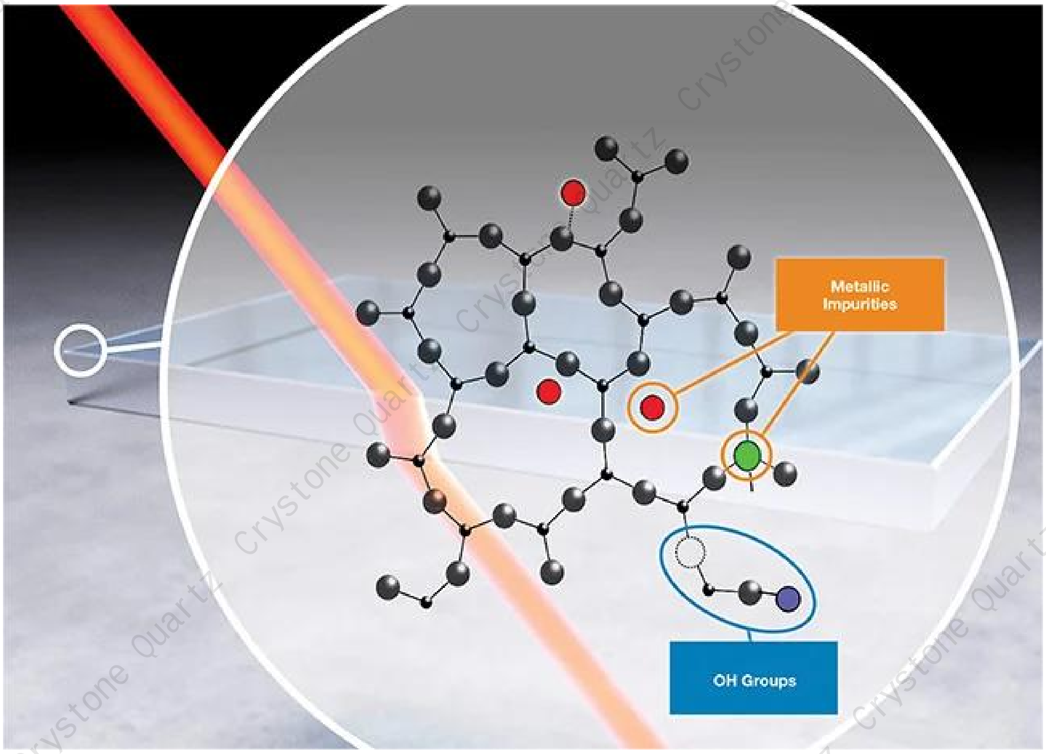
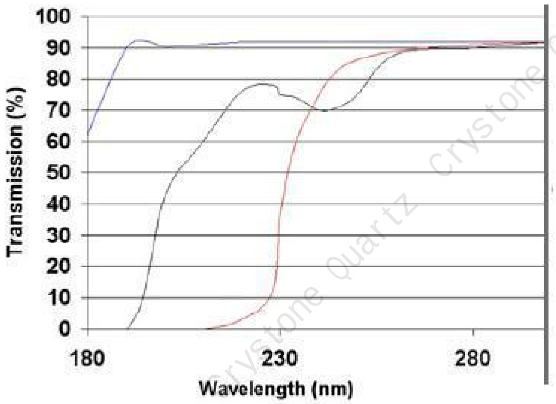
Quartz Glass

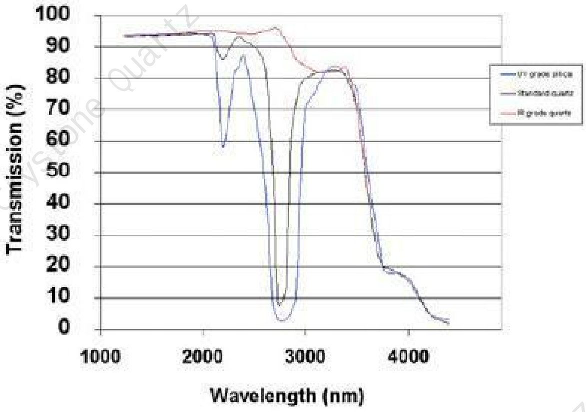
Quartz glass is a glass consisting of almost pure silica (silicon dioxide, SiO_2) in amorphous (non-crystalline) form. This differs from all other commercial glasses in which other ingredients are added which change the glasses' optical and physical properties, such as lowering the melt temperature. Fused quartz, therefore, has high working and melting temperatures, making it less desirable for most common applications.

