QUARTZ GLASS

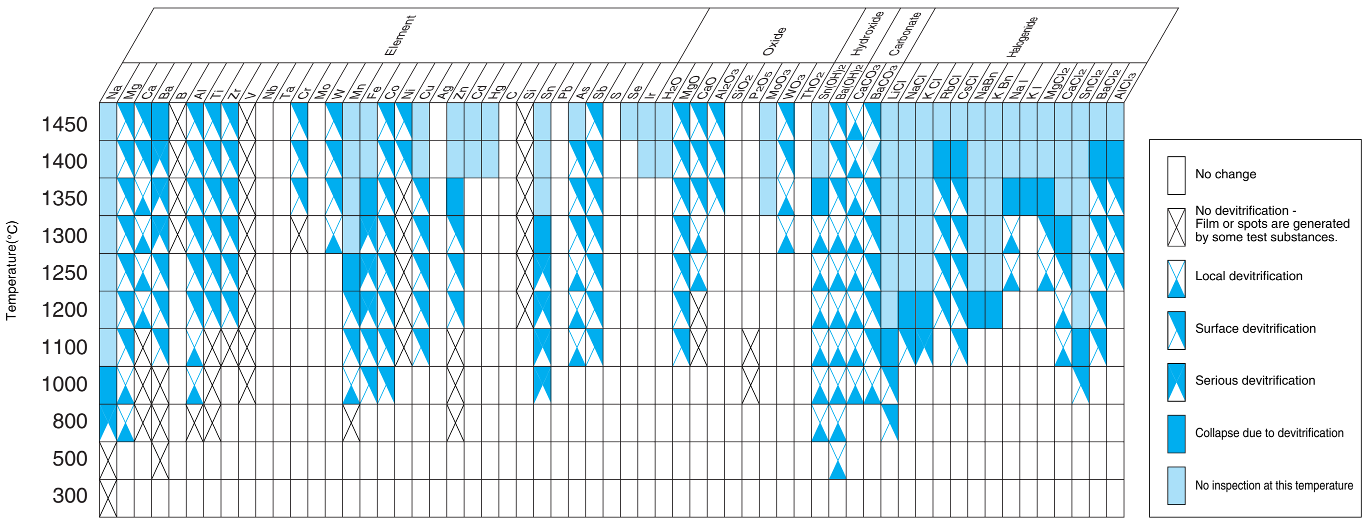
■Fused quartz products (for semiconductor)

Kind	Features	Applications
214 solid bar	Transparent fused quartz solid bars with minimized air lines and foreign substances, and very stable dimensions.	Processed and used for wafer carrier in the semiconductor industry.
214 LD quartz tube	Transparent fused quartz tubes with excellent features equal to those of 214. Used for large diameters.	Used for diffusion, oxidation, LPCVD, etc. in the semiconductor industry.
224 quartz tube, LD tube, solid bar	Excellent high-viscosity and appearance equal to those of 214. The alkali content is lowered to the PPB level by a special process.	Used for a semiconductor diffusion furnace of severe conditions, under which even a very small quantity of alkaline component will adversely affect the chip yield.
244 quartz tube, LD tube, solid bar	Equivalent to 224. The alumina level is lower.	For customers looking for quartz with a low alumina level.
124 ingot	Used for transparent quartz plates and transparent window plates. Made from an ingot of 1.8 meter in diameter, 60 centimeters in height, and 4 tons in weight. High-purity material, containing very small bubbles occasionally. Made in various sizes and shapes.	Used for wafer carrier and flange structure processing in the semiconductor industry. Also used for various chemical purposes that demand low cost and high quality.
144 ingot	Equivalent to the 124 grade. The alumina, potassium, and sodium levels are lower.	For customers looking for materials with low alumina, potassium, and sodium levels.
012 ingot	Transparent synthetic fused quartz ingot in the same shape as 124.	The very high purity permits its use for plates and discs used in the most important semiconductor process.

