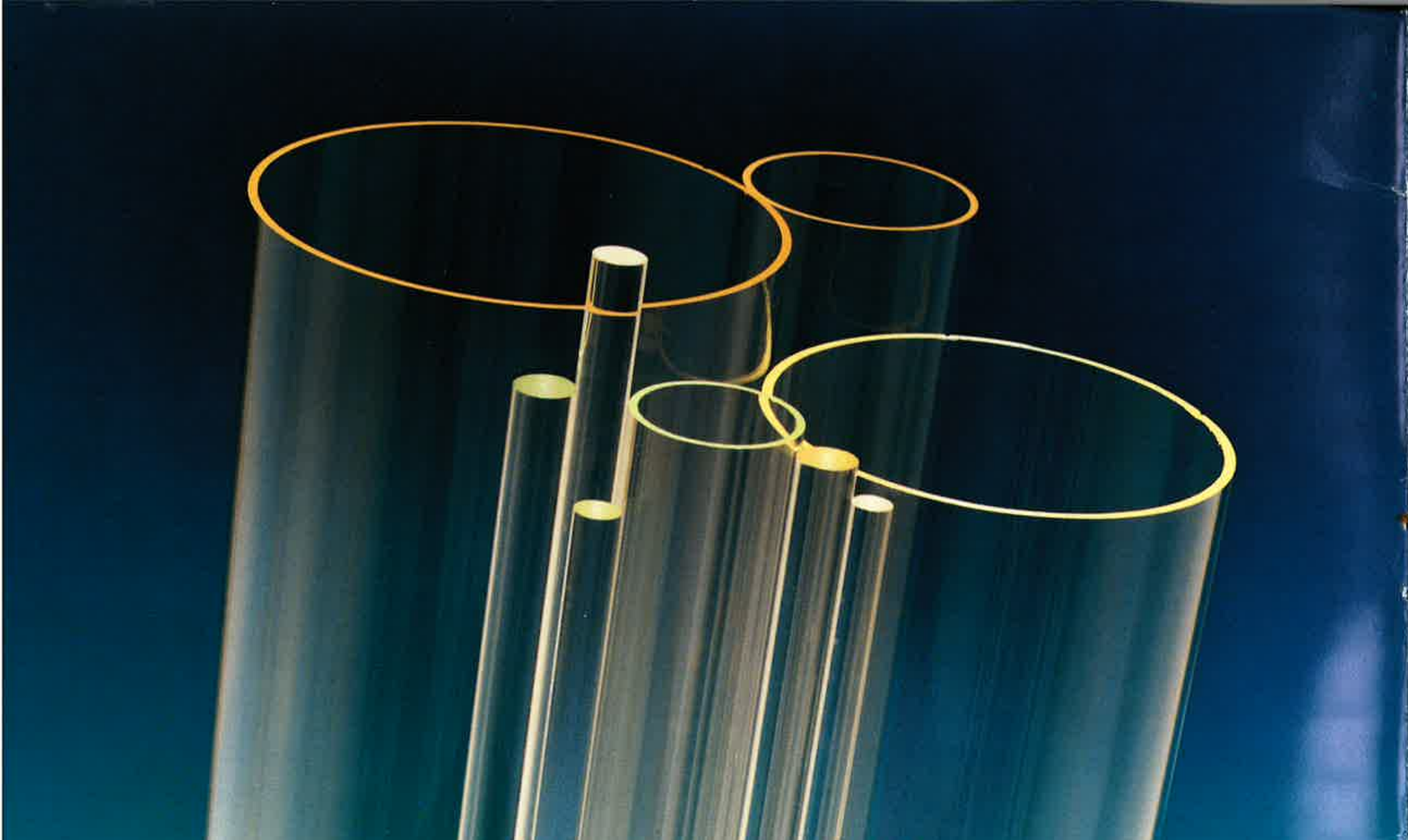
GE Quartz



High Purity Materials For Demanding Applications

Contents

Fused quartz was first developed by GE to withstand the elevated operating temperatures of high performance lamps. Indeed, lighting is a leading use for quartz today in such products as metal halide, quartz halogen and mercury vapor lamps. Newer applications include UV lamps and UV blocking lamps.

Uses for high purity GE quartz have grown beyond lighting, however, to include semiconductor and fiber optics applications.

In its production of fused quartz, GE utilizes a proprietary beneficiation process that produces ultra high-purity starting materials. Continual improvements in this technology enables GE to offer the highest quality products for the world's growing number of quartz users.

In fact, GE is so confident of the quality level of its quartz that the familiar GE monogram appears on those products that can accept it. Putting the brand name on the product gives you the assurance that it meets GE's high standards for purity and that we regard it as superior to commodity varieties of fused quartz tubing.

The quartz product line from GE includes clear and translucent tubing, rod and other solid shapes, and fused quartz crucibles for growing single crystal silicon.

On the following pages, the various GE fused quartz products and their applications are discussed in detail, complete with engineering data that designers can use in preparing their specifications.

