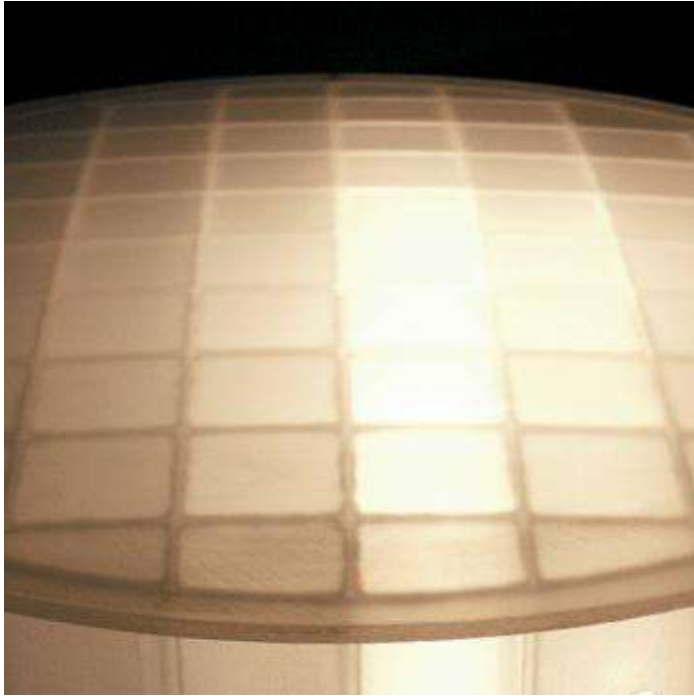


ULE[®] Corning Code 7972

Ultra Low Expansion Glass

Advanced Optics and Materials



ULE[®] Corning Code 7972 Ultra Low Expansion Glass is a titania silicate glass with unique characteristics that have made it the material of choice in applications ranging from machine tool reference blocks to solid and lightweight mirror blanks for large astronomical telescopes and space satellite applications. It is formed as 1.5-meter boules from which virtually any size or shape product can be made.

Near Zero Thermal Expansion is the key attribute for which system designers specify Corning ULE[®]. This material offers superior dimensional stability ~

- ❖ *Coefficient of thermal expansion (CTE) is nominally zero at room temperature*
- ❖ *Expansivity can be adjusted to provide zero CTE at other temperatures when needed for specific applications*
- ❖ *High homogeneity of CTE within boules enables efficient material utilization*
- ❖ *CTE is nondestructively measured on all ULE[®] boules, enabling precision engineering and analysis of the thermal response of products in the end use environment*

Fabrication Flexibility is the key to product design freedom. Corning utilizes several key manufacturing processes which enable the production of a variety of products ~

- ❖ *Monolithic solids from a few centimeters to over 8 meters in diameter*
- ❖ *Lightweight fusion bonded structures offering up to 80% weight reduction over the same sized solid*
- ❖ *Ultralightweight frit bonded structures with up to 95% weight reduction are possible using a proprietary glass ceramic frit designed to closely match the thermal expansion of ULE[®] glass.*

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CTE Variation and Inclusion Quality Grades

Mean Linear Coefficient of Thermal Expansion (CTE)

