standard | Class 4 | Class 3 | Class 2 | Class 1 |
|---|---|---|---|---|---|
| < 500 mm | 2.5 | 2 | 1.5 | 0 | 0 |
| < 2000 mm | 2.5 | 2 | 1.5 | 1 | 0 |
| < 4000 mm | 2.5 | 2 | 1.5 | 1 | 0 |

*Table 4: Quality levels for stress birefringence caused by ribbon shaped striae in ZERODUR®*

## Special requirements (higher quality level)

We invite inquiries for requirements that go beyond the mentioned inclusion, striae, and bulk stress specifications. If no quality is specified upon order entry, ZERODUR® is supplied in standard quality.

# 4. Mechanical Properties

## Length stability over time

Since 1973, 400 mm long gauge blocks maintained at 20°C made from ZERODUR® have been interferometrically connected to a wavelength standard at the PTB (Physikalisch-Technische Bundesanstalt, Germany). Interpolation formulas that have been derived from previous measurements on the basis of theoretical consideration allow predictions to be made for the expected change in the length of ZERODUR® relation to time.
In a formal analogy to the thermal linear expansion coefficient $\alpha$ the following applies:

$$l = l_o \, (1 + A \cdot \Delta t)$$

The value of A is always negative for isothermal storage, indicating shrinkage over time. It depends on the cooling process and on the age of the sample and has an order of magnitude $|A| < 10^{-7}$ per year.

## Young's modulus E

The Young's modulus for a typical melt is shown in figure 6 as a function of temperature.

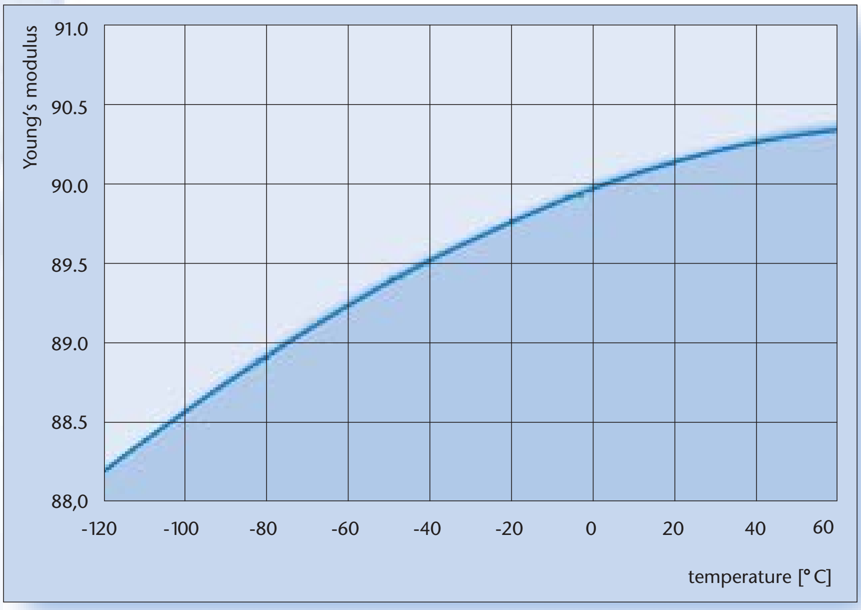



*Figure 6: The Young's modulus of ZERODUR® as a function of temperature*

| | |
|---|---|
| Young's modulus E at 20°C [GPa]-mean value | 90.3 |

## Bending strength

The practical bending strength of glasses and glass ceramics is not a material constant. It is particularly dependent upon the following factors:

- Micromechanical condition of the tension loaded surfaces
- Size of the tension loaded surfaces subjected to stress
- Rate of load increase
- Surrounding medium, usually air