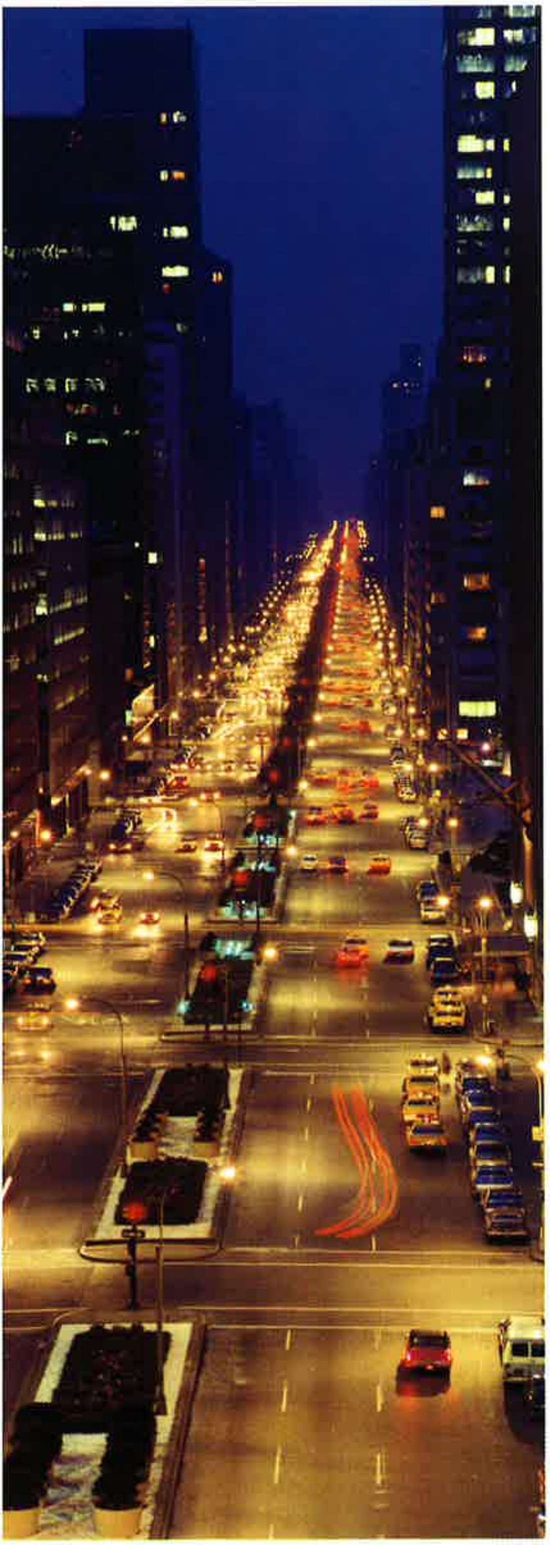
Worldwide Distribution

GE Quartz products are supplied directly to users, or through a worldwide network of sales representatives. A list is available from GE Quartz.

Fused Quartz Products

Type	Description	Typical Applications
STANDARD GRADE		
214 Tubing	The industry standard clear fused quartz material. Economical and available in a full range of sizes. Excellent visual, thermal and mechanical properties with low hydroxyl content and tight dimensional tolerances.	High performance and high temperature lamps such as mercury and quartz halogen, UV lamps, thermocouples, semiconductor quartzware, waveguide handles, and other high temperature products.
LIGHTING GRADES		
219 Tubing	Clear fused quartz tubing doped with titanium oxide to block deep UV radiation. Visual and dimensional characteristics are identical to Type 214, while thermal and mechanical properties are similar. Commonly called "germicidal" or "ozone-free" quartz.	Anti-bacterial and other lamps where UV transmittance in the germicidal range is required but where deeper UV radiation or ozone generation is undesirable.
254 Tubing	UV blocking cerium doped clear fused quartz which absorbs essentially all UV-B and UV-C radiation while maintaining transmittance efficiency in the visible spectral range.	UV-sensitive high temperature applications including halogen and discharge lamps where UV radiation would create personal or material exposure risks. Eliminates need for coatings, filters and lenses for UV blocking.
214A, 219A, 254A Tubing	Identical to the standard varieties but with hydroxyl and other dissolved gas content essentially eliminated.	Metal halide lamp envelopes and other applications requiring hydroxyl-free material.
021 Tubing	Clear synthetic fused silica with high UV transmittance and ultra high purity. Provides maximum transparency to deep UV and resistance to solarization. Low hydroxyl content plus excellent visual, thermal, mechanical and dimensional properties.	Envelopes and sleeve tubing for UV and ozone producing lamps; curing, chemical processing and germicidal lamps; and the most advanced semiconductor applications. Also solarization sensitive applications.
SEMICONDUCTOR GRADES		
214 Rod	Clear fused quartz rod with minimal air lines and inclusions, and excellent dimensional stability.	Used to fabricate silicon wafer carriers for the semiconductor industry.
214LD Tubing	Clear fused quartz with the same excellent properties as Type 214 but for large diameter applications.	Used by the semiconductor industry for diffusion, oxidation and LPCVD processing.
224 Tubing, LD Tubing, Rod	Similar to Type 214 with the same exceptional high viscosity and visual standards. Special methods are used to reduce alkali content to the PPB range.	Used in critical semiconductor diffusion systems where even trace levels of alkali content can reduce chip yields.
244 Tubing, LD Tubing, Rod	Similar to Type 224 but with reduced levels of aluminum.	For users who prefer a lower aluminum quartz.
124 Ingots	Clear fused quartz plate and window material produced in 72 inch diameter x 26 inch thick ingots. This material has high purity and will contain some fine bubbles. Various sizes and shapes readily available.	Used to fabricate wafer carriers and flanges for the semiconductor industry and in a variety of optical applications where low cost commercial quality material is specified.
144 Ingots	Same as 124 Grade with reduced levels of aluminum.	For users who prefer a low-aluminum material.
012 Ingots	Clear synthetic fused silica ingots in the same form as GE 124.	Its ultra high purity makes it useful for plates and discs used in the most critical semiconductor processes.
FIBER OPTIC GRADES		
982WGY	Clear fused quartz made by a special proprietary process to provide tubing virtually free of air lines and with exceptional tolerance control.	Used as deposition material in the fiber optics industry for optical waveguide manufacture.
098/095 WGY	Synthetic quartz with the same characteristics as natural occurring quartz but with higher purity and high tensile strength.	Deposition material for fiber optics applications.
CRYSTAL GROWING CRUCIBLES		
Types 510, 512, 520, 522, 530, 532	High purity opaque crucibles with a high gloss internal surface and a white granular outside surface.	Used by the semiconductor industry for growing single crystal silicon.
Types 567, 568, 577, 578, 587, 588	Ultra-high purity opaque crucibles with alkali content reduced to PPB levels.	Used to produce single crystal silicon for low micro-defect quality wafers.