The terms fused quartz and fused silica are used interchangeably but can refer to different manufacturing techniques, as noted below, resulting in different trace impurities. However fused quartz, being in the glassy state, has quite different physical properties compared to crystalline quartz. Due to its physical properties it finds specialty uses in semiconductor fabrication and laboratory equipment, for instance.



Compared to other common glasses, the optical transmission of pure silica extends well into the ultraviolet and infrared wavelengths, so is used to make lenses and other optics for these wavelengths. Depending on manufacturing processes, impurities will restrict the optical transmission, resulting in commercial grades of fused quartz optimized for use in the infrared, or (then more often referred to as fused silica) in the ultraviolet. The low coefficient of thermal expansion of fused quartz makes it a useful material for precision mirror substrates.





Manufacture

Fused quartz is produced by fusing (melting) high-purity silica sand, which consists of quartz crystals. There are four basic types of commercial silica glass:

Type I is produced by induction melting natural quartz in a vacuum or an inert atmosphere.

Type II is produced by fusing quartz crystal powder in a high-temperature flame.

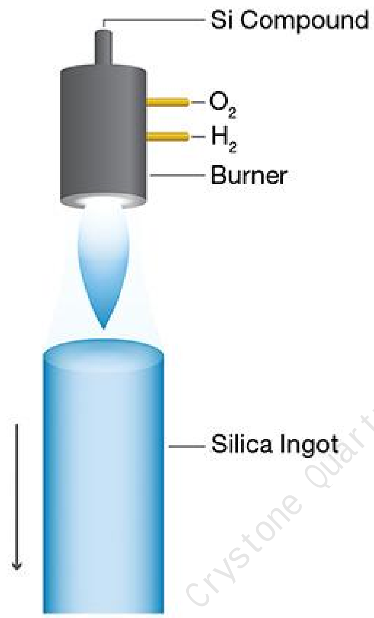
Type III is produced by burning $SiCl_4$ in a hydrogen-oxygen flame.

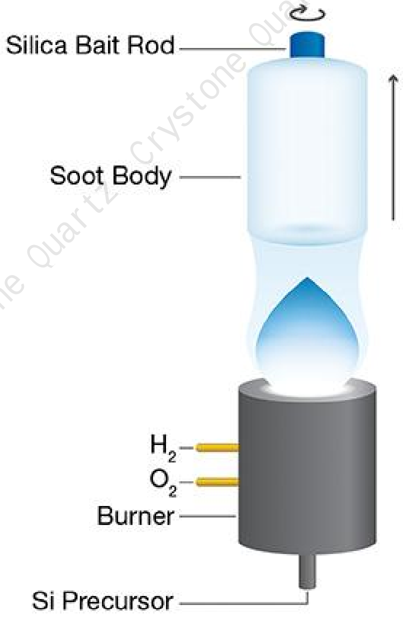
Type IV is produced by burning $SiCl_4$ in a water vapor-free plasma flame.

Quartz contains only silicon and oxygen, although commercial quartz glass often contains impurities. Two dominant impurities are aluminium and titanium which affect the optical transmission at ultraviolet wavelengths. If water is present in the manufacturing process, hydroxyl (OH) groups may become embedded which reduces transmission in the infrared.

