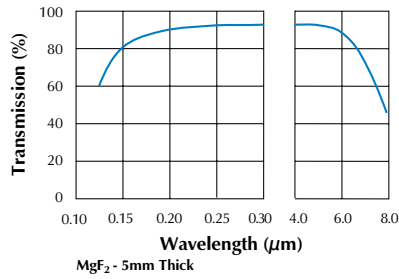


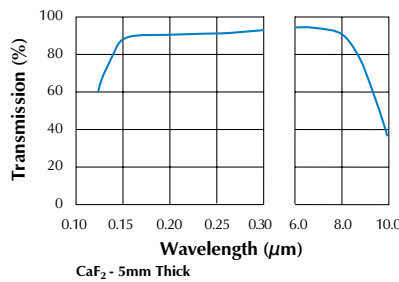
For more detailed information ► 432-437



MgF₂

MgF₂ is a tetragonal positive birefringent crystal grown using the vacuum Stockbarger technique. MgF₂ is a rugged material resistant to chemical etching, mechanical, and thermal shock. High vacuum UV transmission and resistance to laser damage make MgF₂ a popular choice for VUV and excimer laser windows, polarizers, and lenses.

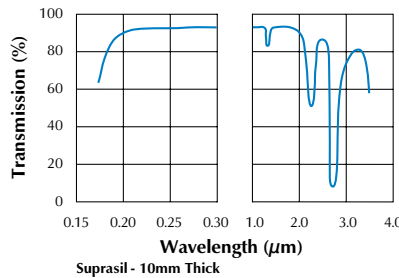
- **Thermal expansion coefficients:**
- **Hardness (Knoop): 415**
- **Density: 3.177 g/cm³**
- $dn_o/dT: 2.3 \times 10^{-6}/^{\circ}C$
- $dn_e/dT: 1.7 \times 10^{-6}/^{\circ}C$



CaF₂

CaF₂ is a cubic single crystal grown using the vacuum Stockbarger technique. Care must be used when thermally cycling CaF₂. Common CaF₂ uses include vacuum ultraviolet components such as excimer laser windows, lenses, and prisms. Contact CVI for additional information regarding Deep UV applications.

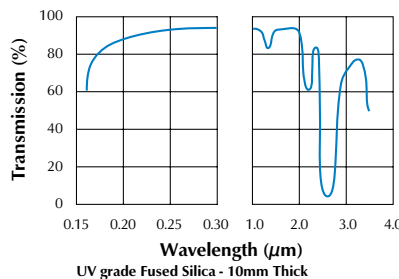
- **Thermal expansion coefficient: 18.85 x 10⁻⁶/°C (20°C to 60°C)**
- **Hardness (Knoop): 160**
- **Density: 3.18 g/cm³**



Suprasil 1

Suprasil 1 is a type of fused silica with high chemical purity and excellent homogeneity in all axes. With a metallic content less than 8 ppm, Suprasil 1 has superior UV transmission and minimal fluorescence. Suprasil 1 is primarily used for low fluorescence UV windows, lenses, and prisms where multiple axis homogeneity is required.

- **Typical index homogeneity: $\Delta n < 8 \times 10^{-6}$**
- **Thermal expansion coefficient: 0.58 x 10⁻⁶/°C (0°C to 200°C)**
- **Density: 2.201 g/cm³**

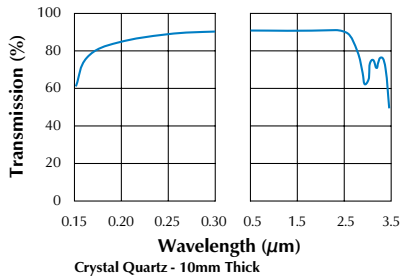


UV grade Fused Silica

UV grade Fused Silica is an amorphous form of silicon dioxide made by flame hydrolysis of silicon tetrachloride. Properties include high UV transmission, low thermal expansion coefficient, and high laser damage threshold. Used for UV windows, lenses, prisms, and mirror substrates.

- **Typical homogeneity: $\Delta n < 3 \times 10^{-6}$**
- **Thermal expansion coefficient: 0.57 x 10⁻⁶/°C (0°C to 200°C)**
- **Hardness (Knoop): 500**
- **Density: 2.202 g/cm³**

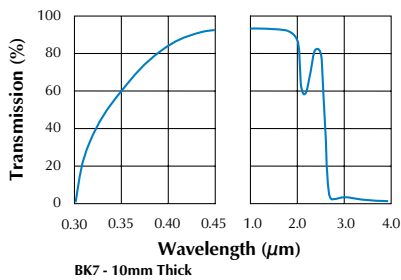
continued



Crystal Quartz

Crystal quartz is a positive uniaxial birefringent single crystal grown using a hydrothermal process. CVI's crystal quartz is selected to minimize inclusions and refractive index variation. Crystal quartz is most commonly used for high damage threshold waveplates and solarization resistant Brewster windows for argon lasers.