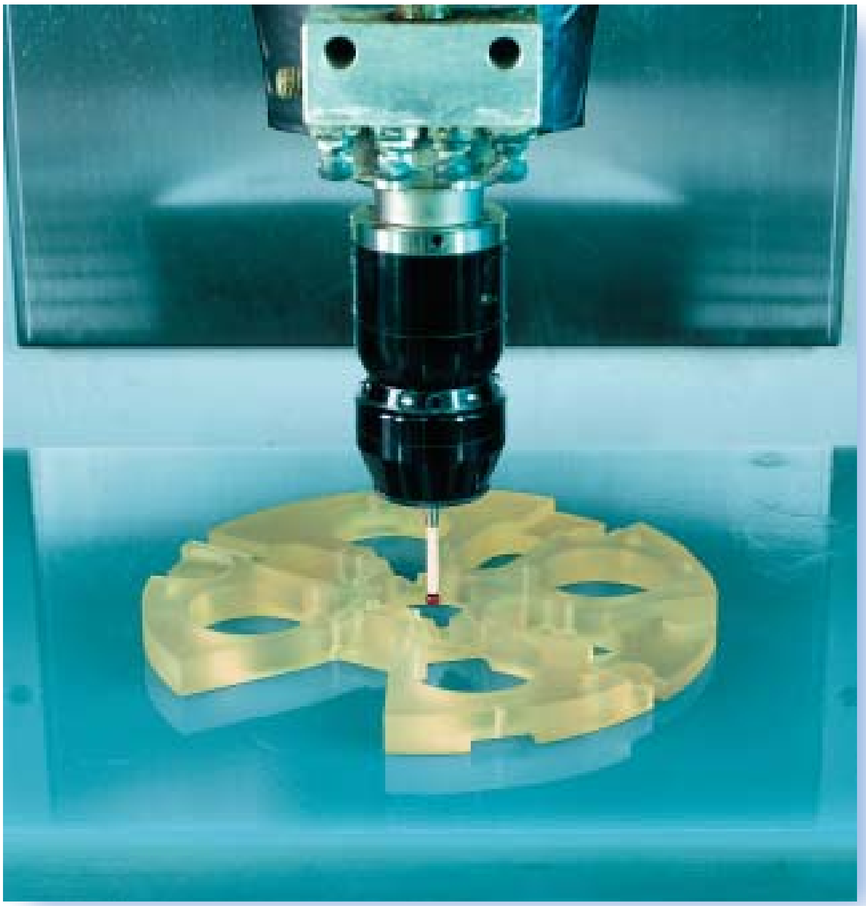
Owing to the statistical nature of strength experiments, bending strength is listed as a failure probability. The Weibull distribution is an established tool for the description of the failure probability.

Measurement results for different surface conditions and further information on the bending strength of ZERODUR® are available on request.

In many applications, a tensile stress of 10 MPa can be assumed as a limiting value. This applies, for example, to small objects with scratch-free surfaces.

## Other mechanical characteristics

| | |
|---|---|
| Poisson's ratio $\mu$ | 0.243 |
| Density $\rho$ [g/cm$^3$] | 2.53 |
| Knoop Hardness HK 0.1/20 according to ISO 9385 | 620 |



*Measurement head of a high precision grinding machine for complex structures*

# 5. Optical Properties

## Refractive indices, Abbe number

| Wavelength [nm] | Designation | Refractive index n | Abbe number ν |
|---|---|---|---|
| 656.3 | C | 1.5394 | |
| 643.8 | C′ | 1.5399 | |
| 587.6 | d | 1.5424 | 56.1 |
| 546.1 | e | 1.5447 | 55.9 |
| 486.1 | F | 1.5491 | |
| 480.0 | F′ | 1.5497 | |
| 435.8 | g | 1.5544 | |

*Table 5: Refractive indices and Abbe number of ZERODUR®*

## Principal dispersion

| | |
|---|---|
| $n_F - n_C$ | 0.00967 |
| $n_{F'} - n_{C'}$ | 0.00975 |

## Temperature coefficient of refractve index

Δn/ΔT is dependent upon the wavelength λ, the temperature T and the air pressure p. There are two possibilities to express these relations:
For the relative temperature coefficient $\Delta n_{relativ}/\Delta T$, the material and the surrounding air have the same temperature. The information pertains to the air pressure p = 0.10133 MPa.
The absolute temperature coefficient $\Delta n_{abs}/\Delta T$ applies to a vacuum.