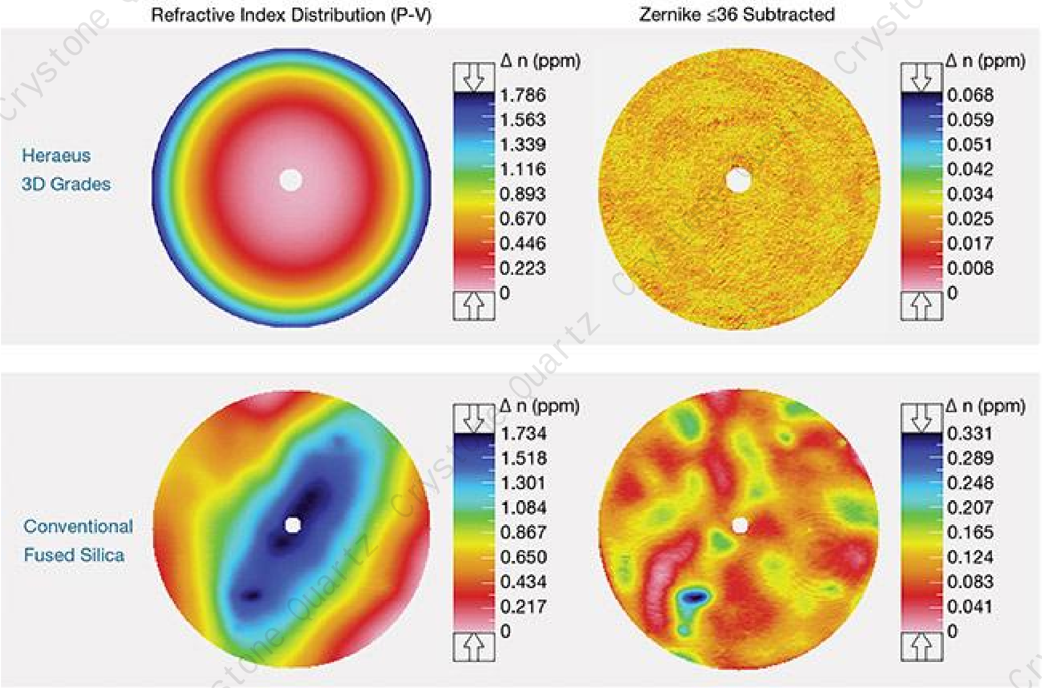
Fusion

Melting is effected at approximately 2200 °C (4000 °F) using either an electrically heated furnace (electrically fused) or a gas/oxygen-fuelled furnace (flame-fused). Fused silica can be made from almost any silicon-rich chemical precursor, usually using a continuous process which involves flame oxidation of volatile silicon compounds to silicon dioxide, and thermal fusion of the resulting dust (although alternative processes are used). This results in a transparent glass with an ultra-high purity and improved optical transmission in the deep ultraviolet. One common method involves adding silicon



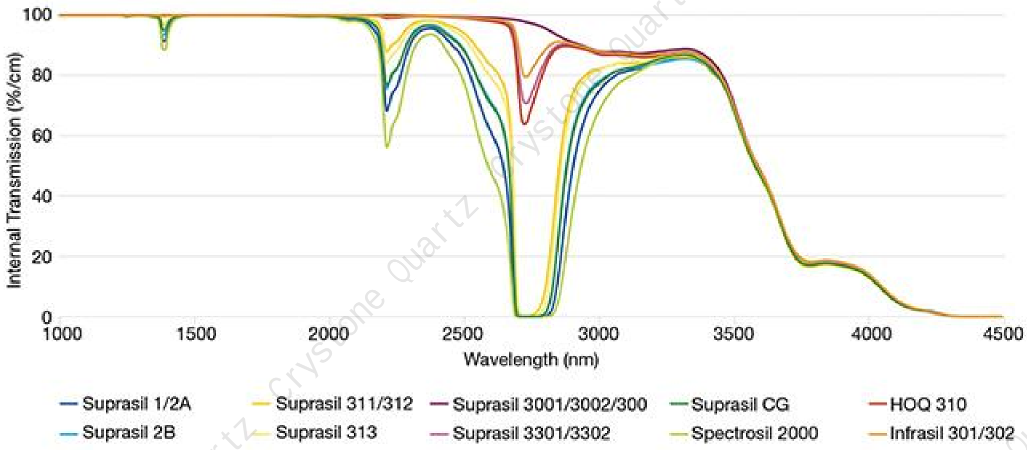


tetrachloride to a hydrogen-oxygen flame.



Product quality

Fused quartz is normally transparent. The material can, however, become translucent if small air bubbles are allowed to be trapped within. The water content (and therefore infrared transmission) of fused quartz is determined by the manufacturing process. Flame-fused material always has a higher water content due to the combination of the hydrocarbons and oxygen fueling the furnace, forming hydroxyl [OH] groups within the material. An IR grade material typically has an [OH] content below 10 ppm.