- **Thermal expansion coefficients:**
7.1 x 10⁻⁶/°C parallel to [0001]
13.2 x 10⁻⁶/°C perpendicular to [0001]
- **Density:** 2.649 g/cm³

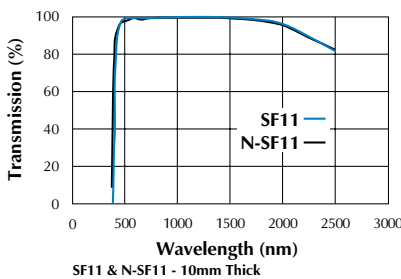


BK7

BK7 is a borosilicate crown optical glass with high homogeneity and low bubble content. This general purpose material is widely used in visible and NIR windows, lenses, and prisms.

- **Typical homogeneity:** Δn < 1 x 10⁻⁵
- **Thermal expansion coefficient:** 8.3 x 10⁻⁶/°C (30°C to 300°C)
- **Hardness (Knoop):** 610
- **Density:** 2.51 g/cm³

For up-to-date information on materials compliance with the European Union RoHS ► www.cvilaser.com

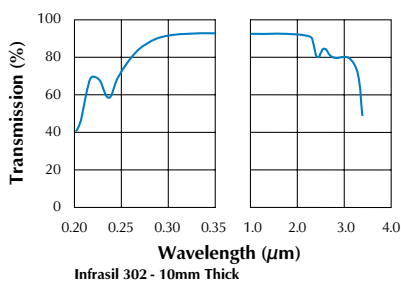


SF11 and N-SF11

SF11 and its lead-free equivalent (N-SF11) are high refractive index materials used to provide more optical power with less curvature. Used in achromats and other multi-element lenses to correct for chromatic aberrations, it exhibits lower LDT than BK7 or fused silica. CVI maintains inventory of both SF11 and N-SF11, please specify when ordering.

- | | |
|---|---|
| SF11 | N-SF11 |
| ● Thermal expansion coefficient:
6.8 x 10 ⁻⁶ /°C (20°C to 300°C) | ● Thermal expansion coefficient:
-1.4 x 10 ⁻⁶ /°C (20°C to 40°C) |
| ● Hardness (Knoop): 450 | ● Hardness (Knoop): 615 |
| ● Density: 4.74 g/cm ³ | ● Density: 3.22 g/cm ³ |

For up-to-date information on materials compliance with the European Union RoHS ► www.cvilaser.com

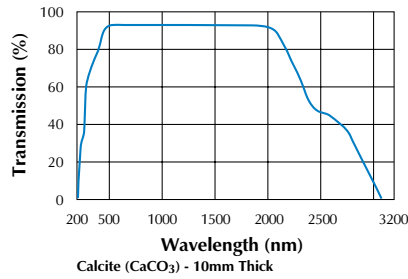


Infrasil 302

Infrasil 302 is a low OH content fused quartz. Fused quartz is produced by electrically fusing high quality quartz crystal. Infrasil 302 is used for applications where minimum OH absorption is required, including NIR high energy laser windows and lenses.

- **Typical homogeneity:** Δn < 3 x 10⁻⁶
- **OH content:** < 8 ppm
- **Thermal expansion coefficient:** 0.58 x 10⁻⁶/°C (0°C to 200°C)
- **Density:** 2.203 g/cm³

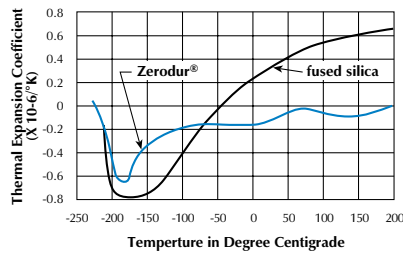
continued



Calcite (CaCO₃)

Birefringent crystal with wide spectral transmission. Most commonly used in visible and NIR polarizers: Glan Taylor, Glan Thompson and Glan laser. This soft material scratches easily. Take care in handling these polarizers.