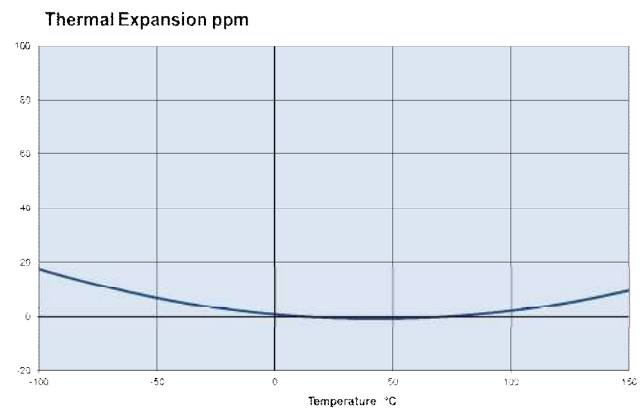
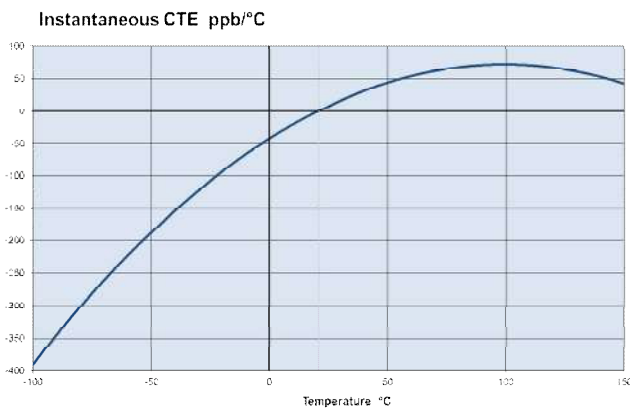
The guaranteed maximum limits for the mean linear CTE are as follows:

The mean linear CTE shall be 0 ± 30 ppb/°C from 5°C to 35°C with a 95% confidence level.

Quality Grade Selection Chart

Grade	Maximum CTE Variation (ppb/°C)		Optical Retardation	Inclusions	<i>Special grades and sizes available on request</i>	
	Radial Range	Axial Range	Birefringence (nm/cm)	Inclusion Quality	Diameter < 20"	Diameter 20" to 56"
Premium Grade	10	10	10	Inclusion max mean diameter: Inclusions per cubic inch: Avg. no. of inclusions per cu. in.:	0.040" 4 0.1	N/A
Mirror Grade	15	15	20	Critical Zone: Inclusion max mean diameter: Inclusions per cubic inch: Avg. no. of inclusions per cu. in.:	0.040" 4 0.1	0.080" 6 0.2
				Non-Critical Zone: Inclusion max mean diameter: Inclusions per cubic inch: Avg. no. of inclusions per cu. in.:	0.100" N/S 0.2	0.250" N/S 0.6
Standard Grade	15	15	20	Inclusion max mean diameter : Inclusions per cubic inch: Avg. no. of inclusions per cu. in.:	0.100" N/S 0.2	0.250" N/S 0.6
Tooling Grade	N/A	N/A	N/A	N/A	Contact Corning for availability.	

- ◆ CTE verification is performed using a non-destructive ultrasonic method.
- ◆ Excellent long term dimensional stability is exhibited at room temperature. No residual figure change is observed when taking an optic from 350°C to water quench.
- ◆ There has been no measurable delayed elastic effect. This is an important consideration when large strain is present during fabrication or when environmental loading is present, such as during gravity release or dynamic control of active optics.
- ◆ No measurable hysteresis results from thermal cycling.



Thermal Properties

Mean Linear Coefficient of Thermal Expansion 5°C to 35°C (α)	$0 \pm 30 \times 10^{-9}/K$ [0 ± 30 ppb/°C]	Mean Specific Heat (C_p)	767 J/(kg · °C) [0.183 cal/(g · °C)]
Thermal Conductivity (K)	1.31 W/(m · °C) [1.13 kcal/(m · h · °C)]	Strain Point	890°C [1634°F]
Thermal Diffusivity (D)	0.0079 cm ² /s	Annealing Point	1000°C [1832°F]
D.C. Volume Resistivity, 200°C 100Hz (R)	$10^{11.6}$ ohm · cm	Softening Point (estimated)	1490°C [2714°F]

Mechanical Properties

Poisson's Ratio (ν)	0.17	Specific Stiffness (E/ρ)	3.12×10^6 m [1.23×10^8 in]
Ultimate Tensile Stress (MOR)	49.8 MPa [7220 psi]	Shear Modulus (G)	29.0 GPa [4.20×10^6 psi]
Knoop Hardness, 200g load	460 kg/mm ²	Bulk Modulus (K)	34.1 GPa [4.95×10^6 psi]
Density (ρ)	2.21 g/cm ³ [0.079 lb/in ³]	Elastic Modulus (E)	67.6 GPa [9.80×10^6 psi]

