Heraeus

Conamic

Fused Quartz and Fused Silica for Optical Applications

Data and Properties

Fused Quartz and Fused Silica

for Optical Applications

Fused Silica is an ideal optical material for many applications. It combines an exceptionally high transmission over a wide spectral range with several beneficial physical and chemical properties. For each application, a different combination of these properties may be important. In the following paragraphs we will introduce these properties and mention how we measure and specify.

Clear aperture (CA)

The clear aperture is typically given as a percentage (%) of the dimension of the part. All specified properties apply to the CA. The CA is the fraction of the optical component that the light passes (with a certain oversize for fixing and preventing edge effects). Our products are sold with a CA of 80% of the diameter or edge length for raw formed ingots and 90% for machined ingots and discs.

Transmission

The most important property for transmissive optics is transmission. Typically, the values are given as internal transmittance or including surface reflections, the so-called Fresnel loss. For finished optical components, the Fresnel loss is typically reduced through optical coatings (anti reflective (AR) coatings). We give typical transmission values for the various grades in a transmission calculator.

Absorption

Light that is not transmitted or reflected is either absorbed or scattered. In high purity fused silica, the most pronounced absorption bands are due to OH groups in the silica matrix (945 nm, 1245 nm, 1385 nm, 2210 nm, 2700-2800 nm). Therefore, it is important to know the OH-content of fused silica.

Other absorption due to trace impurities can be observed in the UV, or, given their larger length, in optical fibers. In the case of fused quartz, which is made from natural raw material, more absorption can be observed due to the more limited purity of the material. For some applications, absorption is desired over a certain wavelength region (typically in the UV). Here, the fused silica matrix is doped (e.g., with titania or cerium).

Scattering

Scattering has many components. The glassy matrix itself has a scattering effect. Stronger but localized scattering is due to bubbles and inclusions. The number of these defects depends on the process and raw material used. There are standards defined such as ISO 10110, which defines bubble classes.

Another way to specify the number of bubbles is by the total cross-section of all bubbles (in mm^2). It is the projected cross-section of the defect.

Optical homogeneity

Local variance of the refractive index

A local variance of the refractive index causes a variation of how light propagates. This is looked at in a plane perpendicular to light propagation, but can also be done in the depth. If the variation is low in the perpendicular plane and in light direction, the material is called 3D grade (denoted by 3D).

Typically, the variation of the refractive index is differentiated in symmetric gradual changes and random fluctuations as well as strong sudden changes (called striae). A way to characterize the optical homogeneity is by using the Zernike polynomials. The lower Zernikes are easier to compensate than the higher. The peak to valley value is a first indication of optical homogeneity, but as it is relatively easy to compensate, the higher Zernike polynomials will be more important for higher quality optics. Striae are specified in striae classes per ISO 10110 or by MIL-G-174B.

We perform interferometric measurements for all 2D and 3D Grades over full aperture of 450 mm, or with sub-apertures for larger sizes. We measure at 632.8 nm and subtract tilt and offset for the CA area as defined above.

Stress induced Birefringence

Birefringence means that the two polarization components of the light will experience different refractive indexes and thus will propagate differently inside of the material resulting in a wavefront distortion and a change in the polarization properties of the light. It is measured as the phase difference per cm light path. It is given as nm/cm.

Fluorescence

The emission of light under illumination of (typically UV) light with a higher energy (shorter wavelength). The origin of the fluorescence are defects in the SiO_2 matrix, or metallic impurities.

We inspect our products with an 8 W Hg-lamp (254 nm and UG 5 filter) and adapted eyes.

Specification of Heraeus Material Grades
Optical Specification

Optical specification

	Striae class per ISO 10110	Homogeneity PV- value [ppm]	Stress induced birefringence [nm/cm]	Fluorescence	OH-Content [ppm]
Synthetic Fused Silica					
Suprasil® 311	2/-;5	≤ 3	≤ 5	free	~ 200
Suprasil® 312	2/-;5	≤ 4	≤ 5	free	~ 200
Suprasil® 313	2/-;5	n. sp. *	≤ 5	free	~ 200
Suprasil® 3001	2/-;5	≤ 4	≤ 5	slight blue	≤ 1
Suprasil® 3002	2/-;5	≤ 10	≤ 5	slight blue	≤ 1
Suprasil® 300	2/-;SW30 †	n. sp.	≤ 5	slight blue	≤ 1
Suprasil® 3301	2/-;5	≤ 2	≤ 2	free	~ 15
Suprasil® 3302	2/-;5	≤ 3	≤ 3	free	~ 15
Suprasil® 1	2/-;5	≤ 5	≤ 5	free	~ 750
Suprasil® 2 Grade A	2/-;5	≤ 5	≤ 5	free	~ 750
Suprasil® 2 Grade B	2/-;5	≤ 10	≤ 5	free	500 – 800
Suprasil® 1 ArF / KrF	2/-;5	≤ 5	≤ 5	free	~ 750
Suprasil® 2 ArF / KrF	2/-;5	≤ 5	≤ 5	free	~ 750
Suprasil® UVL	2/-;5	≤ 10	≤ 5	free	~ 1100
Spectrosil® 2000	2/-;5	≤ 10	≤ 5	free	~ 1100
Natural Fused Quartz					
Infrasil® 301	2/-;5	≤ 5	≤ 5	blue-violet	≤ 8
Infrasil® 302	2/-;5	≤ 6	≤ 5	blue-violet	≤ 8
HOQ® 310	n. sp.	n. sp.	≤ 10	blue-violet	~ 30

* Typically, ≤ 10 ppm I † According to ISO 12123

All Specifications are valid for the clear aperture. Unless otherwise agreed, the CA of our raw formed ingots is 80 % of the geometrical dimension and for surface worked parts 90 %. For sizes above 450 mm individual specifications may apply.