Lamp Grade Tubing



GE Quartz is the world's leading producer of fused quartz for lighting applications. Four basic types of lamp grade quartz are available, each designed to fulfill specific performance requirements. Together, these materials cover a wide variety of applications.

They include:

Type 214

The worldwide standard for clear fused quartz lamp tubing. GE 214 is a high purity, high transmittance, high temperature material with a low hydroxyl (OH^-) content. It is suitable for a broad range of mercury, halogen and other quartz lamp applications.

Type 219

Known as "Ozone-Free" or "Germicidal" quartz tubing. GE 219 transmits UV-A and UV-B while blocking the deep, high energy wavelengths that cause ozone generation and pose the greatest exposure risks. Type 219 transmits the 253.7 nanometer mercury emission very efficiently, making it an ideal material for disinfection applications and various other UV treatments.

Type 254

A doped quartz material that blocks virtually all UV-B and UV-C radiation. Type 254 has a transmittance cutoff wavelength between 350 and 400 nanometers.

Left: Street and automotive lighting are two major applications of quartz lamps.
Below: A few of the many quartz lamps now being made.

It is ideal for lamps requiring maximum visible transmittance with nearly complete UV protection. Applications for GE 254 are those where UV exposure to people or property is undesirable, including some quartz halogen and metal halide lamps and other UV sources.

Type 021

This is a dry synthetic fused silica material providing high transmittance in the deep ultraviolet range. It combines the advantages of low hydroxyl content with ultra high purity to yield superior UV transmittance and resistance to solarization for a variety of UV lamp applications including water purification, ozone generation, paint and ink curing, and chemical processing.

Types 214A, 219A, and 254A

These are identical to the standard types but are produced with a lower hydroxyl content. "A" products contain < 1ppm [OH⁻] and are intended for metal halide lamps and other applications where the quartz must be devoid of hydroxyl as well as all dissolved gases.

Table I - Typical Sizes, Clear Fused Quartz Tubing*

Designation ID×OD (mm)	Wall (mm)	Designation ID×OD (mm)	Wall (mm)	Designation ID×OD (mm)	Wall (mm)
1× 3	1.00	10× 12	1.00	25×28.8	1.90
1.2× 3	0.90	10.5×12.75	1.13	27× 30	1.50
1.6× 3	0.70	11× 13	1.00	30× 33	1.50
2× 3	0.50	11.7× 14.1	1.20	32× 35	1.50
2× 4	1.00	12× 14	1.00	34× 38	2.00
2× 6	2.00	12.75× 15	1.13	35× 38	1.50
2.3× 3.6	0.60	13× 15	1.00	37× 40	1.50
2.35×3.65	0.65	15× 17	1.00	38× 44	3.00
2.35× 4	0.83	15× 18	1.50	38.1×42.1	2.00
2.35×4.35	1.00	16× 18	1.00	40× 43	1.50
3× 5	1.00	18×20.5	1.25	42× 45	1.50
4× 6	1.00	18×21.6	1.80	45× 48	1.50
5× 7	1.00	19× 25	3.00	47× 50	1.50
6× 8	1.00	20× 22	1.00	48× 52	2.00
6× 10	2.00	20×22.8	1.40	50× 54	2.00
7× 9	1.00	20× 23	1.50	50× 55	2.50
7.75×9.75	1.00	20.2× 23	1.40	53× 57	2.00
7.8× 10	1.10	22× 25	1.50	55× 59	2.00
8× 10	1.00	22×25.3	1.65	57× 61	2.00
8× 12	2.00	22×25.8	1.90	60× 64	2.00
8.5×10.5	1.00	23× 26	1.50	63× 67	2.00
9× 11	1.00	25×27.5	1.25	65× 69	2.00
9×11.8	1.40	25× 28	1.50	66× 70	2.00

*Intermediate Sizes Also Available

Table II: Dimensional Tolerances

OD Range	Wall as % of OD	OD	Wall	Siding	Ovality	Bow/ 1220mm
<5mm	>18%	±2.50%	±10%	10%	2.0%	2.44mm
5mm-13mm	>18%	±2.00%	±10%	10%	1.5%	2.0mm
6mm-13mm	<18%	±1.25%	±8%	8%	1.5%	2.0mm
13mm-30mm	<18%	±1.50%	±8%	8%	1.5%	2.0mm
30mm-60mm	<18%	±1.50%	±10%	10%	1.5%	2.0mm

Table III: Physical Properties

	214	219	254
Density (g/cc)	2.2	2.21	2.21
Thermal Expansion Coefficient (cm/cm °C)	5.5×10^{-7}	5.9×10^{-7}	6.7×10^{-7}
Softening Point (°C)	1683	1660	1615
Annealing Point (°C)	1215	1204	1163
Strain Point (°C)	1120	1106	1066
Index of Refraction	1.4585	1.456	1.460
Specific Heat (J/kg °K) (0-50 °C)	670	700	690
Compressive Strength (Pa)	$>1.1 \times 10^{9}$	$.94 \times 10^{9}$	$.55 \times 10^{9}$
Young's Modulus (Pa)	7.2×10^{5}	7.5×10^{6}	7×10^{6}
Electrical Resistivity (ohm cm @ 350 °C)	7×10^{9}	2.5×10^{10}	5×10^{10}
Dielectric Constant (@ 1MHz)	3.75	5.8	6

Semiconductor Grade Fused Quartz Tubing

In the semiconductor industry, a combination of extreme purity and excellent high temperature properties make fused quartz tubing an ideal furnace chamber for processing silicon wafers. The material can tolerate the wide temperature gradients and high heat rates of the process. And its purity creates the low contamination environment required for achieving high wafer yields.