■Reactivity

Most acid, metal, chlorine, and bromine will not react with fused quartz at normal temperatures. Fused quartz slightly react with an alkaline solution, and the activity increases as the temperature and the concentration of the solution increase. Phosphoric acid reacts with fused quartz at temperatures exceeding 150°C. Hydrofluoric acid alone reacts with fused quarts at any temperature. Carbon and some metals deoxidize the fused quartz, while basic oxides, carbonates, sulfates, etc. react with fused quartz generating high temperatures. In short, fused quartz will not react at all in general use. Reaction of various elements and compounds with fused quartz at high temperatures can be observed in vacuum. Each specimen is kept at the lowest temperature for one hour, and then kept at a higher temperature for one hour. Such operation is repeated. The reactivity depends on the retention time.

● **Profile of the reaction of fused quartz with specific elements and compounds at high temperature**



■Pressure-proof design

Fused quartz is used for products that receive pressure; therefore, it is necessary to understand the maximum pressure that tubes of respective dimensions can withstand. Values at room temperature can be calculated according to the following formula.

● Rupture formula for transparent fused quartz tube

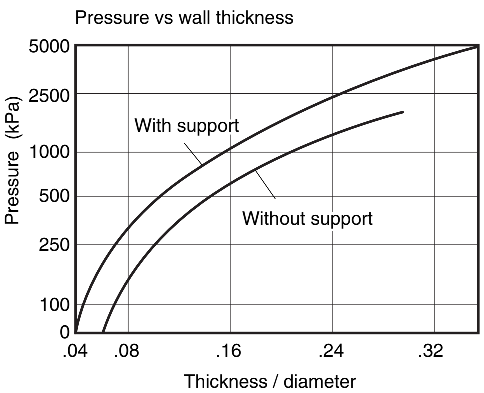
Formula : $S=\frac{pr}{t}$

S =Annular stress(Pa)
p =Working pressure(Pa)
r =Tube bore(mm)
t =Wall thickness(mm)

This formula does not apply to cases where the inner pressure exceeds 7×10^5 Pa (100 psi).

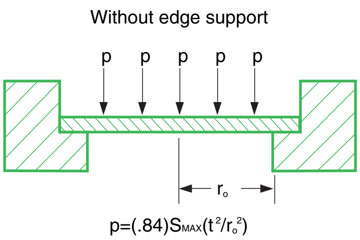
● Rupture formula for transparent fused quartz disc and flat plate

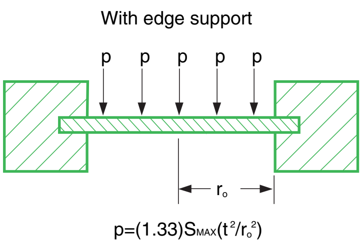
It is necessary to calculate the pressure difference with respect to various apllications of fused quartz discs, flat plates, and transparent windows that receive stress.



Max. pressure with and without support: Obtained by multiplying by the coefficient of the horizontal axis with respect to a specific pressure.
Source: Momentive Performance Materials Inc.

The formula shown below applies to cases where a circular part is used at room temperature irrespective of the existence of a surrounding support.





p=Pressure difference (Pa)
r_0=Radius (mm) of a disc (width in the case of a flat plate) that is not supported
Smax=Max. stress (safety factor of approx. 7:1) 7.0 x 106 (Pa)
t=Thickness of a disc (mm)

However, the following conditions that affect the strength of these parts must be taken into consideration when using this formula.

a.The surface shall be sufficiently polished and free from damage.
b.Method of clamping a sample to attach it to a pressure implement
c.Gasket material
d.Temperature gradient on the surface and between two sides
e.Pressure increasing rate
f.Temperature of the sample itself

■Physical properties

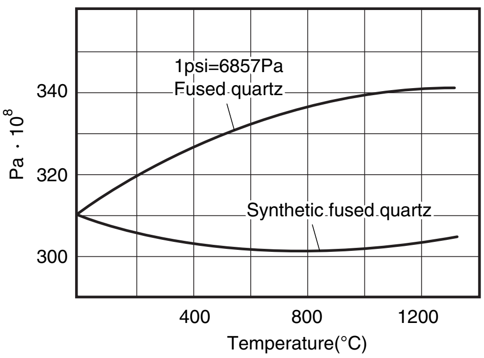
The physical properties of fused quartz are almost the same as those of other types of glass. Fused quartz is not affected by compression, and the design compressive strength exceeds 1.1 x 109 Pa (160,000 psi). Any glass will lose its original strength substantially when the surface is scratched, and the tensile strength will also be affected substantially. When the condition of the surface is satisfactory, the design tensile strength of fused quartz exceeds 4.8 x 107 (7000 psi). In practice, the design stress of 0.68 x 107 Pa (1,000 psi) is recommended in general. The table below shows the data as to the standard physical properties.