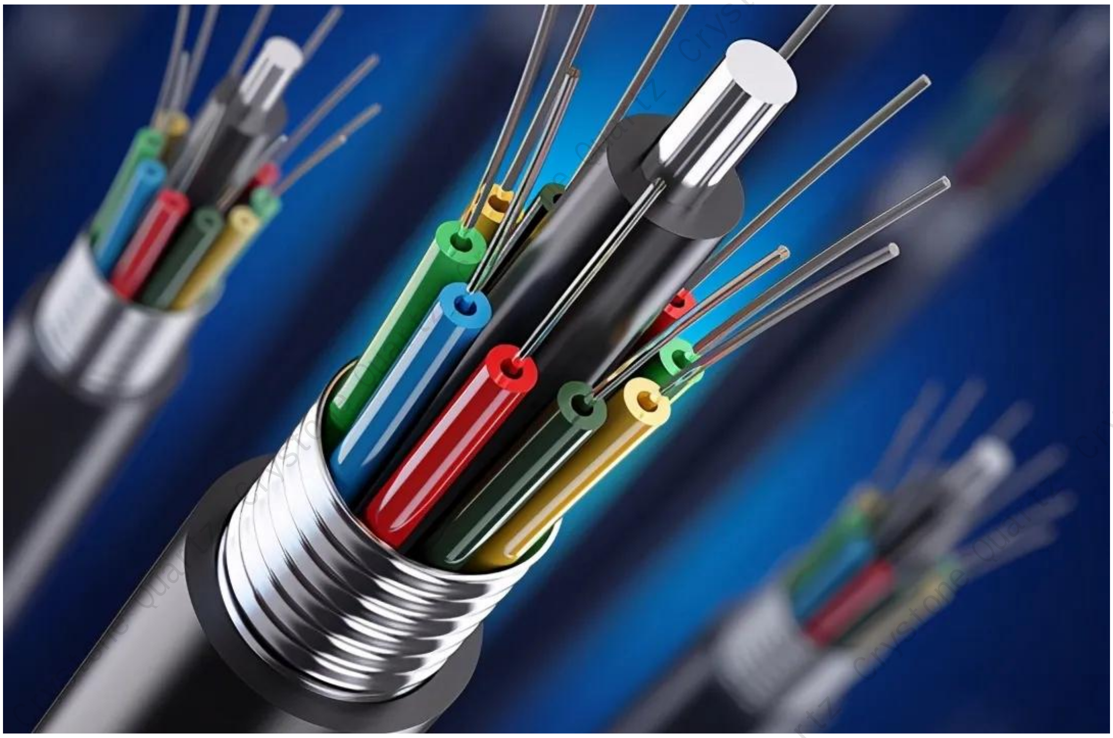


Applications

Many optical applications of fused quartz exploit its wide transparency range, which can extend well into the ultraviolet and into the near-mid infrared. Fused quartz is the key starting material for optical fiber, used for telecommunications.

Because of its strength and high melting point (compared to ordinary glass), fused quartz is used as an envelope for halogen lamps and high-intensity discharge lamps, which must operate at a high envelope temperature to achieve their combination of high brightness and long life. Some high-power vacuum tubes used silica envelopes whose good transmission at infrared wavelengths facilitated radiation cooling of their incandescent anodes.

Because of its physical strength, fused quartz was used in deep diving vessels such as the bathysphere and benthoscope and in the windows of crewed spacecraft, including the Space Shuttle and International Space Station. Fused quartz was used also in composite armour development.



In the semiconductor industry, its combination of strength, thermal stability, and UV transparency makes it an excellent substrate for projection masks for photolithography.

Fused quartz has nearly ideal properties for fabricating first surface mirrors such as those used in telescopes. The material behaves in a predictable way and allows the optical fabricator to put a very smooth polish onto the surface and produce the desired figure with fewer testing iterations. In some instances, a high-purity UV grade of fused quartz has been used to make several of the individual uncoated lens elements of special-purpose lenses including the Zeiss 105 mm f/4.3 UV Sonnar, a lens formerly made for the Hasselblad camera, and the Nikon UV-Nikkor 105 mm f/4.5 (presently sold as the Nikon PF10545MF-UV) lens. These lenses are used for UV photography, as the quartz glass can be transparent at much shorter wavelengths than lenses made with more common flint or crown glass formulas.