The advent of eight inch wafers combined with today's smaller chip sizes has increased chip production by a factor of four compared to technology in place just a few years ago. These developments have impacted heavily on quartz producers, requiring both large diameter tubing and significantly higher levels of purity. GE Quartz has responded on both counts.

Quartz tubing is available in a full range of sizes, including diameters of 400mm and larger. Diameter and wall thickness dimensions are tightly controlled. Special heavy wall thicknesses are available on request.

By finding new and better sources of raw material, expanding and modernizing our production facilities, and upgrading our quality control functions, GE has reduced contaminant levels in its fused quartz tubing to less than 25 ppm, with alkali levels below 1 ppm.

Grade 214LD

This is the large diameter grade of industry standard 214 quartz tubing. For all but the highly specialized operations, this low cost tubing offers the levels of purity, sag resistance, furnace life and other properties that diffusion and CVD processes require.

For superior performance at elevated temperatures, GE Type 214 LD furnace tubing gives process engineers a better balance between the effects of higher temperatures and heavier wafer loads.

224LD - Low Alkali Quartz Tubing

As the semiconductor industry moves toward higher densities, furnace atmosphere contamination becomes an increasingly critical factor in controlling wafer yields. One potential contaminant is sodium, which occurs naturally in the silica sand used to make fused quartz. This highly mobile ion can effectively destabilize the electrical characteristics of MOS and bipolar devices if not removed.

For these critical applications, GE has developed Grade 224 low alkali fused quartz tubing. It is made in a special process that eliminates up to 90% of the naturally occurring alkalis. The process achieves a typical sodium level of 0.1 ppm (vs. a normal 0.7 ppm), greatly reduces potassium, and virtually eliminates lithium.

With semiconductor wafers getting bigger, large diameter fused quartz tubing is required for the low contamination furnace chambers used in wafer processing.

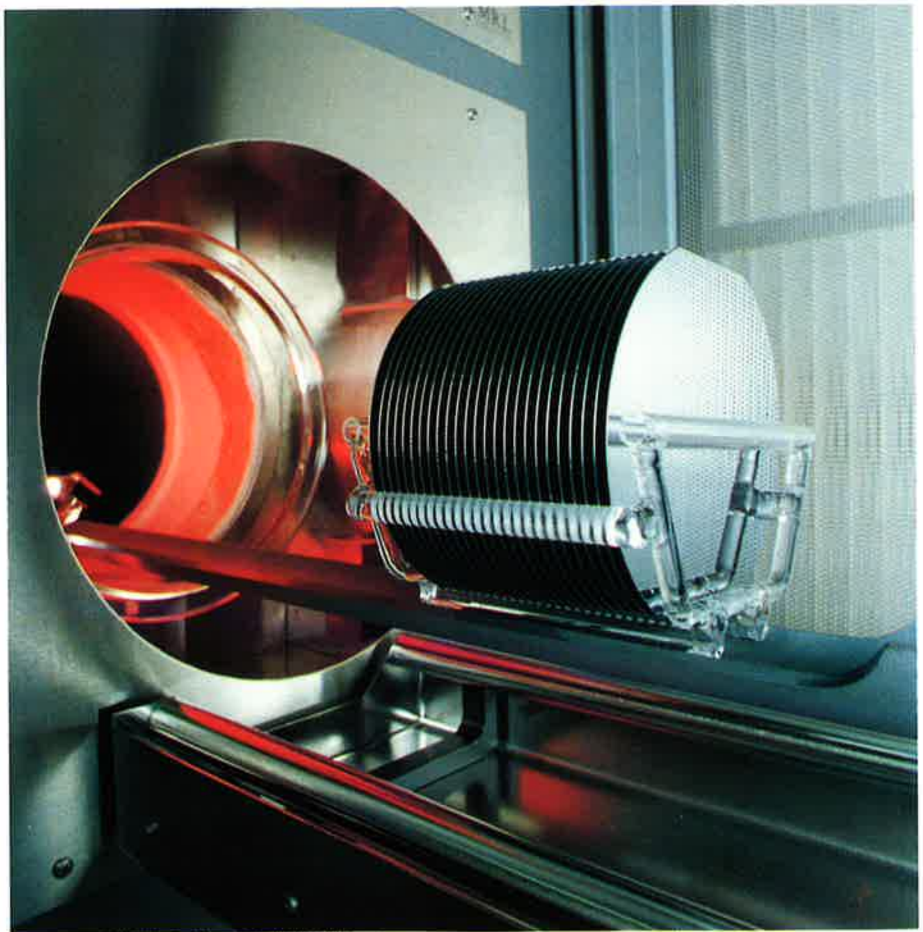


Photo courtesy of MRL Industries, Sonora CA, ©Bill Wood Photography

244LD Low Alkali/Low Aluminum Quartz Tubing

This grade has been specially developed for quartz users concerned about the aluminum level in fused quartz. 244 has a typical aluminum level of 8 ppm.

Low OH^-

One reason that GE fused quartz tubing can withstand the wide thermal gradients and chemical environments of wafer processing operations is its OH^- content of less than 10 ppm water in most grades.

Low OH^- minimizes the sag rate at diffusion temperatures, and effectively retards the progress of devitrification.

Because of its low hydroxyl content, GE Quartz tubing does not require special coatings that could potentially release contaminants at elevated temperatures.