● Standard physical properties of 214 transparent fused quartz

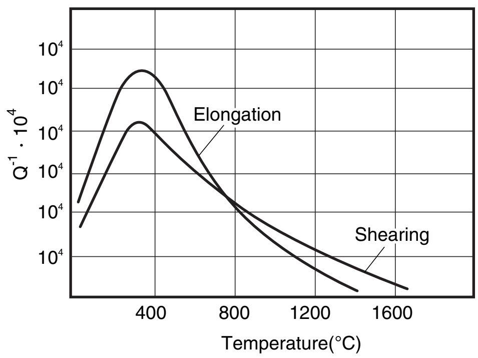
Characteristic	Standard value
Specific gravity	2.2×10^{3}kg/m^{3}
Strength	5.5-6.5(Mohs' scale)
Design tensile strength	570KHN100
Design compressive strength	4.8×10^{7}Pa(N/m^{2})(7000psi)
Modulus of elasticity of volume	1.1×10^{9}Pa(5.3×10^{6}psi)
Modulus of rigidity	3.1×10^{10}Pa(4.5×10^{6}psi)
Young's modulus	7.2×10^{10}Pa(10.5×10^{6}psi)
Poisson's ratio	0.17
Coefficient of thermal expansion (20~320°C)	5.5×10^{-7}/°C
Thermal conductivity (20°C)	1.4W/m · °C
Specific heat (20°C)	670J/kg · °C
Softening point	1683°C
Slow cooling point	1215°C
Distortion point	1120°C
Specific resistance (350°C)	$7\times10^{7}\Omega$cm

Characteristic	Standard value	
Dielectric constant (20°C 1Mz)	3.75	
Withstanding voltage	5×10^{7}V/m	
Loss factor	4×10^{-4} max	
Dissipation factor	1×10^{-4} max	
Refractive index	1.4585	
Shrinkage (nu value)	67.56	
Acoustic velocity (transversal wave)	3.75×10^{3}m/s	
Acoustic velocity (longitudinal wave)	5.90×10^{3}m/s	
Sound damping factor	11db/mMHz max	
Transmissivity (700°C) cm² mm/cm² sec.cm of Hg	Helium	210×10^{-10}
	Hydrogen	21×10^{-10}
	Deuterium	17×10^{-10}
	Neon	9.5×10^{-10}

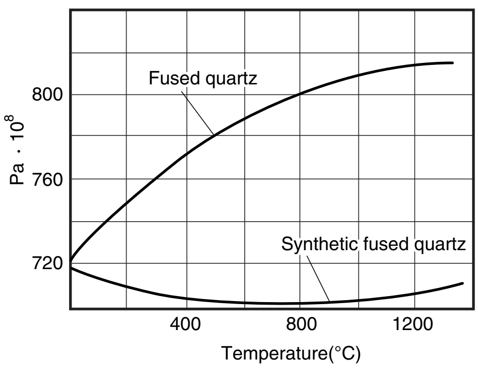
Modulus of rigidity



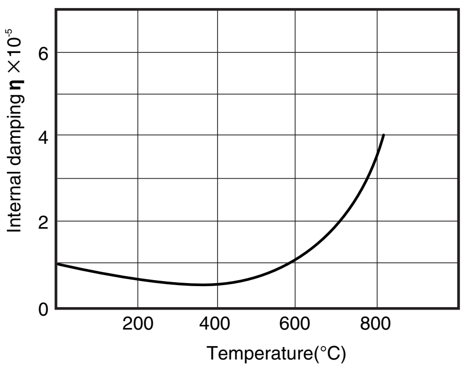
Internal friction due to elongation and shearing with respect to synthetic fused quartz



Young's modulus



Internal damping factor



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■Heat characteristic

One of the most important features of the fused quartz is the very small coefficient of thermal expansion, which is 5.5 x 107/°C (20~320°C). This coefficient is 1/34 of that of copper and 7/1 of that of borosilicate glass. Therefore, fused quartz is used for precision optical products such as optical plates, mirrors, furnace windows, and other products that need minimization of the sensitivity to temperature change. Another specific property is very high thermal shock resistance. For example, a wafer of fused quartz will not break even if it is suddenly heated up to 1500 °C or more and then quenched in water.