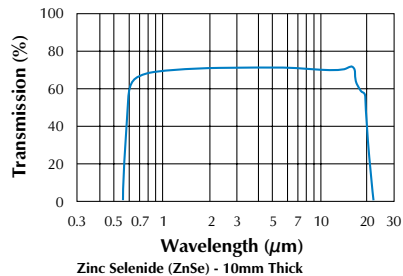
- **Thermal Expansion Coefficient:** $\alpha_a = 24.39 \times 10^{-6}/^{\circ}\text{C}$
- **Hardness (Moh):** 3
- **Density:** 2.71 g/cm³
- $\alpha_c = 5.68 \times 10^{-6}/^{\circ}\text{C}$



Zerodur® (Schott glass)

Zerodur® is a low thermal expansion material used primarily as a thermally stable mirror substrate. It can also be used as a window for etalon plates and spacers. CVI standard material is Thermal expansion Class 2. The graph at left shows the thermal expansion coefficient of Zerodur® vs. fused silica.

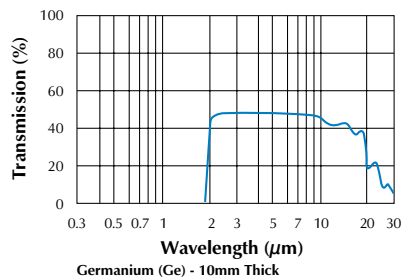
- **Thermal expansion coefficient:** $0 \pm 0.10 \times 10^{-6} \text{ K}^{-1}$
- **Hardness (Knoop):** 620
- **Density:** 2.53 g/cm³



ZnSe

Zinc Selenide is well suited for windows, lenses and partial reflectors in the IR region due to its low absorption at these wavelengths and visible wavelength transmission.

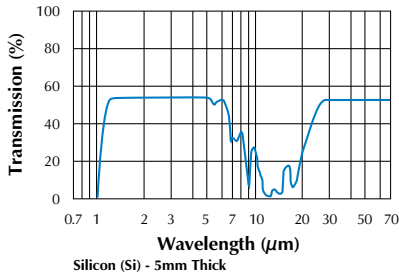
- **Refractive Index of 2.40 at 10.6μm and 2.60 at 632.8nm**
- **Transmission Region from 0.5 to 20μm**
- **Typical Bulk absorptivity (cm⁻¹ at 10.6μm) is 0.0005**
- **Thermal Expansion Coefficient:** $10^{-6}/^{\circ}\text{C}^{\circ}$: 7.6
- **Hardness (Knoop):** 100
- **Density:** 5.27 g/cm³
- $\Delta n/\Delta T (10^{-6}/^{\circ}\text{C})$: 64



Ge

Germanium is commonly used in imaging systems working in the 2 to 12μm wavelength region. Ideal substrate for lenses, windows and mirrors in low power CW and CO₂ laser systems.

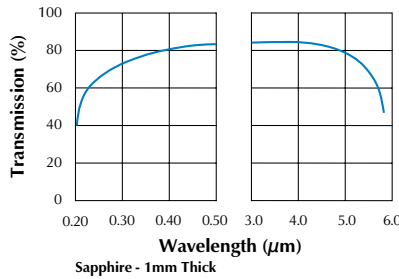
- **Refractive Index of 4.00 at 10.6μm**
- **Transmission Region from 2 to 23μm**
- **Typical Bulk absorptivity (cm⁻¹ at 10.6μm) is 0.035**
- **Thermal Expansion Coefficient:** $10^{-6}/^{\circ}\text{C}^{\circ}$: 5.7
- **Hardness (Knoop):** 692
- **Density:** 5.323 g/cm³
- $\Delta n/\Delta T (10^{-6}/^{\circ}\text{C})$: 277



Si

Silicon is an economical and lightweight material for use in IR applications.

- **Refractive Index of 3.42 at 6.0μm**
- **Transmission Region from 1.5 to 7μm**
- **Typical Bulk absorptivity (cm⁻¹ at 10.6μm) is 0.04 at 6.0μm**
- **Thermal Expansion Coefficient:**
 - 10⁻⁶/C°: 4.15
 - Δn/ΔT (10⁻⁶/C°): 160
- **Hardness (Knoop): 820**
- **Density: 2.33 g/cm³**



Sapphire

Sapphire is a synthetic hexagonal crystal form of aluminum oxide. Sapphire exhibits high mechanical strength, chemical resistance, and thermal stability. Unless otherwise specified, CVI supplies random axis orientation sapphires. Contact CVI for (0001) axis orientation.

- **Thermal expansion coefficient: 8.4 x 10⁻⁶/C° (20°C to 500°C)**
- **Hardness (Knoop): 1370**
- **Density: 3.97 g/cm³**

Corning HPFS® for Deep Ultraviolet Applications

HPFS®, High Purity Fused Silica, Corning Code 7980, is a high purity synthetic amorphous silicon dioxide glass which combines a very low thermal expansion coefficient, excellent optical qualities, and exceptional transmission properties for ultraviolet applications. It is available in a number of grades for different applications.