- Suprasil 1 Arf/KrF, Suprasil 2 ArF/KrF and Suprasil UVL contain H_2 to minimize absorption under UV exposure.
- ArF and KrF grades are measured for transmission at specific wavelength. Please refer to the Transmission chapter.

Specification of Heraeus Material Grades
Bubble Specification

Bubble specification

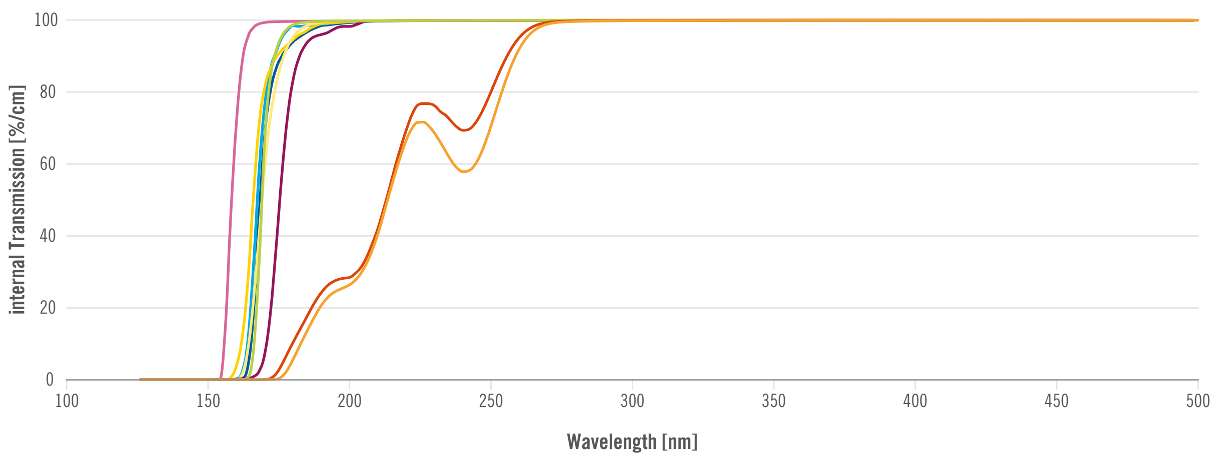
<table>
<tr><th></th><th>< 10 kg</th><th>10 - 20 kg</th><th>20 - 30 kg</th><th>< 50 kg</th><th>< 75 kg</th><th>< 110 kg</th></tr>
<tr><td colspan="7">Synthetic Fused Silica</td></tr>
<tr><td>Suprasil® 311</td><td colspan="3">1 × 0.063</td><td colspan="3">please inquire</td></tr>
<tr><td>Suprasil® 312</td><td colspan="4">1 × 0.063</td><td colspan="2">1 × 0.1</td></tr>
<tr><td>Suprasil® 313</td><td>1 × 0.1</td><td colspan="3">2 × 0.16</td><td>4 × 0.16</td><td>5 × 0.16</td></tr>
<tr><td>Suprasil® 3001</td><td colspan="3">1 × 0.063</td><td colspan="3">please inquire</td></tr>
<tr><td>Suprasil® 3002</td><td colspan="4">1 × 0.063</td><td colspan="2">1 × 0.1</td></tr>
<tr><td>Suprasil® 300</td><td>1 × 0.1</td><td colspan="3">2 × 0.16</td><td>3 × 0.16</td><td>4 × 0.16</td></tr>
<tr><td>Suprasil® 3301</td><td colspan="3">1 × 0.063</td><td colspan="3">please inquire</td></tr>
<tr><td>Suprasil® 3302</td><td colspan="4">1 × 0.063</td><td colspan="2">1 × 0.1</td></tr>
<tr><td>Suprasil® 1</td><td>1 × 0.063</td><td colspan="5">please inquire</td></tr>
<tr><td>Suprasil® 2 Grade A</td><td colspan="4">1 × 0.063</td><td colspan="2">1 × 0.1</td></tr>
<tr><td>Suprasil® 2 Grade B</td><td colspan="2">1 × 0.063</td><td colspan="2">1 × 0.1</td><td colspan="2">2 × 0.1</td></tr>
<tr><td>Suprasil® 1 ArF / KrF</td><td>1 × 0.063</td><td colspan="5">please inquire</td></tr>
<tr><td>Suprasil® 2 ArF / KrF</td><td colspan="4">1 × 0.063</td><td colspan="2">1 × 0.1</td></tr>
<tr><td>Suprasil® UVL</td><td colspan="3">1 × 0.063</td><td>1 × 0.1</td><td colspan="2">3 × 0.16</td></tr>
<tr><td>Spectrosil® 2000</td><td colspan="3">1 × 0.063</td><td>1 × 0.1</td><td colspan="2">3 × 0.16</td></tr>
<tr><td colspan="7">Natural Fused Quartz</td></tr>
<tr><td>Infrasil® 301</td><td colspan="3">1 × 0.16</td><td colspan="3">please inquire</td></tr>
<tr><td>Infrasil® 302</td><td>1 × 0.4</td><td colspan="2">2 × 0.4</td><td colspan="2">3 × 0.4</td><td>4 × 0.4</td></tr>
<tr><td>HOQ® 310</td><td>2 × 1.0</td><td>3 × 1.0</td><td>4 × 1.0</td><td>5 × 1.0</td><td>6 × 1.0</td><td>9 × 1.0</td></tr>
</table>