● Experimental slow cooling rate of fused quartz

Cooling from both sides: $\text{Cooling rate (°C/min)} = 4274.7 \times \dfrac{\text{Residual stress(Pa)}}{(\text{Wall thickness mm})^2}$

Cooling from one side: $\text{Cooling rate(°C/min)} = 4274.7 \times \dfrac{\text{Residual stress(Pa)}}{(2 \times \text{Wall thickness mm})^2}$

The residual stress or the design stress depend on the usage, but they are within the range of 1.7×10^7~20.4×10^7 Pa (25~300 psi).
When the wall thickness is less than 25 mm, fused quartz can be cooled at the rate of 100°C/hour, in general.

● Influence of temperature

Fused quartz is a solid at room temperature, but it changes into a glass state at high temperatures. Unlike a crystalline structure, fused quartz has no clear melting point, and it softens within a wide temperature range. The area in which a solid changes into the plastic state is called the transformation range, which is identified by the continuous change of viscosity accompanying the temperature rise.

● Viscosity

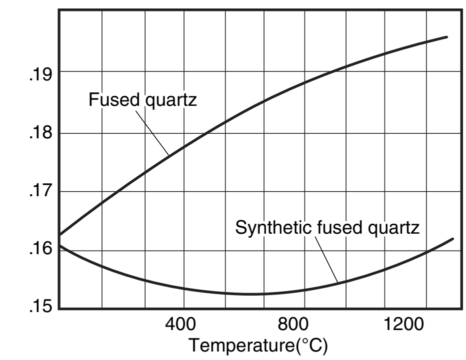
Viscosity is a scale of flow resistance when a substance receives a shear stress. Since the range of “flow property” is very wide, the scale of viscosity is represented by a logarithm usually. Glass terminologies that represent viscosity are the distortion point, slow cooling point, and softening point, which are defined as follows.

Distortion point : The temperature at which the internal stress is practically cancelled, which corresponds to the viscosity of $10^{14.5}$ poise. (1 poise = 1 dyne/cm^2 sec)

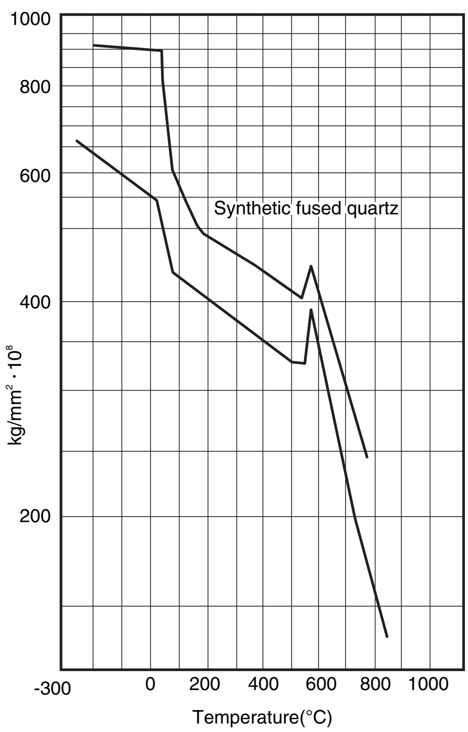
Slow cooling point : The temperature at which the internal stress is practically cancelled in 15 minutes, which corresponds to the viscosity of $10^{13.2}$ poise.

Softening point : The temperature at which the glass deforms by its own weight, which corresponds to the viscosity of $10^{7.6}$ poise. The reported softening point of quartz ranges from 1500°C ~ 1670°C depending on the measuring conditions.