Optical Properties

Stress Optical Coefficient	4.15 (nm/cm)/(kg/cm ²) [0.292 (nm/cm)/psi]	Abbé Number (v_d)	53.1
Refractive index (nominal CTE Material)	n_F (486 nm) 1.4892 n_D (589 nm) 1.4828 n_C (656 nm) 1.4801	dn/dt	20-40°C $10.68 \times 10^{-6}/°C$ 40-60°C $11.24 \times 10^{-6}/°C$

Chemical Durability

- ◆ Excellent resistance to weathering
- ◆ Exhibits virtually no surface clouding or electrical surface leakage when subjected to attack by water, sulfur dioxide, and other atmospheric gases.
- ◆ High resistance to attack by nearly all chemical agents.

Solution at 95°C	Test Duration	Weight Loss mg/cm ²
5% HCl	24h	< 0.01
5% NaOH	6h	0.9
0.02N Na ₂ CO ₃	6h	0.02
5% H ₂ SO ₄	24h	< 0.01
H ₂ O	24h	< 0.01

Unless otherwise stated, all values @ 25°C

Worldwide Accessibility

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Corning Advanced Optics

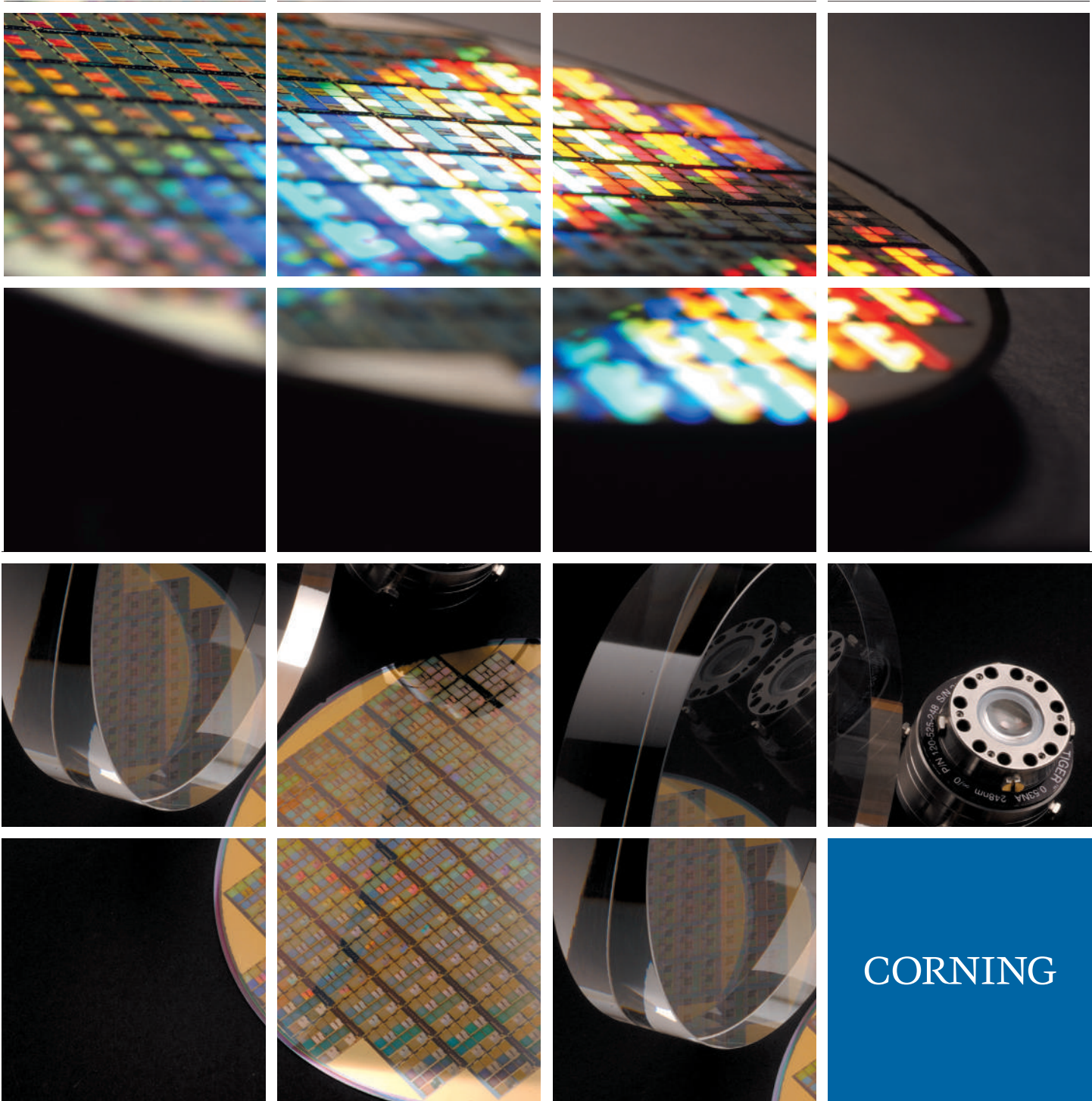
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Corning® ULE® 7973 Low Expansion Glass