The area obscured by bubbles can be derived from ISO 10110. The accumulation rule applies.
Bubbles smaller than 0.063 mm are not counted. Tighter bubble specification upon request.

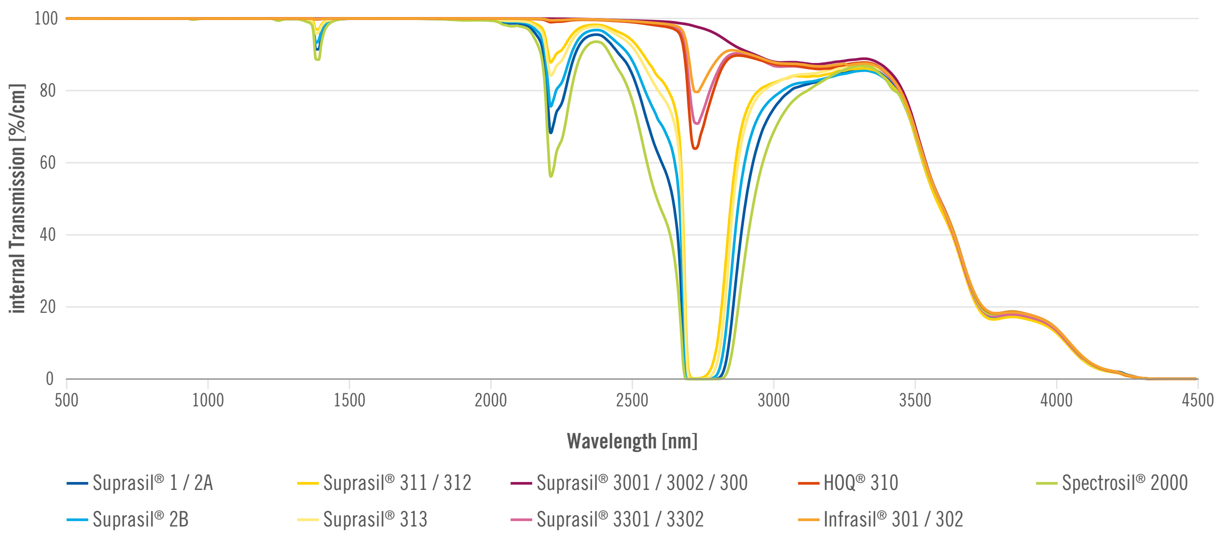
Optical Properties
Transmission

Typical internal transmission (for 10 mm thickness)

UV-transmission



NIR-transmission



Wavelength [nm]	Suprasil typical value [%/cm]	Suprasil ArF [%/cm]	Suprasil KrF [%/cm]
193.4	98.5	≥ 99.3	–
248.4	99.5	≥ 99.8	≥ 99.8
266.0	99.9	≥ 99.9	≥ 99.9

Transmission Calculator

Typical transmission values for various thicknesses can be found on our website:

www.herae.us/transmission_calculator_opt

Optical Properties
Dispersion

Dispersion

Sellmeier Equation

$$n^2(\lambda) - 1 = \frac{B_1 \times \lambda^2}{(\lambda^2 - C_1)} + \frac{B_2 \times \lambda^2}{(\lambda^2 - C_2)} + \frac{B_3 \times \lambda^2}{(\lambda^2 - C_3)}$$

	Natural Fused Quartz	Synthetic Fused Silica	Synthetic Fused Silica with OH < 1 ppm
Sellmeier Constants*			
B1	6.70528671E-01	6.72472034E-01	6.73693289E-01
B2	4.33889824E-01	4.31646851E-01	4.31173589E-01
B3	9.09353456E-01	8.85914296E-01	9.05320925E-01
C1	4.48160190E-03	4.50684530E-03	4.50899296E-03
C2	1.32966549E-02	1.33090179E-02	1.33349842E-02
C3	9.94989893E+01	9.67375952E+01	9.92216527E+01
Partial Dispersions			
nF-nC	0.00676	0.00677	0.00677
nF'-nC'	0.00680	0.00680	0.00681
Abbe Constants			
Vd	67.8	67.8	67.8
Ve	67.7	67.6	67.6