Fused quartz can be metallised and etched for use as a substrate for high-precision microwave circuits, the thermal stability making it a good choice for narrowband filters and similar demanding applications. The lower dielectric constant than alumina allows higher impedance tracks or thinner substrates.

Refractory material applications

Fused quartz as an industrial raw material is used to make various refractory shapes such as crucibles, trays, shrouds, and rollers for many high-temperature thermal processes including steelmaking, investment casting, and glass manufacture. Refractory shapes made from fused quartz have excellent thermal shock resistance and are chemically inert to most elements and compounds, including virtually all acids, regardless of concentration, except hydrofluoric acid, which is very reactive even in fairly low concentrations. Translucent fused-quartz tubes are commonly used to sheathe electric elements in room heaters, industrial furnaces, and other similar applications.

Owing to its low mechanical damping at ordinary temperatures, it is used for high-Q resonators, in particular, for wine-glass resonator of hemispherical resonator gyro. For the same reason fused quartz is also the material used for modern glass instruments such as the glass harp and the verrophone, and is also used for new builds of the historical glass harmonica, giving these instruments a greater dynamic range and a clearer sound than with the historically used lead crystal.

Quartz glassware is occasionally used in chemistry laboratories when standard borosilicate glass cannot withstand high temperatures or when high UV transmission is required. The cost of production is significantly higher, limiting its use; it is usually found as a single basic element, such as a tube in a furnace, or as a flask, the elements in direct exposure to the heat.

Properties of fused quartz

The extremely low coefficient of thermal expansion, about 5.5×10^{-7}/K (20 – 320 ° C), accounts for its remarkable ability to undergo large, rapid temperature changes without cracking (see thermal shock).

Phosphorescence in fused quartz from an extremely intense pulse of UV light in a flashtube, centered at 170 nm

Refractive index

The optical dispersion of fused quartz can be approximated by the following Sellmeier equation:

where the wavelength is measured in micrometers. This equation is valid between 0.21 and 3.71 μm and at 20 °C. Its validity was confirmed for wavelengths up to 6.7 μm. Experimental data for the real (refractive index) and imaginary (absorption index) parts of the complex refractive index of fused quartz reported in the literature over the spectral range from 30 nm to 1000 μm have been reviewed by Kitamura et al. and are available online.

Its quite high Abbe Number of 67.8 makes it among the lowest dispersion glasses at visible wavelengths, as well as having an exceptionally low refractive index in the visible (n_d = 1.4585). Note that fused quartz has a very different and lower refractive index compared to crystalline quartz which is birefringent with refractive indices n_o = 1.5443 and n_e = 1.5534 at the same wavelength. Although these forms have the same chemical formula, their differing structures result in different optical and other physical properties.

List of physical properties

- Density: 2.203 g/cm^3
- Hardness: 5.3–6.5 (Mohs scale), 8.8 GPa
- Tensile strength: 48.3 MPa
- Compressive strength: > 1.1 GPa
- Bulk modulus: ~37 GPa
- Rigidity modulus: 31 GPa
- Young's modulus: 71.7 GPa
- Poisson's ratio: 0.17
- Lamé elastic constants: λ = 15.87 GPa, μ = 31.26 GPa
- Coefficient of thermal expansion: 5.5 × 10^{-7}/K (average 20–320 °C)
- Thermal conductivity: 1.3 W/(m•K)
- Specific heat capacity: 45.3 J/(mol•K)
- Softening point: ≈ 1665 °C
- Annealing point: ≈ 1140 °C
- Strain point: 1070 °C
- Electrical resistivity: > 10^{18} Ω•m
- Dielectric constant: 3.75 at 20 °C 1 MHz
- Dielectric loss factor: less than 0.0004 at 20 °C 1 MHz typically 6 × 10^{-5} at 10 GHz

- Dielectric strength: 250 - 400 kV/cm at 20 °C
- Magnetic susceptibility: -11.28×10^{-6} (SI, 22 °C)
- Hamaker constant: $A = 6.5 \times 10^{-20}$ J.
- Surface tension: 0.300 N/m at 1800 - 2400 °C
- Index of refraction: $n_d = 1.4585$ (at 587.6 nm)
- Change of refractive index with temperature: 1.28×10^{-5}/K (20 - 30 °C)
- Stress-optic coefficients: $p_{11} = 0.113$, $p_{12} = 0.252$.
- Abbe number: Vd = 67.82