Optical Materials Product Information
Specialty Materials Division



Corning ULE® 7973

7973 is a titania-silicate low expansion glass that has been tailored to meet the needs for mask and optical substrates for EUVL applications. 7973 has a similar composition to ULE® 7972 glass and is made using the same flame deposition process. The lithography transition from 193nm to 13.4nm required a major design shift in stepper optics from refractive to reflective. In reflective optics, substrate materials should be purely passive. The incident light should reflect off of the multilayer coatings of the optics and the photomask without the introduction of any mechanical or optical distortion caused by the underlying substrate. To minimize distortion from the minute temperature changes and meet the stringent EUVL specifications, the substrates must have a near-zero coefficient of thermal expansion (CTE) and tightly controlled zero cross over range. The extremely low CTE requirements are specified in parts per billion per degree Celsius (ppb/C).

Quality Grade Selection Chart 7973 EUV

Grade	Inclusion Quality	Blank Dimensions (Diameter or Diagonal)	
		< 20" (< 508 mm)	20 - 58" (508 - 1473 mm)
EUV Grades	Critical Zone: Total Inclusion Cross Section: ≤ 0.03 mm ² /100cc Maximum Inclusion Size: 0.1 mm		
	Non-Critical Zone: Total Inclusion Cross Section: ≤ 2.00 mm ² /100cc Maximum Inclusion Size: 1.27 mm		
EUV Mask A Grade	No visible inclusions > 0.05 mm		

Notes:

- Critical Zone — a quality layer typically extending to a depth of 0.200" (5 mm) below the surface specified by the customer for finishing.
- Non-Critical Zone — all glass outside the critical zone
- Inclusions with 0.005" (0.13 mm) or smaller mean diameter are disregarded.
- Mirror and standard grades are available in sizes up to 58" (1473 mm) diameter

7973 Summary of Key Attributes

Attribute	7973 Premium Grade	7973 Mirror Grade	7973 Standard Grade	7973 Tooling Grade	7973 EUV Premium Grade	7973 EUV Standard Grade	7973 EUV Mask A Grade
No visible inclusions > 0.05 mm							■
Low Birefringence	■				■	■	■
Low Radial CTE Range	■				■		■
Low Axial CTE Range	■				■		■
Tzc specified					■	■	■
Low Striae					■	■	■
Low Inclusions in CZ		■			■	■	■
Available in larger sizes (up to 58" diameter)		■	■				
Economical (No certification of any properties)				■			