* 185 – 2326 nm, 22 °C, 1013.25 bar N_2

Refractive index

λ [nm]		Natural Fused Quartz	Synthetic Fused Silica	Synthetic Fused Silica with OH < 1 ppm
193.40	**ArF**	1.5603	1.5602	1.5607
248.40	**KrF**	1.5085	1.5084	1.5087
280.40		1.4942	1.4941	1.4944
296.73		1.4889	1.4888	1.4891
312.57		1.4846	1.4845	1.4848
334.15		1.4799	1.4798	1.4801
355.00		1.4762	1.4761	1.4764
365.01	n_i	1.4747	1.4746	1.4749
404.66	n_h	1.4697	1.4696	1.4699
435.83	n_g	1.4668	1.4667	1.4670
479.99		1.4636	1.4635	1.4638
486.13	n_F	1.4632	1.4631	1.4634
532.00		1.4608	1.4607	1.4610
546.07	n_e	1.4602	1.4601	1.4604
587.56	n_d	1.4586	1.4585	1.4587
589.29		1.4585	1.4584	1.4587
632.80	**HeNe**	1.4571	1.4570	1.4573
643.85		1.4568	1.4567	1.4570
656.27	n_C	1.4565	1.4564	1.4566
706.52		1.4553	1.4552	1.4554
852.11	n_s	1.4526	1.4525	1.4527
1013.98		1.4504	1.4502	1.4505
1064.00	**Nd:YAG**	1.4497	1.4496	1.4499
1529.58		1.4444	1.4443	1.4446
1970.00		1.4387	1.4385	1.4388
2325.42		1.4331	1.4329	1.4333

at 22 °C, 1013.25 bar N_2

Optical Properties
Refractive Index

Temperature dependency of the refractive index

$$\frac{dn_{abs}(\lambda,T)}{dT} = \frac{n^2(\lambda,T_0)-1}{2\times n(\lambda,T_0)} \times \left(D_0 + 2\times D_1 \times \Delta T + 3\times D_2 \times \Delta T^2 + \frac{E_0 + 2\times E_1 \times \Delta T}{\lambda^2 - \lambda_{TK}^2}\right)$$

Definitions:

- T_0 Reference temperature (20 °C)
- ΔT Temperature difference versus T_0
- λ Wavelength of the electromagnetic wave in a vacuum [µm]
- T Temperature [°C]
- D_0, D_1, D_2, E_0, E_1, λ_{TK} constants depending on glass type

	Infrasil® 301	HOQ® 310	Suprasil® 1	Suprasil® 311	Suprasil® 3001	Spectrosil® 2000
D0	2.19E-05	2.22E-05	2.15E-05	2.18E-05	2.09E-05	2.13E-05
D1	2.50E-08	2.05E-08	2.44E-08	2.45E-08	2.39E-08	2.90E-08
D2	-1.52E-11	-5.01E-11	-3.69E-11	-2.72E-11	1.07E-11	5.53E-11
E0	3.19E-07	2.94E-07	3.78E-07	2.31E-07	3.67E-07	3.24E-07
E1	4.34E-10	3.14E-10	5.02E-10	2.21E-10	4.28E-10	1.11E-10
λ_{TK}	0.167	0.190	0.122	0.235	0.145	0.148

valid for the respective unhomogenized and 2D grades

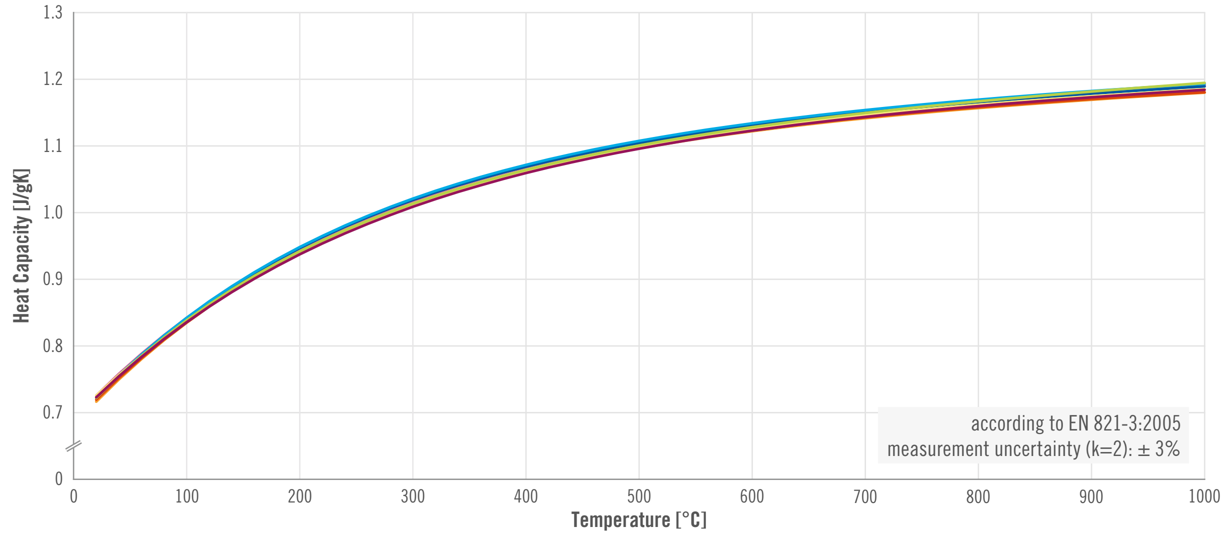
Relative temperature coefficient of the refractive indices [ppm/K] (to ambient air)