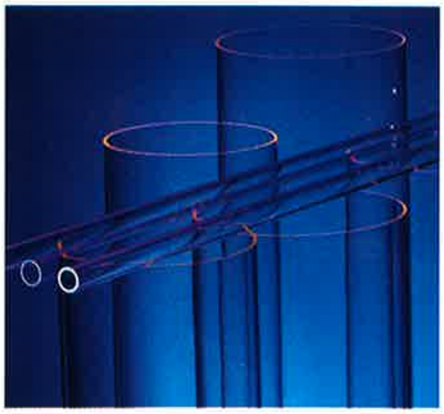


Table IV - Standard Sizes, Types 214LD, 224LD and 244LD Fused Quartz Circular Tubing

Designation (mm)	OD (mm)	Max. Siding (mm)	Max. Ovality (mm)
70×74	74.0±2.0	.50	.35
75×80	80.0±2.0	.60	.35
80×84	84.0±2.0	.50	.50
80×85	85.0±2.0	.60	.40
85×90	90.0±2.0	.60	.40
90×95	95.0±2.0	.60	.50
95×100	100.0±2.0	.60	.50
100.6×106.6	106.6±2.0	.60	.50
101.6×114.3	114.3±2.0	1.00	.50
105 ×110	110.0±2.0	.60	.55
105 ×117.7	117.7±2.0	1.00	.50
110 ×115	115.0±2.0	.60	.60
115 ×120	120.0±2.0	.60	.60
115 ×127.7	127 .7±2.0	1.00	.55
120 ×125	125.0±2.0	.50	.60
130 ×135	135.0±2.0	.60	.70
130 ×136	136.0±2.0	.75	.70
130 ×142.7	142.7×2.0	1.00	.65
135 ×141	141.0±2.0	.75	.70
135 ×147.7	147.7±2.0	1.00	.65
140 ×146	146.0±2.0	.75	.70
140 ×152.7	152.7±2.0	1.00	.70
145 ×151	151.0±2.0	.75	.80
145 ×157.7	157.7±2.0	1.00	.70
150 ×156	156.0±2.0	.75	1.00
150 ×162.7	162.7±2.0	1.00	.75
155 ×161	161.0±2.0	.75	1.00
160 ×166	166.0±2.0	.75	1.00
165 ×171	171.0±2.0	.75	1.00
170 ×176	176.0±2.0	.75	1.80
170 ×178	178 ±2.0	1.20	1.80
170 ×182.7	182.7±2.0	1.00	1.70
176 ×184	184 ±2.0	1.20	1.80
184 ×190	190.0±2.0	.90	1.90
184 ×196.7	196.7±3.0	1.00	1.80
190 ×196	196.0±3.0	.60	1.90
200 ×206	206.0±3.0	.60	2.00
203 ×211	211.0±3.0	1.20	2.11
208 ×216	216.0±3.0	1.20	2.20
210 ×216	216 ±3.0	.90	2.15
211 ×221	221 ±3.0	1.50	2.20
215 ×221	221.0±3.0	.90	2.20
215 ×225	225 ±3.0	1.50	2.25
220 ×228	228 ±3.0	1.20	2.25
220 ×216	216 ±3.0	.90	2.25
220 ×230	230 ±3.0	1.50	2.30
225 ×235	235.0±3.0	1.00	2.25
227 ×235	235.0±3.0	1.20	2.40
230 ×236	236.0±3.0	.90	2.35
235 ×245	245 ±3.0	1.50	2.45
240 ×246	246.0±3.0	.90	2.50
241 ×251	251 ±3.0	1.50	2.50
250 ×260	260.0±3.0	1.50	2.60
255 ×265	265.0±3.0	1.00	2.50
270 ×280	280 ±3.0	1.50	2.80
320 ×330	330 ±3.0	1.50	3.30

Note: Other sizes available upon request. Tighter tolerances available on request.

Table V - Typical Tolerances, Types 214/224/244LD Fused Quartz Tubing

Size (ID)	OD	Wall	Maximum Siding	Maximum Ovality	Maximum Bow
Up to 165 mm	±2.0 mm	20%	15% of Nom. OD	0.5% of Nom. OD	3 mm/ft
166 mm to 191 mm	±2.0 mm	20%	15% of Nom. OD	1% of Nom. OD	3 mm/ft
191 mm to 260 mm	±2.0 mm	20%	15% of Nom. OD	1% of Nom. OD	3 mm/ft
261 mm to 350 mm	±2.0 mm	20%	20% of Nom. OD	1% of Nom. OD	3 mm/ft
351 mm and over	±3.0 mm	20%	20% of Nom. OD	1% of Nom. OD	3 mm/ft

Tighter tolerances available on request.

Fused Quartz Rod & Solids

GE supplies two forms of high purity fused quartz solid shapes for fabricators of quartzware.

Type 214 rod has the high purity, elevated temperature characteristics and low coefficient of thermal expansion required for wafer carriers and push rods used in semiconductor wafer processing.

The material is available in diameters of 1 to 20 mm. Very tight quality control and special processing of raw materials is used to achieve low levels of trace element contamination.

When larger sizes and different shaped starting materials are required, GE supplies fabricators with pieces cut from fused quartz ingots. They are up to 72 inches in diameter, two feet thick, and weigh up to 9000 pounds.

Large Ingots

GE Type 124 ingots have been the semiconductor industry's material of choice for fabricating diffusion and CVD furnace components for a number of years.

The advent of larger wafer sizes, tighter device geometries, and the drive for lower contaminant levels has stimulated GE's development of an even higher purity grade.

Type 144 is specially processed to reduce alkali content by up to 90%. Sodium is held to 0.2 ppm or lower, potassium is significantly reduced and lithium is all but eliminated in this grade.

Type 012 provides the ultra high purity of synthetic fused silica.