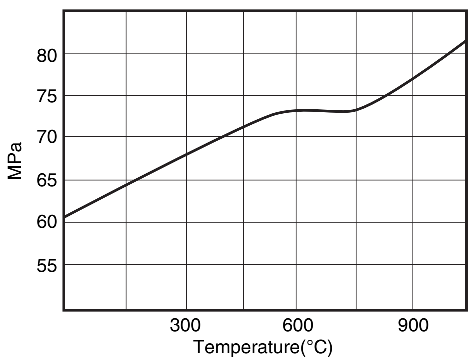
Poisson's ratio



Hardness



Fracture value



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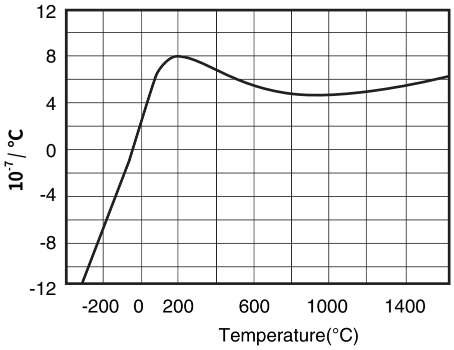
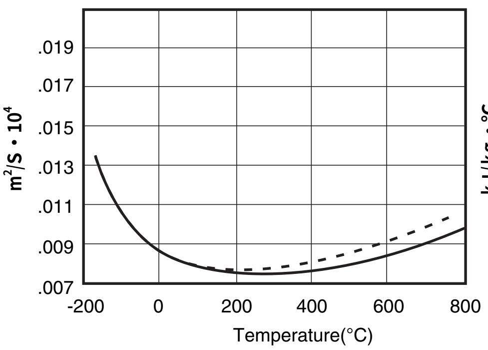
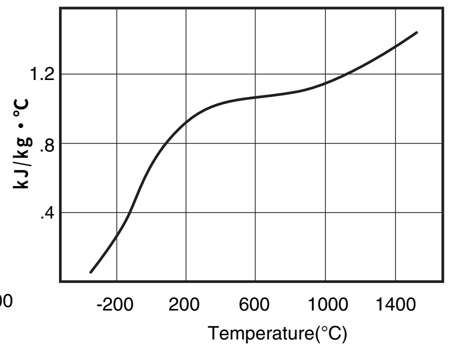
Specific heat