	Natural Fused Quartz		Synthetic Fused Silica		Synthetic Fused Silica with OH < 1 ppm	
λ [nm]	**0...20°C**	**20...40°C**	**0...20°C**	**20...40°C**	**0...20°C**	**20...40°C**
365.0	11.3	11.5	11.1	11.4	11.0	11.2
404.7	10.9	11.1	10.7	11.0	10.6	10.8
435.8	10.7	10.9	10.5	10.8	10.4	10.6
480.0	10.5	10.7	10.3	10.5	10.2	10.4
546.1	10.3	10.5	10.1	10.3	9.9	10.1
587.6	10.2	10.4	10.0	10.2	9.8	10.0
632.8	10.1	10.3	9.9	10.1	9.7	9.9
643.8	10.1	10.3	9.9	10.1	9.7	9.9
852.1	9.9	10.0	9.7	9.9	9.5	9.7
1014.0	9.8	9.9	9.6	9.8	9.4	9.6
1064.0	9.8	9.9	9.6	9.8	9.4	9.6

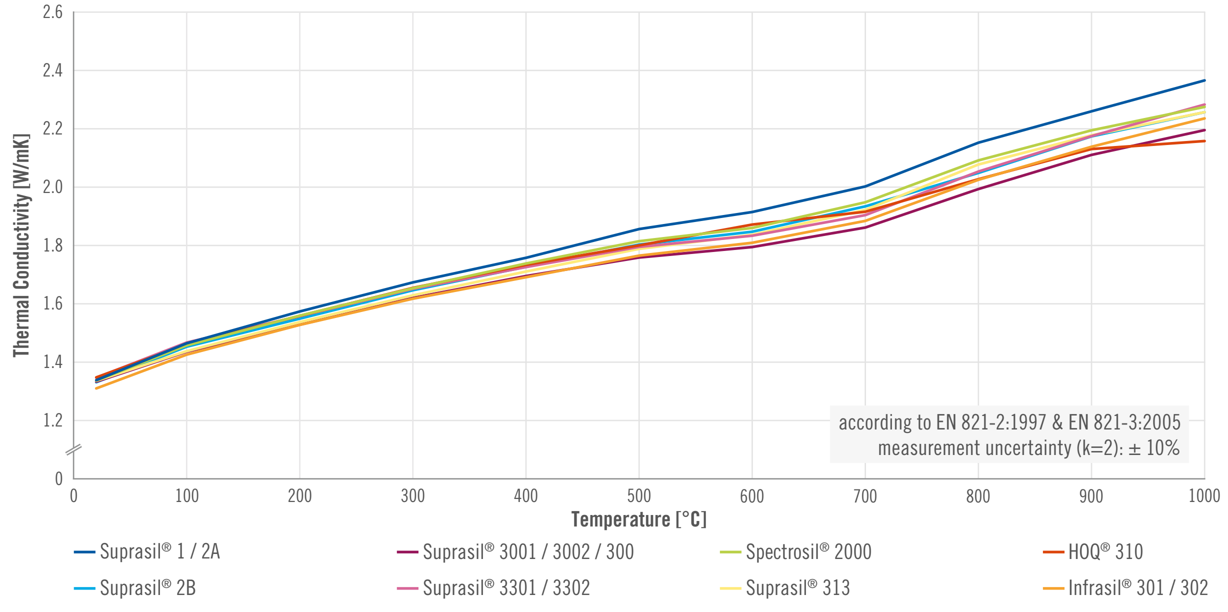
Thermal Properties

Heat Capacity, Thermal Conductivity

Heat capacity



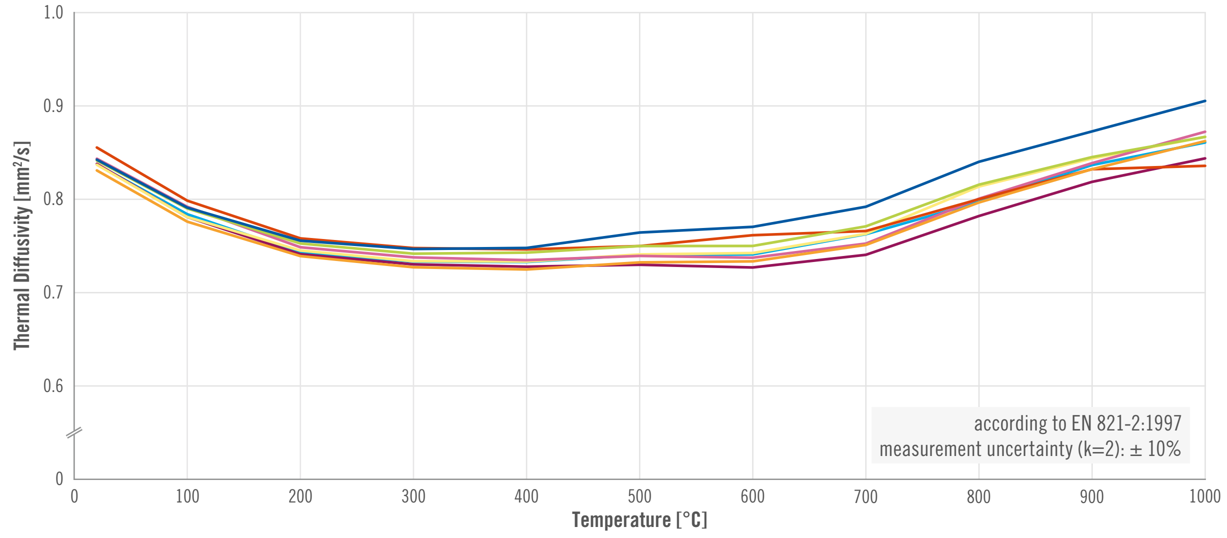
Thermal conductivity



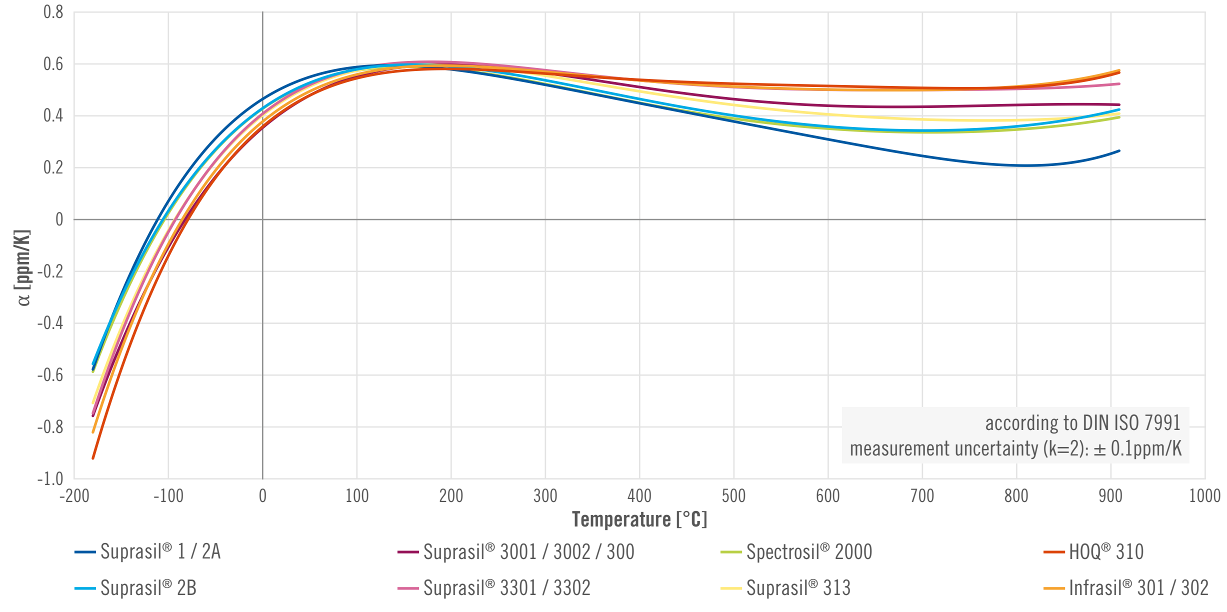
Thermal Properties