Both coefficients are listed for different temperature ranges and wavelengths in table 6. These values are guideline values.
Since ZERODUR® has the residual glass phase of approximately 22 - 30 weight %, the refractive index and density are influenced by the actual cooling rate. The effect is smaller than that for pure glass.

| Temperature | $\Delta n_{relativ}/\Delta T$ [$10^{-6}$/K] | | | | | $\Delta n_{absolut}/\Delta T$ [$10^{-6}$/K] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| °C | C′ | d | e | F′ | g | C′ | d | e | F′ | g |
| -100/-80 | 12.2 | 12.4 | 12.5 | 12.8 | 13.2 | 8.6 | 8.7 | 8.8 | 9.1 | 9.4 |
| -80/-60 | 12.4 | 12.6 | 12.7 | 13.0 | 13.4 | 9.4 | 9.6 | 9.7 | 10.0 | 10.3 |
| -60/-40 | 12.7 | 12.9 | 13.0 | 13.4 | 13.8 | 10.3 | 10.4 | 10.5 | 10.9 | 11.2 |
| -40/-20 | 13.1 | 13.3 | 13.4 | 13.8 | 14.2 | 11.0 | 11.2 | 11.3 | 11.7 | 12.1 |
| -20/0 | 13.5 | 13.7 | 13.9 | 14.3 | 14.7 | 11.8 | 11.9 | 12.1 | 12.5 | 12.9 |
| 0/20 | 14.0 | 14.1 | 14.3 | 14.7 | 15.2 | 12.4 | 12.6 | 12.8 | 13.2 | 13.6 |
| 20/40 | 14.4 | 14.6 | 14.8 | 15.2 | 15.7 | 13.1 | 13.2 | 13.4 | 13.9 | 14.3 |
| 40/60 | 14.8 | 15.0 | 15.2 | 15.7 | 16.0 | 13.6 | 13.8 | 14.0 | 14.5 | 14.9 |
| 60/80 | 15.2 | 15.4 | 15.6 | 16.1 | 16.6 | 14.2 | 14.4 | 14.6 | 15.0 | 15.5 |
| 80/100 | 15.6 | 15.8 | 16.0 | 16.5 | 17.0 | 14.6 | 14.9 | 15.1 | 15.6 | 16.1 |
| 100/120 | 15.9 | 16.1 | 16.3 | 16.9 | 17.4 | 15.4 | 15.3 | 15.5 | 16.0 | 16.6 |
| 120/140 | 16.2 | 16.7 | 16.7 | 17.2 | 17.8 | 15.4 | 15.7 | 15.9 | 16.4 | 17.0 |

*Table 6: The relative and absolute temperature coefficient of the refractive index of ZERODUR® in the range -100°C to +140°C*

## Rayleigh scattering

ZERODUR® is a clear transparent material. The crystalline phase in ZERODUR® leads to wavelength-dependent scattering, which is typical for Rayleigh scattering.

This is shown in table 7 with the help of $R_{90}$ values, a measure of the proportion of light scattered at 90 degrees per path length of the observed primary ray.

| Wavelength [nm] | $R_{90}$ [$10^{-3}$/cm] |
|---|---|
| 404.7 | 23 |
| 435.8 | 16 |
| 546.1 | 6 |
| 578.1 | 5 |

*Table 7: Rayleigh scattering of ZERODUR®*

## Transmission

The typical light transmission of ZERODUR® in the visible and near infrared spectral range is shown in figure 7. The given values are guideline values.