Table VI - Typical Sizes, Type 214 Fused Quartz Rod

Diameter (mm)* And Tolerances		Maximum Ovality (mm)
1.0	.40	.10
1.5	.12	.12
2.0	.16	.15
2.5	.20	.10
3.0	.24	.10
3.5	.70	.10
4.0	.20	.10
5.0	.30	.10
6.0	.30	.1
6.4	.30	.1
7.0	.30	.1
8.0	.12	.04
9.0	.14	.05
10.0	.15	.05
12.0	.18	.06
13.0	.20	.07
15.0	.23	.08
19.0	.29	.10

* Other sizes available

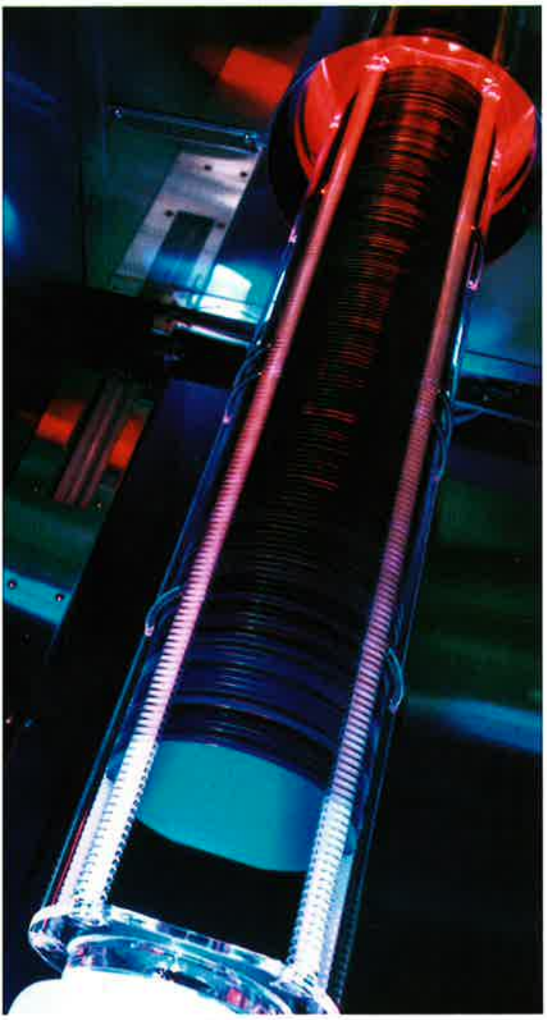
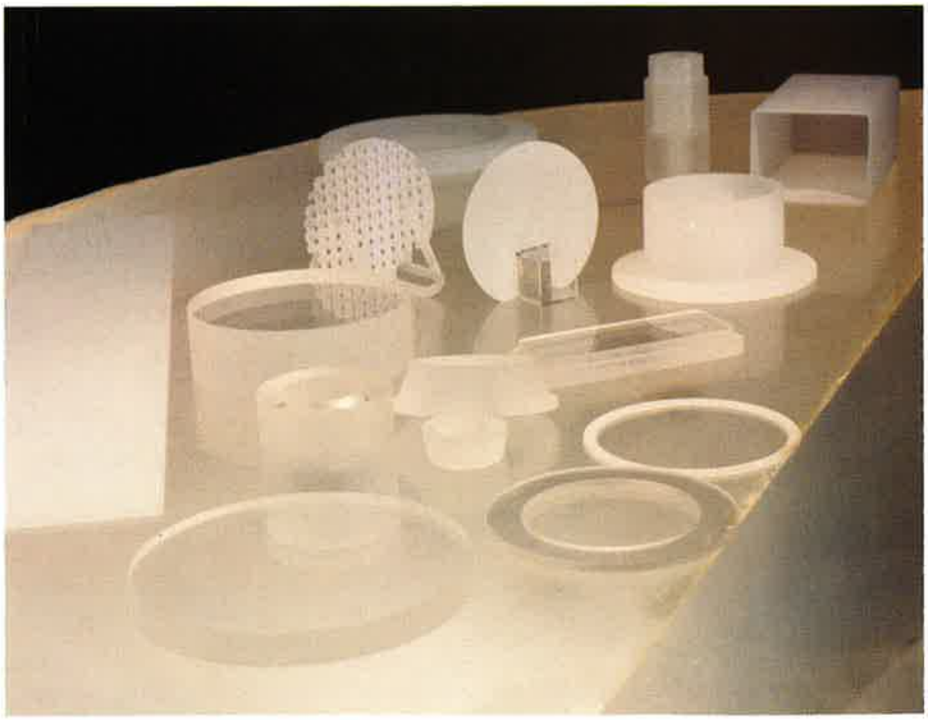


Photo courtesy of Varian Semiconductor Equipment, Palo Alto, CA

Fused quartz rod is used in the fabrication of precision wafer carriers and other quartzware for semiconductor wafer processing.



When shapes other than tube or rod are required, large fused quartz boules manufactured by GE are the ready-made source.

Fiber Optic Tubing

GE fused quartz serves as deposition tubing for one of the major methods of producing optical waveguides, the modified chemical vapor deposition (MCVD) process.

For this application, GE offers high quality quartz tubing that is virtually airline free, with tight dimensional tolerances and low OH^-. This combination of characteristics translates into excellent attenuation for the fiber manufacturer.

GE produces fiber optic tubing from either naturally occurring or synthetic quartz. The synthetic grades, combined with GE's unique continuous fusion process, produces fiber optic tubing with all the advantages found in natural occurring quartz, plus the higher tensile strength required for producing long length fibers.

Along with waveguide material, GE offers high quality quartz tubing and handles required by the MCVD process.

Each waveguide tube produced by GE is serialized, characterized and accompanied by a data slip showing the complete geometry of the tube. If desired, a computer disc can be supplied with the shipment for direct entry into your data bank.