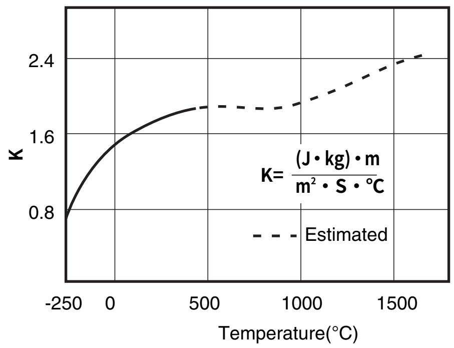
Diffusion of heat



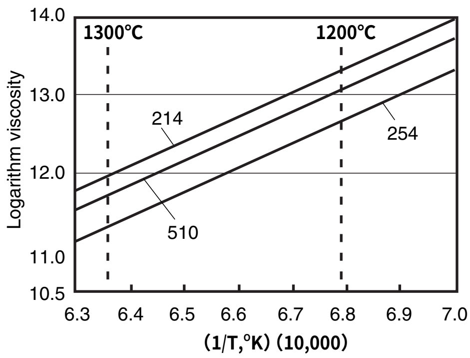
Heat capacity



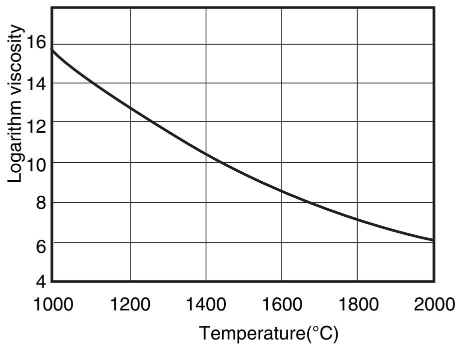
Thermal conductivity



Viscosity test



Viscosity



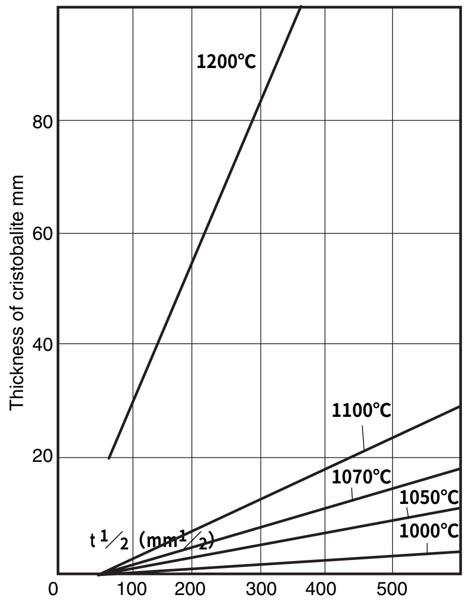
● Devitrification

Devitrification and particle production are factors that put limitations on the performance of fused quartz at high temperatures. Devitrification has two processes – nucleus formation and crystal growth. In general, the devitrification rate of fused quartz is small because the nucleus formation of the cristobalite phase occurs only on the surface and the growth rate of the crystal phase is small. The nucleus formation of fused quarts begins, in general, when the surface of contaminated by alkaline elements and other metals. It is known that the rate of nuclear formation that occurs irregularly is comparatively smaller in the non-stoichiometric fused quarts like the quartz made by Momentive Performance Materials Inc. than in the stoichiometric quartz materials.

● Growth of cristobalite

The growth rate of cristobalite in a nucleus formation place depends on certain environmental factors and the characteristics of the material. The temperature and viscosity of quartz are the most important factors, while oxygen and the partial pressure of steam also affect the crystal growth rate. The devitrification rate of fused quartz increases as the hydroxyl group (OH-) content increases, the viscosity decreases, and the temperature rises. Therefore, the high-viscosity fused quartz containing a small quantity of hydroxyl groups, which are produced by Momentive Performance Materials Inc. excels in the devitrification resistance. Transfer to the β cristobalite does not occur usually at temperatures below 1000°C. When exposed to the temperature cycle of the transfer temperature (-250°C) from the β cristobalite to the α cristobalite, fused quartz may lose its original structure. Since the specific volume changes substantially during the transfer, spalling or physical rupture in some cases will occur.

Thickness of cristobalite/time



204 fused quartz. Similar phenomenon is observed in 214.

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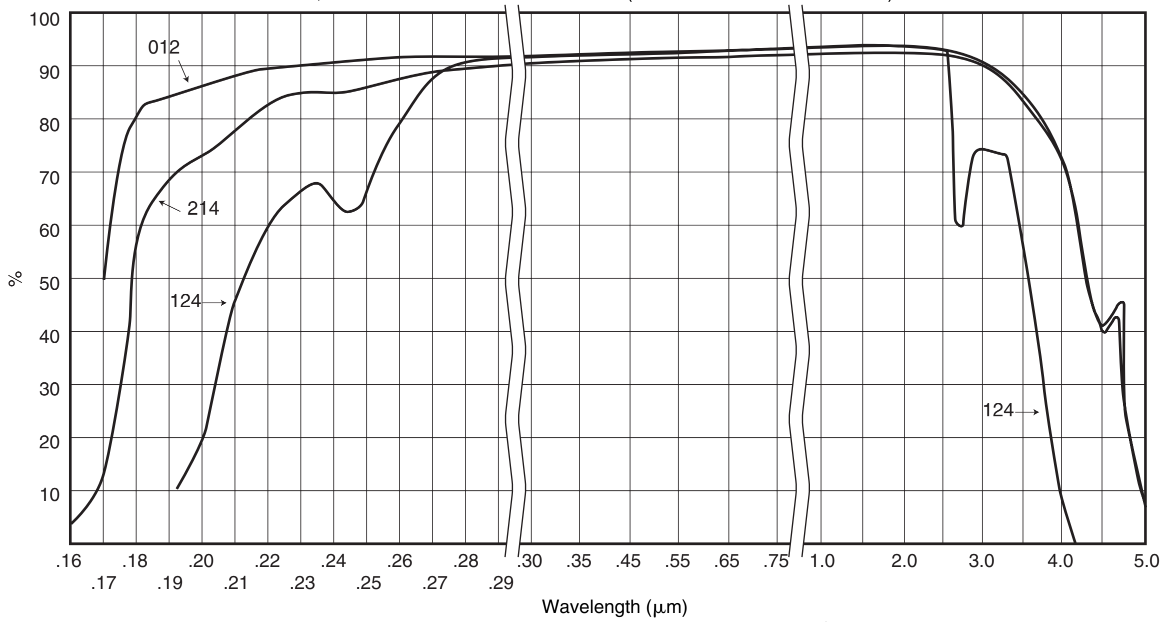
■Optical characteristics