Quality Grade Selection Chart 7973

Grade	Inclusion Quality	Blank Dimensions (Diameter or Diagonal)	
		< 20" (< 508 mm)	20 - 58" (508 - 1473 mm)
Premium	Max. Mean Diameter	0.040" (1 mm)	N/A
	No./Cu. Inch	4	
	Avg. No./Cu. Inch	0.1	
Mirror	Critical Zone:		
	Max. Mean Diameter	0.040" (1 mm)	0.080" (2 mm)
	No./Cu. Inch (No./mm ³)	4 (2.4 x 10 ⁻⁴)	6 (3.7 x 10 ⁻⁴)
	Avg. No./Cu. Inch (Avg. No./mm ³)	0.1 (6.1 x 10 ⁻⁶)	0.2 (1.2 x 10 ⁻⁵)
	Non-Critical Zone:		
	Max. Mean Diameter	0.100" (2.5 mm)	0.250" (6.4 mm)
	No./Cu. Inch (No./mm ³)	N/S	N/S
Standard	Avg. No./Cu. Inch (Avg. No./mm ³)	0.2 (1.2 x 10 ⁻⁵)	0.6 (3.7 x 10 ⁻⁵)
	Max. Mean Diameter	0.100" (2.5 mm)	0.250" (6.4 mm)
	No./Cu. Inch	N/S	N/S
Tooling	Avg. No./Cu. Inch (Avg. No./mm ³)	0.2 (1.2 x 10 ⁻⁵)	0.6 (3.7 x 10 ⁻⁵)
	Max. Mean Diameter	0.100" (2.5 mm)	0.250" (6.4 mm)

Optical and Thermal Properties

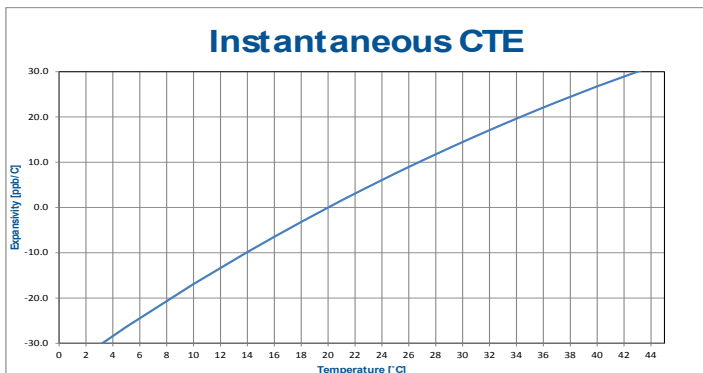
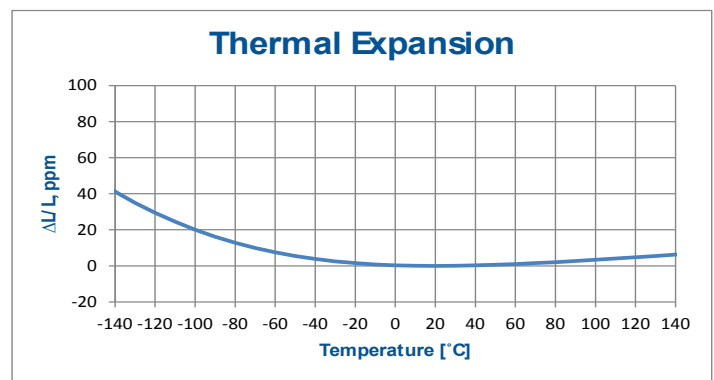
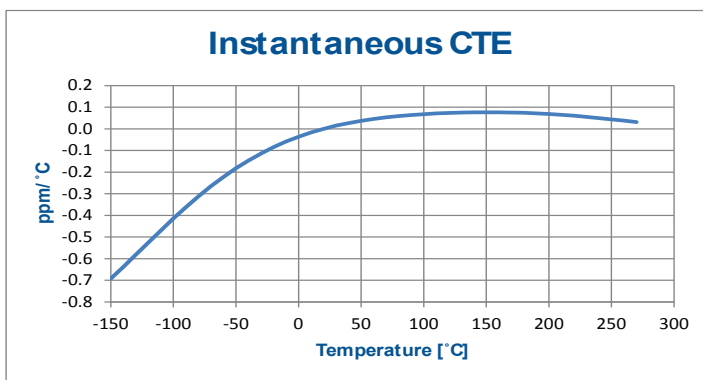
Glass Code	Striae	Optical Retardation	CTE Zero Cross Over Temperature	Coefficient of Thermal Expansion (CTE) Range	
				Radial [ppb/°C]	Axial [ppb/°C]
	0 to 400 Scale [%]	Birefringence [nm/cm] maximum	T_{zc} [°C]		
7973 Premium Grade	100	10	See note below*	≤ 10	≤ 10
7973 Mirror Grade	100	20	See note below*	≤ 15	≤ 15
7973 Standard Grade	100	20	See note below*	≤ 15	≤ 15
7973 Tooling Grade	NS	NS	See note below*	≤ 100	≤ 100
7973 EUV Premium Grade	Critical Zone: 50	10	User defined within 15 °C to 32 °C ± 5 °C	≤ 10	≤ 10
	Non-Critical Zone: 100				
7973 EUV Standard Grade	Critical Zone: 50	20	20 °C ± 10 °C	≤ 15	≤ 15
	Non-Critical Zone: 100				
7973 Mask A Grade	50	NS	20 °C ± 3 °C	≤ 6	N/A