Fiber optic tubing is serialized and comes with complete data on tube geometry. Fused quartz rod, also shown, is available in diameters from 1 to 20 mm.

Table VII - Typical Tolerances, Fiber Optic Tubing

Within Tubes:	
Outside Diameter	±2%
Wall Thickness	±5%
Ovality = $\frac{\text{Maximum OD—Minimum OD}}{\text{Nominal OD}}$	.75% maximum of nominal OD
Bow	.8mm/meter
Siding = $\frac{\text{Maximum Wall—Minimum Wall}}{\text{Nominal Wall}}$	4.5% maximum of nominal wall
Length	±3mm
Cross Section Variation	≤4%
Among Tubes:	100% are within 4% nominal CSA

Quartz Crucibles

In the manufacture of silicon metal for semiconductor wafer applications, polysilicon starting materials are placed in fused quartz crucibles, heated to high temperatures and pulled from the melt as a single crystal.

Fused quartz is one of the few materials that can combine the high purity and high temperature properties required.

Other Compositions

To keep pace with the increasingly stringent purity requirements of the industry, GE now offers a variety of compositions in its quartz crucibles. Each type is designed to address specific microcontamination concerns. Table IX shows some of the types now offered.

However, other options are also available.

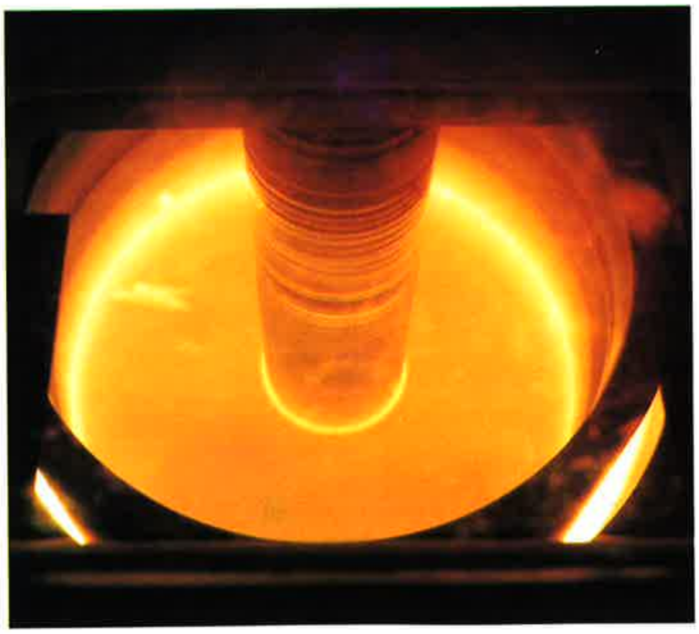
GE's "Crucible Team" is prepared to work with you on your specific crucible designs.

Let us know your requirements.

Table VIII - Typical Viscosity Data for Type 510 Crucibles

	For Type 510 Crucibles
Log $_{10}$ Viscosity @ 1100°C	14.7
@ 1200°C	13.0
@ 1300°C	11.5
Annealing Pt. °C	1200

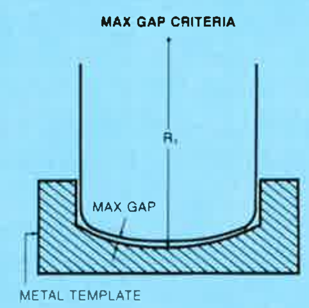
GE quartz crucibles are available in a range of standard sizes, from eight to 24 inches in diameter, and in custom-made sizes.



GE quartz crucibles for single-crystal silicon growing achieve extremely consistent results and maintain the ultra-high purity of the melts.

Table IX - GE Crucible Products

Types	Description
510	Standard fusion, standard chemistry
512	Standard fusion, low aluminum, low boron
520	Bubble composite, standard chemistry
522	Bubble composite, low aluminum, low boron
530	Bubble composite with a virtually bubble free 1 mm to 3 mm inner layer, standard chemistry
532	Bubble composite with a virtually bubble free 1 mm to 3 mm inner layer, low aluminum, low boron
567	Standard fusion, low alkali
568	Standard fusion, low alkali, low aluminum, low boron
577	Bubble composite, low alkali
578	Bubble composite, low alkali, low aluminum, low boron
587	Bubble composite with a virtually bubble free 1 mm to 3 mm inner layer, low alkali
588	Bubble composite with a virtually bubble free 1 mm to 3 mm inner layer, low, alkali, low aluminum, low boron



Type 510 crucibles are made with semi-flat bottoms and are available with a square cut edge. Letter symbols in diagram are keyed to the column headings in Table X.

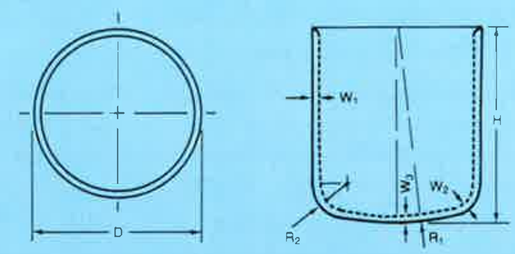


Table X - Typical Sizes & Tolerances For Fused Quartz Crucibles
(Dimensions and Tolerances in Inches)

Crucible Sizes	Typical Diameter	Typical Height	Wall 1	Wall 2	Wall 3	Nominal Radius R1	R2	Maximum Gap
12″	12.000±.075	9.500±.125	.300±.050	.300±.075	.300±.075	12.0	3.0	.125
13″	13.000±.080	9.500±.125	.300±.080	.300±.080	.300±.080	12.0	3.0	.188
14″	14.000±.100	11.000±.125	.300±.100	.300±.100	.300±.100	15.0	3.5	.188
15″	15.000±.100	12.000±.118	.310±.100	.310±.100	.310±.100	15.0	3.0	.188
16″	16.000±.100	12.000±.118	.380±.100	.380±.100	.380±.100	16.0	3.5	.188
18″	18.000±.118	14.000±.118	.350±.118	.350±.118	.350±.118	18.0	3.5	.188
20″	20.000±.118	15.000±.118	.400±.118	.400±.118	.400±.118	20.0	3.5	.188
22″	22.000±.185	17.000±.125	.400±.118	.400±.118	.400±.118	22.0	3.5	.188
24″	24.000±.185	15.000±.125	.400±.118	.400±.118	.400±.118	24.0	3.5	.188

GE Quartz crucibles are designed for your specific application. Call GE Quartz to discuss your requirements (address and telephone number are on the back page of this catalog).