Quality Grade Selection Chart

Inclusion Class No.	Total Inclusion Cross-Section	Maximum Inclusion Cross-Section
0	0.00-0.03mm ²	0.10mm (0.004")

Notes:

- 1.Total Inclusion Cross-Section: Defines the sum of the cross-section in mm² of inclusions per 100cm³ of glass. Inclusions with a cross-section equal to or less than 0.10mm diameter are disregarded.
- 2.Maximum Inclusion Cross-Section: Refers to the diameter of the largest single inclusion in any single 100cm³ of glass.

Birefringence

≤ 2nm/cm	Lower specifications available
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248nm Induced Absorption

Fluence (mJ/cm ²)	Number of Pulses (x 10 ⁶)	248nm Induced Absorbance/cm
250	5	No Change
400	1	No Change

Exposure Conditions: 400Hz, 16nsec pulse duration

Index Homogeneity Grade

Grade AA	Grade A
≤ 0.5 x 10 ⁻⁸	≤ 1 x 10 ⁻⁸

Notes:

1. Index Homogeneity: The maximum index variation (relative) measured over the clear aperture of the blank.
2. The minimum thickness for index homogeneity verification is 20.3mm (0.800"). For sizes less than 20.3mm thickness, the parent piece is certified.
3. Index homogeneity is certified using an interferometer at 632.8nm. The numerical homogeneity is reported as the average through the thickness.

Striae

MIL-G-174B: Class 1, Grade A (through thickness)
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193nm Induced Absorption

Number of Pulses (x 10 ⁶)	193nm Transmittance %/cm ±0.05	193nm Induced Absorbance/cm
0	99.26	0.0
351	98.67	0.0026 ± 0.004
859	98.64	0.0027 ± 0.004

Exposure Conditions: 300Hz, 16nsec pulse duration, fluence 0.56mJ/cm²/pulse, 120mm pathlength

continued

Corning HPFS® for Deep Ultraviolet Applications *continued*

Internal Transmittance

Ti = 99.8 ± 0.1%/cm at 248nm
Ti = 99.0 ± 0.2%/cm at 193nm

Note:

Normalized to a 10mm thickness, surface reflection losses excluded.

Refractive Index

248nm	1.508551 ± 25ppm
193nm	1.560769 ± 25ppm
632.8nm	1.457018
(calculated per Malitson)	

Malitson's Dispersion Equation

$$n^2-1 = \frac{0.6961663\lambda^2}{\lambda^2 - (0.0684043)^2} + \frac{0.4079426\lambda^2}{\lambda^2 - (0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2 - (9.896161)^2}$$

Malitson I.H. Journal of the Optical Society of America: 1965 (λ=microns)

248nm and 193nm Densification Results

$\Delta\rho/\rho$ is defined as the unconstrained densification of the glass¹

[193nm: $\Delta\rho/\rho$ (ppm) = a x (NI)^b (N=Pulses, I=Fluence where a= 91.00 x 10⁻⁶, b=0.53)]

[248nm: $\Delta\rho/\rho$ (ppm) = a x (NI)^b (N=Pulses, I=Fluence where a= 7.00 x 10⁻⁶, b=0.53)]

Wavelength (nm)	Number of Pulses (x 10 ⁶)	Dose ³ (NI2 x 10 ⁶)	$\Delta\rho/\rho$ (ppm) (Measured) ⁴	$\Delta\rho/\rho$ (ppm) (Predicted)
193	32.0	5.73 ²	0.39	0.447
193	532.0	157.00	2.38	2.580
193	662.1	207.60	2.71	2.990
248	0.5	7,565.00	1.06	1.231
248	6.0	90,774.00	4.40	4.481

1 The unconstrained densification of the glass is that which would occur under conditions of uniform illumination of a sample. The optical path difference, OPD, for a specific sample geometry and illumination profile can be derived from $\Delta\rho/\rho$ using elastic analysis.

2 The fluence was 0.42 mJ/cm²/pulse. All other samples were tested at 0.56 mJ/cm²/pulse.

3 Exposure conditions 248nm: 400Hz, 16nsec pulse duration, fluence 123 mJ/cm²/pulse, 120mm pathlength.
Exposure conditions 193nm: 300Hz, 16nsec pulse duration, fluence 0.56 mJ/cm²/pulse, 120mm pathlength.