Thermal Diffusivity, Thermal Expansion

Thermal diffusivity

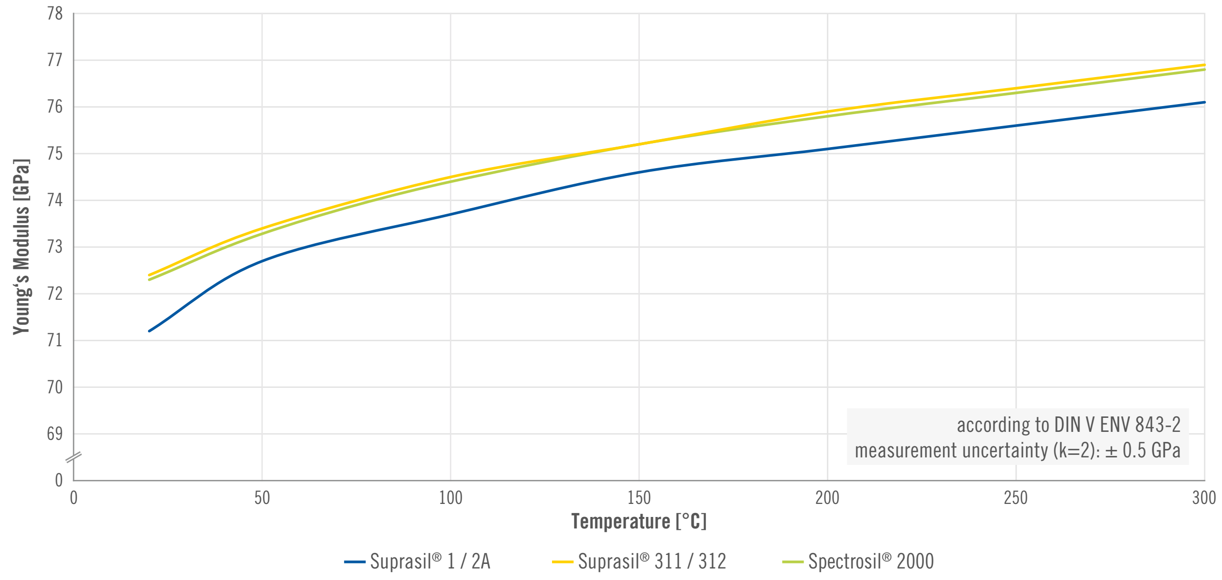


Thermal expansion

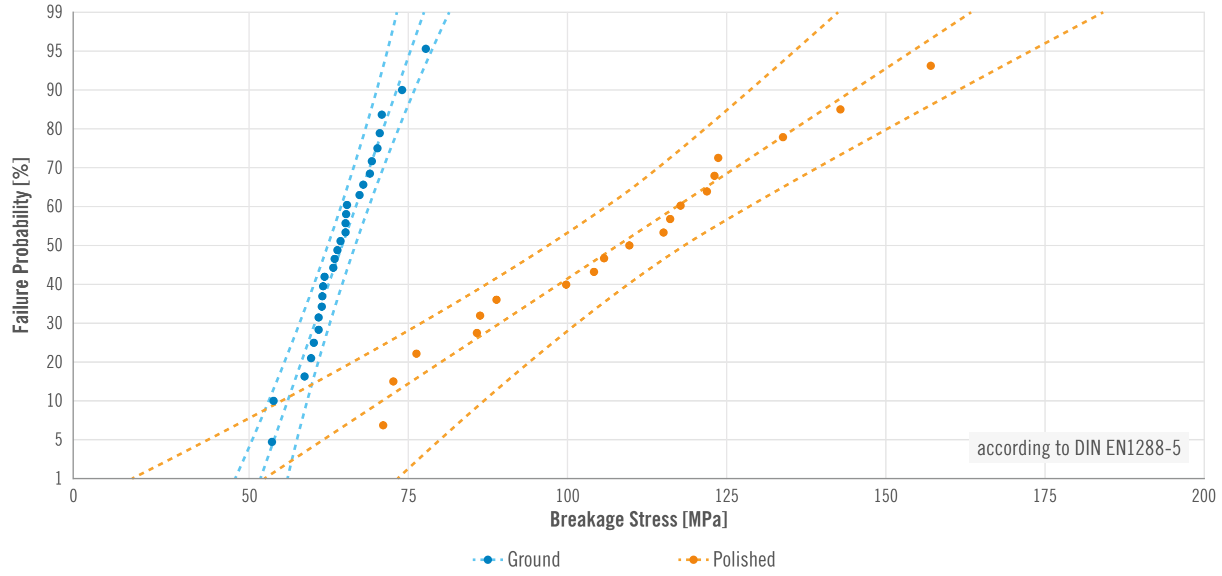


Mechanical Properties
Youngs Modulus, Weibull Modulus

Young's Modulus



Weibull Modulus



Other mechanical properties (at room temperature)

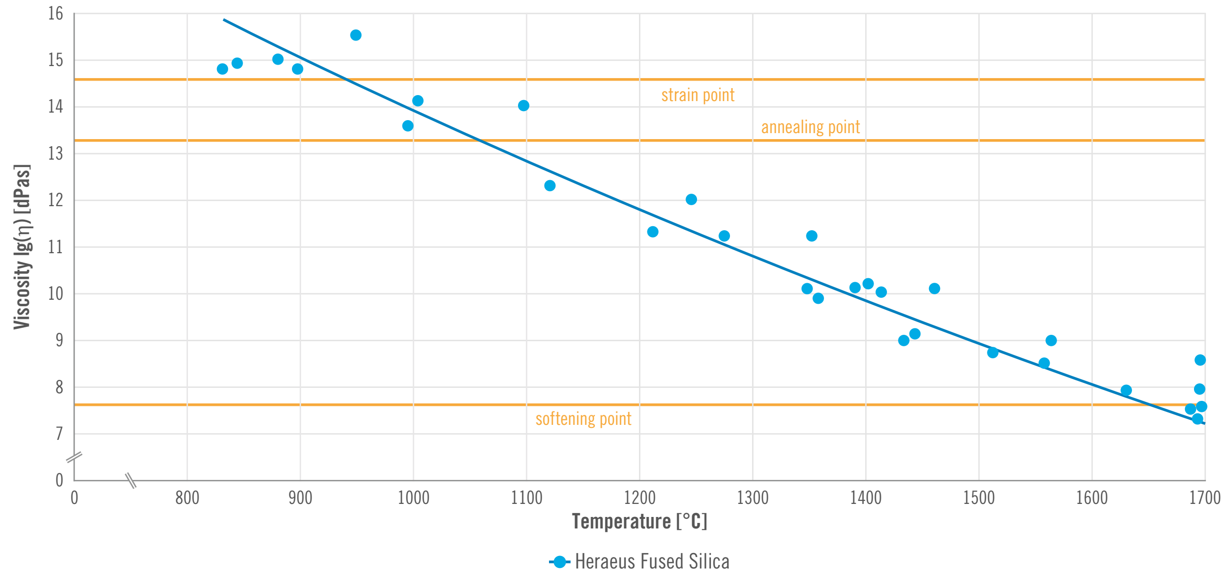
Youngs Modulus	72 GPa
Shear Modulus	31 GPa
Poisson's Ratio	0.16