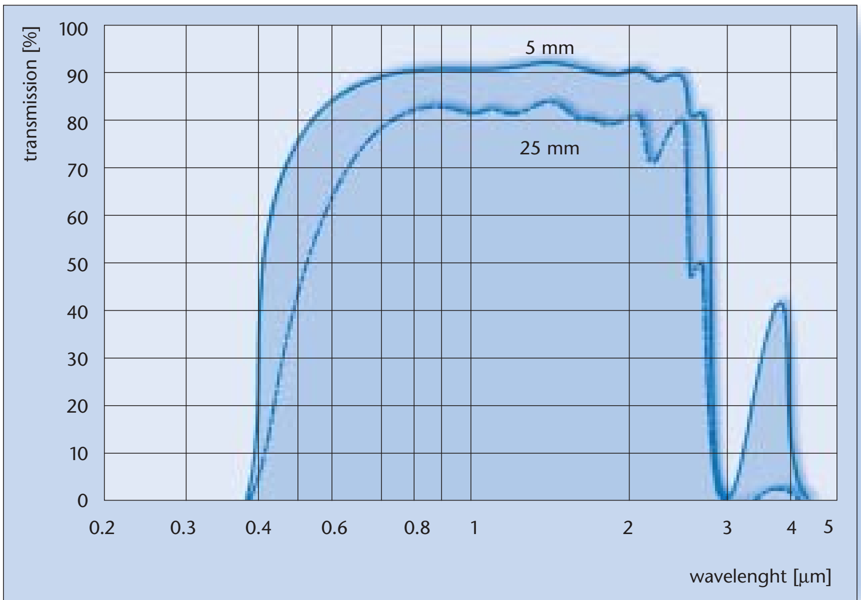



*Figure 7: The light transmission of ZERODUR® at sample thickness of 5 mm and 25 mm*

## Stress optical coefficient K

| | |
|---|---|
| K at $\lambda$ = 589.3 nm [$10^{-6}$ MPa$^{-1}$] | 3.0 |

# 6. Electrical Properties

## Specific electrical resistivity

The specific electrical resistivity ρ for different temperatures is listed in table 8.

*Table 8: The specific electrical resistivity of ZERODUR®*

| Temperature [°C] | Specific resistivity ρ [Ω · cm] |
|---|---|
| 20 | $2.6 \cdot 10^{13}$ |
| 100 | $1.3 \cdot 10^{10}$ |
| 200 | $3.5 \cdot 10^{7}$ |
| 300 | $7.4 \cdot 10^{5}$ |
| 400 | $4.9 \cdot 10^{4}$ |
| 500 | $6.6 \cdot 10^{3}$ |
| 600 | $1.4 \cdot 10^{3}$ |

$t_{K100}$ [°C], temperature for $\rho = 10^{8}\,\Omega \cdot cm$ 178

## Dielectric properties at 20°C

*Table 9: Dielectric properties of ZERODUR®*

| | at 1 kHz | at 1 MHz |
|---|---|---|
| Dielectric constant ε | 8.0 | 7.4 |
| Loss factor tan δ | $29 \cdot 10^{-3}$ | $15 \cdot 10^{-3}$ |

*Leightweighted mirror: low weight and stable*

# 7. Chemical Properties

## Hydrolytic resistance

Hydrolytic resistance class (ISO 719) — HGB 1

## Acid resistance (SR)

Acid resistance class (ISO 8424) — 1.0

## Alkali resistance (AR)

Alkali resistance class (ISO 10629) — 1.0

## Climatic resistance

Climatic resistance — Class 1

## Stain resistance

Stain resistance — Class 0

## Reactivity with other materials

At room temperature, acids (with the exception of hydroflouric acid), alkalis, salts and dye solutions leave no residual traces on ZERODUR® surfaces (elapsed time 170 hours). Concentrated sulfuric acid attacks the material at high temperatures. The construction and insulating materials mica, chamotte, MgO and $SiO_2$ do not noticeably react with ZERODUR® at temperatures up to 600°C after 5 hours elapsed time. By contrast, enamel reacts with Zerodur above 560°C with surface destruction.