Note:
 * Linear Coefficient of Thermal Expansion - The mean CTE shall be 0 ± 30 ppb/°C from 5 °C to 35 °C with a 95% confidence level and 0 ± 100 ppb/°C from 5 °C to 35 °C for Tooling Grade

Stress Optical Coefficient	4.15 (nm/cm)/(kg/cm ²)
Striae Normal to Blank Faces	None
Abbé Constant	53.1
D.C. Volume Resistivity, 200 °C 100 Hz (R)	$10^{11.6}$ ohm•cm
Thermal Conductivity (K)	1.31 W/(m•K)
Unless otherwise stated, all values above @ 25 °C	

Thermal Diffusivity (D)	0.0079 cm ² /s
Mean Specific Heat (C _p)	767 J/(kg•°C)
Strain Point	890 °C
Annealing Point	1000 °C
Softening Point (estimated)	1490 °C
Unless otherwise stated, all values above @ 25 °C	

Expansivity



- CTE verification is achieved through a non-destructive ultrasonic method.
- Stability: Excellent long term dimensional stability at room temperature. No residual figure change when taking a blank from 350 °C to water quench.
- Delayed elastic effect: There has been no measurable delayed elastic effect in Corning 7973. This is an important consideration when large strain is present during fabrication or when environment loading is present, such as during gravity release or dynamic control of active optics.
- No measurable hysteresis results from thermal cycling of Corning 7973.

Chemical Durability

- Excellent resistance to weathering.
- Exhibits virtually no surface clouding or electrical surface leakage when subject to attack by water, sulfur dioxide, and atmosphere gases.
- High Resistance to attack by nearly all chemical agents.

Solution @ 95 °C	Test Duration	Weight Loss
5% HCl	24 hrs	< 0.01 mg/cm ²
5% NaOH	6 hrs	0.9 mg/cm ²
0.02N Na ₂ CO ₃	6 hrs	0.02 mg/cm ²
5% H ₂ SO ₄	24 hrs	< 0.01 mg/cm ²
H ₂ O	24 hrs	< 0.01 mg/cm ²

Mechanical Properties

Unless otherwise stated, all values @ 25 °C

Elastic Modulus (E)	67.6 GPa
Shear Modulus	29.0 GPa
Bulk Modulus	34.1 GPa
Poisson's Ratio	0.17
Density	2.21 g/cm ³
Knoop Hardness (200g load)	460 kg/mm ²
Ultimate Tensile Strength	49.8 MPa
Specific Stiffness (E/ρ)	3.12 x 10 ⁶ m

Worldwide Accessibility

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