The optical transmissivity is used as a means to distinguish various types of vitreous silica, because the transparency reflects the purity of material and production method. Specific indexes are the ultraviolet blockade, ultraviolet absorption at 245 nm, and the existence of absorption band at 2.73μm. The UV blockade range of a 10 mm-thick sample is 155-175 nm, which reflects the purity of pure fused quartz. Transition metal impurities shift the blockade value in the longer wavelength direction. If desirable, impurities are added intentionally to increase the UV absorption. For example, titanium is added to the 219 fused quartz tube. The absorption band at 245 nm is a characteristic of deoxidized glass, indicating that it is made by electric fusion. When vitreous silica is made by the “wet” process, for example the oxyhydrogen fusion and synthesis method, the basic vibrational band of the hydroxyl ions contained structurally is strongly absorbed at 2.73μm.

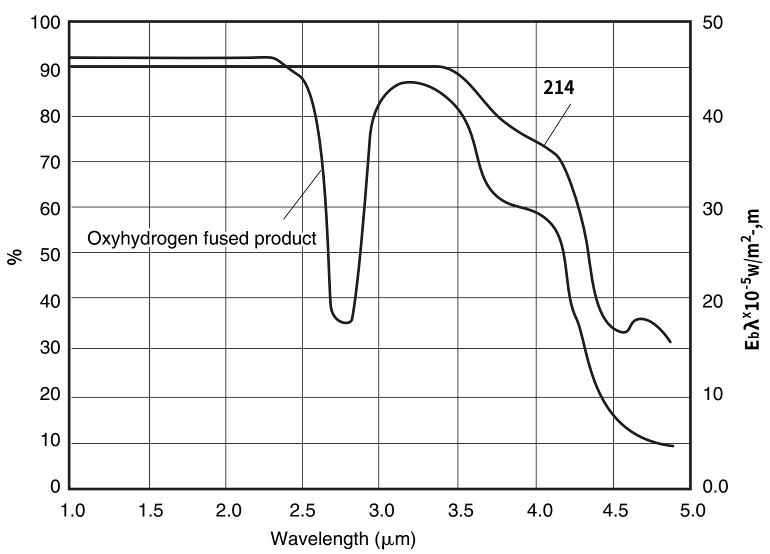
● UV blockade

As the transmission curve shows, the UV blockade value of the 214 fused quartz tube (1 mm in thickness) is below 160 nm, and slight absorption is observed at 245 nm. Absorption by hydroxyl ions is unrecognizable. The 219 fused quartz contains titanium at the rate of approx. 100 ppm. Samples of 1mm in thickness can block UV below 230 nm. The infrared range of samples of 1 mm in thickness is 4.5-5.0 μm. The graph below shows in detail the transmissivity of the 214 and 124 fused quartz, including the loss due to reflection on both sides. The transmissivity of a 214 sample of 1 mm in thickness and that of a 124 sample of 1 mm in thickness are shown. The 124 fused quartz is a very effective infrared radiation transmission material. The infrared is transmitted up to 4μm and is slightly in the “water absorption band” at 2.73μm. The transmissivity of samples that are different in thickness from these samples can be calculated by the formula shown below.
$T = (1-R)2e^{-\alpha t}$, where T = transmissivity represented by a decimal point, R = surface reflection loss on one side, e = base number of natural logarithm, α = absorption factor (cm^{-1}), and t = thickness (cm).