Density	2.2 g/cm³
Knoop Hardness	565 HK 0.1/20
Sound Velocity (longitudinal)	5900 – 5940 m/s

according to ASTM C1259 – 21 & DIN EN 4545-1:2018

Mechanical Properties
Viscosity

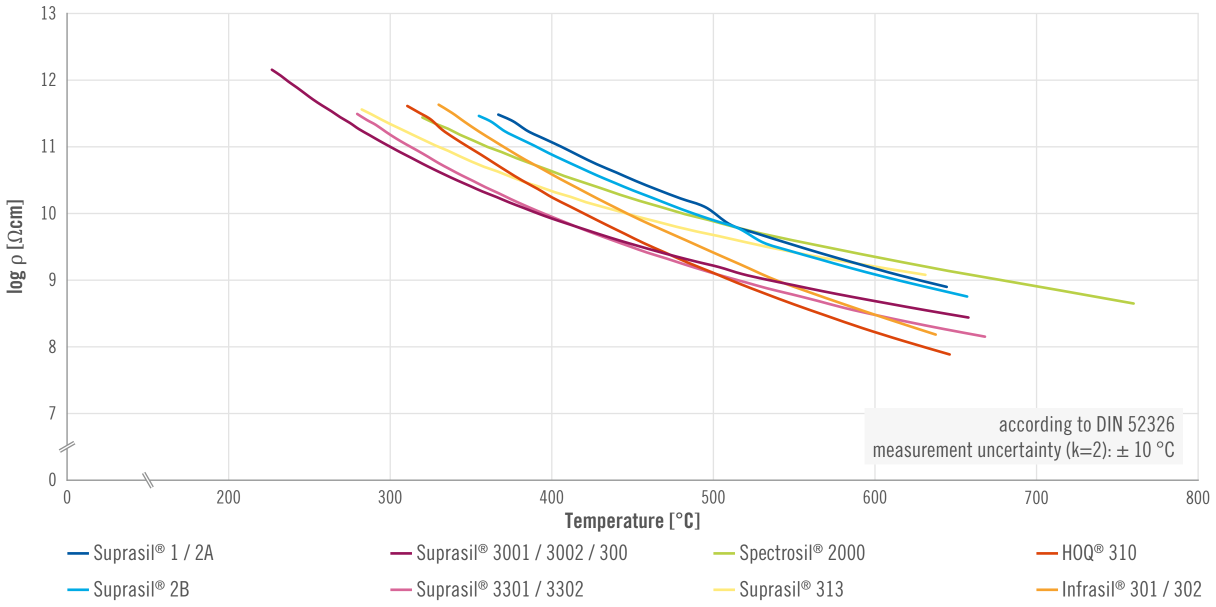
Viscosity



Other Properties

Electric Resistivity, Chemical Resistance, Metallic Impurities

Electric resistivity



Chemical resistance

	Natural Fused Quartz	Synthetic Fused Silica
Alkali resistance class	A1	A1
Acid resistance class	S1W	S1W

Alkali resistance classes according to ISO 695

A1: low attack
A2: slight attack
A3: high attack

Acid resistance classes for glass according to DIN 12116

S1W: acid-resistant
S2W: weakly acid-soluble
S3W: moderately acid-soluble
S4W: highly acid-soluble

Typical metallic impurities

Synthetic grades	< 300 ppb
Natural grades	< 50 ppm

Notes

Germany
Heraeus Quarzglas GmbH & Co. KG
Heraeus Conamic
Kleinostheim, Germany
Phone: +49 6181 35-6285
conamic.optics.eu@heraeus.com

USA
Heraeus Quartz North America, LLC.
Heraeus Conamic
Buford, Georgia, USA
Phone: +1 678 714-4351
conamic.optics.us@heraeus.com

China
Heraeus (China) Investment Co., Ltd.
Heraeus Conamic
Minhang, Shanghai, China
Phone: +86 21 3357-5175
conamic.optics.cn@heraeus.com

www.optics.heraeus-conamic.com