## Repeated metal coatings

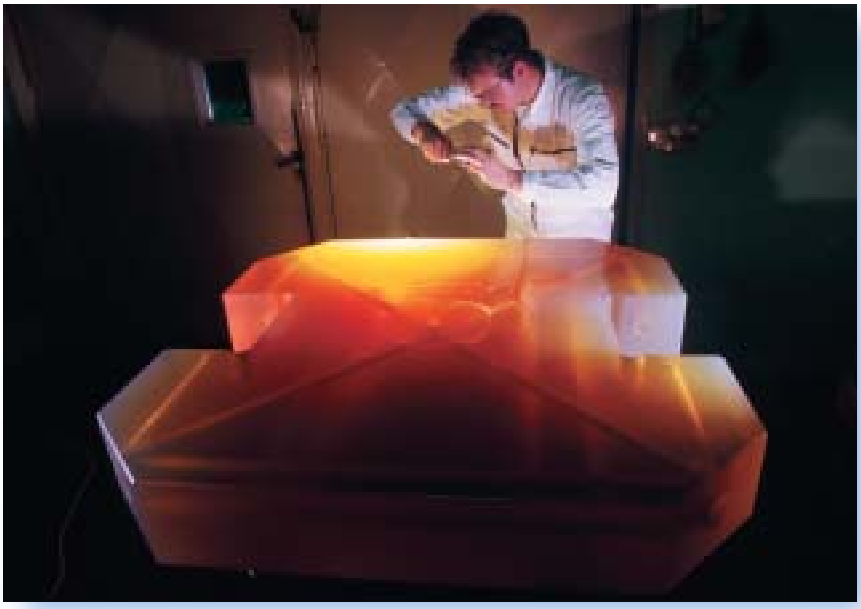
ZERODUR® can be coated with aluminum, for example. Based on the good chemical resistance of the material, the mirror coating can be removed repeatedly. The polished surface can be cleaned and recoated. A process has been optimized for coating and cleaning of the polished surface (see Product Information #3097).

# 8. Helium Permeability

An important application for ZERODUR® are laser gyroscopes. This modern technology of measurement in aircraft navigation, helicopters and other means of transportation is based on the Sagnac effect and requires frame components with particularly low permeability for helium atoms. The gas charge should remain constant for the longest time period possible.
Due to its unusually low helium permeability and its low thermal expansion coefficient, the glass ceramic ZERODUR® is especially suited for this application.

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 | $7.2 \cdot 10^{8}$ |



*Low helium permeability makes ZERODUR® the preferred material for laser gyroscopes*

# 9. Forms of supply and tolerances

ZERODUR® can be supplied in the form of disks up to a diameter of 2.5 meters and in the form of rectangular blocks, prisms, rods and cut pieces measuring up to approximately 2.5 meters in length. The technology for manufacturing larger volumes is being mastered. Therefore larger dimensions can be fabricated on special request.

Special shapes and processing treatments are possible.
Modern CNC processing equipment, high performance diamond tools and expert know-how allow a multitude of geometric shapes to be produced. Holes, backside grinding, blind holes and freeform surfaces are only a few examples of the variety of possible geometries.

## Shapes and dimensional tolerances

Standard tolerances for simple disc shaped or plate shaped parts are ± 0.5 mm depending on the geometry. Tighter tolerances can be provided upon request. The customer should also request values for angle-, flatness-, shape-, run-out- and other tolerances. For parts that cannot be simply described by length, width and thickness (or diameter and thickness), a drawing will be provided.

Typically all parts are provided with protective bevels on all sharp edges for protection against edge damage. The surfaces of the parts are usually processed in such a way that the surface roughness is not more than Ra ≤ 3.5 µm. Finer surfaces can be quoted upon request.


*Modern coordinate measurement equipment in the final inspection of ZERODUR®*

# Notes

# 10. Necessary Data for Quotation Preparation

For quick quotation the following details (as a minimum) should be clearly stated. Essential details are marked blue.

| | value | tolerance |
|---|---|---|
| length [mm]<br>alt. diameter [mm] | | |
| width [mm] | | |
| thickness [mm] | | |
| quantity | | |

| | |
|---|---|
| expansion class* | |
| inclusion class* | |
| striae class* | |
| bulk stress* | |

* if better than standard

| | |
|---|---|
| other<br>geometry or<br>shape tolerances | |

| | |
|---|---|
| other<br>material properties<br>like transmission,<br>homogeneity etc. | |

please include drawing/sketch

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