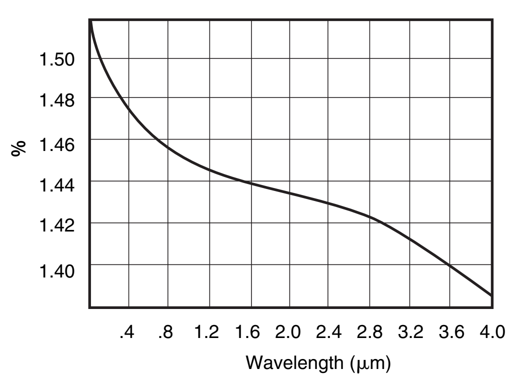
Average transmission curve of fused quartz
The thickness of 124 is 10 mm, and the thickness of others is 1 mm (surface reflection loss included).



Infrared ray transmissivity



Refractive index



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Average transmissivity of 124 fused quartz
100 mm in thickness (surface reflection loss included)

Wavelength (μm)	Average transmissivity (%)	Average Absorption tactor(CM^{-1})
.225	65.0	.342
.230	67.4	.308
.240	62.6	.383
.250	69.5	.280
.270	89.0	.035
.300	91.2	.014
.350	91.9	.009
.450	92.5	.005
.550	92.3	.004
.650	92.9	.003
.750	92.8	.005
1.00	93.2	.002
1.50	93.4	.001
2.00	93.6	.001
2.50	93.2	.007
2.60	92.9	.011
2.73	59.3	.460
2.90	85.2	.099
3.00	83.3	.122
3.17	82.5	.132
3.32	83.6	.120
3.60	48.3	.671
3.80	17.2	1.704
3.88	17.5	1.687
4.14	1.7	4.017
4.27	1.5	4.135
4.31	0	∞

Average transmissivity of 214 fused quartz
1 mm in thickness (surface reflection loss included)

Wavelength (μm)	Average transmissivity (%)	Average Absorption tactor(CM^{-1})
.160	4.6	4.6
.162	5.8	5.8
.164	7.4	7.4
.166	8.4	8.4
.168	10.9	10.9
.170	18.5	18.5
.175	43.6	43.6
.180	60.4	60.4
.185	66.1	66.1
.190	70.4	70.4
.200	71.3	71.3
.205	73.4	73.4
.210	76.1	76.1
.220	79.4	79.4
.230	85.3	85.3
.240	87.3	87.3
.245	86.5	86.5
.250	86.6	86.6
.260	87.7	87.7
.270	89.5	89.5
.280	90.2	90.2
.290	90.7	90.7
.300	90.9	90.9
.350	91.1	91.1
.450	92.2	92.2
.550	92.5	92.5
.650	92.7	92.7
.750	92.9	92.9
1.00	93.1	93.1
1.50	93.2	93.2
2.00	93.5	93.5
2.50	93.4	93.4
2.65	93.5	93.5
2.75	93.0	93.0
2.80	92.9	92.9
2.90	92.9	92.9
3.00	92.7	92.7
3.10	92.7	92.7
3.20	92.8	92.8
3.30	92.8	92.8
3.43	92.7	92.7
3.80	81.2	81.2
3.92	81.0	81.0
4.20	67.5	67.5
4.25	66.0	66.0
4.30	57.5	57.5
4.45	43.1	43.1
4.58	49.7	49.7
4.70	36.1	36.1

● Storage

Store the fused quartz in the original shipping container as long as there is space. If it is impossible, keep the packed fused quartz as it is. Do not remove the cover at both ends of quartz tubes in order to prevent damage to both ends, protecting them from dust and humidity that adversely affect the purity and performance of quartz tubes.

● Washing

When cleanliness is required in the application, wash products in the following manner. Wash the products, especially the quartz tube, with demineralized water or distilled water to which a degreasing agent is added. Soak the fused quartz in a 7% (max.) hydrogen fluoride ammonia solution within 10 minutes or in a 10 vol% (max.) hydrofluoric acid solution within 5 minutes. Surface etching will remove all sorts of dirt together with a small quantity of fused quarts from the surface. In order not to leave traces of water drops that cause devitrification in the later heating process, wash the fused quartz with several times demineralized water or distilled water and dry it immediately. In order to reduce the possibility of contamination, carefully handle the fused quartz. It is also important to wear clean gloves at all times. Avoid washing semitransparent quarts tubes because water and acid solutions easily enter most of capillaries of semitransparent quarts tubes. When the capillary section is heated rapidly up to a high temperature to cope with the above phenomenon, quartz tubes may burst.

Rate of dissolution