4 Measurements are made through the 12 cm path length on an interferometer at 632.8nm. Measurement error ± 0.04.

References:

(a) 193 nm Excimer Laser Induced Densification of Fused Silica, D.C. Allan, C. Smith, N.F. Borrelli, T.P. Seward III. Corning Incorporated, Corning N.Y. 14831. Optics Letters 1996. (b) Densification of Fused Silica Under 193 nm Excitation, N.F. Borrelli, C. Smith, D.C. Allan, T.P. Seward III. Corning Incorporated, Corning N.Y. 14831. Accepted for publication JOSA, B, July 1997.

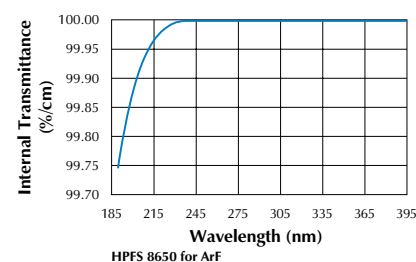
Corning HPFS® for ArF Applications

HPFS® 8650 fused silica has a very stable and predictable behavior under ArF laser exposure and is a low compaction, zero expansion material with minimized polarization induced birefringence. It can be used to manufacture state-of-the-art optical lenses for use in polarized immersion systems that require low wavefront distortion, higher laser damage resistance, low residual birefringence,

and high transmission specifications. HPFS® 8650 has a much greater laser resistance at 193nm versus the standard compaction curve. It is a compaction only material, showing no expansion.

Refractive Index

185nm	1.575106
194nm	1.558999
340nm	1.478656
(calculated per Sellmeier)	



Suprasil® for Excimer Laser Applications

Not all fused silica materials are alike.

This is especially true for deep UV applications, where the purity and chemical make-up of the glass may affect performance. All fused silica made today is subject to laser damage (in the form of absorption and/or compaction) when exposed to high intensity deep UV radiation from excimer sources. For a given fused silica, the amount of UV damage, measured by either changes in absorption, refractive index, or fluorescence, depends on the laser parameters (i.e. wavelength, energy density, number of pulses, and pulse width).

Start with well defined, consistent materials.

Heraeus Quarzglas GmbH, in Hanau, Germany, has done some of the most extensive UV laser research on fused silica materials in the world (see references #3 & #5). They have learned how to properly measure UV absorption (which is often a transient or time dependent characteristic).

Heraeus first learned how to measure, characterize, and model different types of fused silica, then they developed process improvements to optimize their materials. Today, Heraeus Suprasil 1 or 2 and Suprasil 312 or 311 are the most widely used materials for deep UV applications.

Because Heraeus' unique manufacturing processes are consistent and repeatable, they produce extremely homogeneous material that has become the material of choice, worldwide, for DUV microlithography applications as well as broadly applied excimer laser applications.

But what conditions cause damage?

For high light intensities (created by excimer lasers), the interaction between UV photons and the optical material must be taken into account. UV photons may generate defect centers, resulting in an aging of components (UV radiation damage). Induced absorption, induced refractive index change (or "compaction"), and induced fluorescence are of significant importance. A broad statement cannot be made covering all applications. Laser damage is highly dependent on the application.

The damage behaviors of two fused silica types, Suprasil® 2 and Suprasil® 312, differ dramatically. One can learn more about fused silica and DUV laser interaction from the papers listed.

References:

1. D. Griscom, Optical Properties and Structure of Defects in Silica Glass (J. Ceram. Soc. Jap., 1991), p. 99, 899-916.
2. D.J. Kraijnovich, I.K. Pour, A.C. Tam, W.P. Leung, and M.V. Kulkarni, 248nm Lens Materials: Performance and Durability Issues in an Industrial Environment (SPIE, 1848, 1993), p. 544.
3. N. Leclerc, Ch. Pfeleiderer, H. Hitzler, J. Wolfrum, K.O. Greulich, St. Thomas, H. Fabian, R. Takke, and W. Englisch, Transient 210nm Absorption in Fused Silica Induced by High-Power UV Laser Irradiation (Opt. Lett., 1991), p. 16(12), 940-942.
4. B. Scruggs and K.J. Gleason, The Role of Proton Nuclear Magnetic Resonance Spin-Lattice Relaxation Centers in the Strong Absorption Transition at 210nm in Fused Silica (J. Appl. Phys., 1994), p. 76(5), 3063-3067.
5. St. Thomas, W. Englisch, and R. Takke, Effect of Excimer Laser Radiation on the Optical Properties of Synthetic Fused Silica (Glass Sci. Techn., 1994), p. 67C, 19.
6. St. Thomas and B Kühn, KrF Laser Induced Absorption in Synthetic Fused Silica (Heraeus Quarzglas GmbH, 1996).