Chemical Composition

Vitreous silica is the generic term used to describe all types of silica glass, with producers referring to the material as either fused quartz or as fused silica. Originally, those terms were used to distinguish between transparent and opaque grades of the material. Fused quartz products were those produced from quartz crystal into transparent ware, and fused silica described products manufactured from sand into opaque ware.

Today, however, advances in raw material beneficiation permit transparent fusions from sand as well as from crystal. Consequently, if naturally occurring crystalline silica (sand or rock) is melted, the material is simply called fused quartz. If the silicon dioxide is synthetically derived, however, the material is referred to as synthetic fused silica.

Controlled Process

The performance of most fused quartz products is closely related to the purity of the material. GE's proprietary raw material beneficiation and fusion processes are closely monitored and controlled to yield typically less than 50 ppm total elemental impurities by weight. GE clear fused quartz varieties have a nominal purity of 99.995 W% SiO_2.

Table XI summarizes the typical trace level impurity content of GE fused quartz products.

Structural hydroxyl (OH^-) impurities are also shown. The strong IR absorption of OH^- species in fused quartz provides a quantitative method for analysis.

Beta Factor

The term Beta Factor is often used to characterize the hydroxyl (OH^-) content of fused quartz tubing. This term is defined by the formula shown below.

Calculation of Hydroxyl Content from IR Transmission

Beta Factor = β

$$\beta = \frac{1}{t} \log_{10} \left(\frac{Ta}{Tb}\right) \quad mm^{-1}$$

t = Quartz thickness, mm

Ta = actual % transmission at λ = 2.6 μm

Tb = actual % transmission at λ = 2.73 μm

$[OH^-]$ = C, ppm

$C = \beta \times 910$

$$910 = \frac{M.W._{(OH)^-} \times 10^6}{E \times \varrho_{(SiO_2)}}$$

$M.W._{(OH)^-}$ = Molecular weight of $(OH)^-$ g = 17g

E = Extinction coefficient for $(OH)^-$ = 85 ϱ/mol-cm

$\varrho_{(SiO_2)}$ = Density of SiO_2 = 2.21 g/cm^3

Quantitative and qualitative analysis of fused quartz constituents is provided by X-ray fluorescence (above) and other instrumentation.

Table XI - Typical Trace Element Composition (ppm by weight)
Analysis via Direct Reading Spectrometer

Type	Al	As	B	Ca	Cd	Cr	Cu	Fe	K	Li	Mg	Mn	Na	Ni	P	Sb	Ti	Zr	*OH⁻
214	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	1.1	0.8	<5
219	14	<0.01	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	100	0.8	<5
254	14	<0.1	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	500	0.8	<5
214A	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	1.1	0.8	<1
214 Rod 214 LD	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	1.1	0.8	10
224/ 224 Rod	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.03	0.2	<0.2	<0.2	0.1	<0.03	<0.2	<0.1	<0.2	0.003	1.4	0.8	10
224 LD	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.01	0.2	<0.2	0.001	0.1	<0.05	<0.1	<0.1	<0.2	0.003	1.1	0.8	10
244/ 244 Rod	8	<0.002	<0.1	0.6	<0.01	<0.05	<0.03	0.2	<0.2	<0.2	<0.1	<0.03	<0.2	<0.1	<0.2	<0.003	1.4	0.3	10
244 LD	8	<0.002	<0.1	0.6	<0.01	<0.05	<0.01	0.2	<0.2	0.001	<0.1	<0.03	0.1	<0.1	<0.2	<0.003	1.4	0.3	10
124	14	<0.002	<0.2	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	<0.1	<0.2	<0.003	1.1	0.8	<5
144	8	<0.002	<0.1	0.6	<0.01	<0.05	<0.05	0.2	<0.2	<0.2	<0.1	<0.03	<0.2	<0.1	<0.2	<0.003	1.4	0.3	<5
982 WGY	14	–	–	0.4	<0.01	<0.05	<0.05	0.2	0.6	0.6	0.1	<0.05	0.7	–	–	–	1.1	0.8	3
098 WGY	0.2	–	–	<0.05	<0.01	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.02	<0.05	–	–	–	<0.02	<0.02	10
095 WGY	9	–	–	<0.05	<0.01	<0.05	<0.05	0.07	0.1	<0.05	<0.05	<0.02	0.1	–	–	–	<0.02	<0.02	<10
510, 520, 530 512, 522, 532	14 8	<0.01 <0.01	<0.2 <0.1	0.4 0.6	<0.01 <0.01	<0.05 <0.05	<0.05 <0.05	0.2 0.2	0.6 0.5	0.6 0.5	0.1 <0.1	<0.05 <0.05	0.7 0.7	<0.1 <0.1	<0.2 <0.2	<0.003 <0.003	1.1 1.4	0.8 0.2	50 50
567, 577, 587 568, 578, 588	14 8	<0.01 <0.01	<0.2 <0.1	0.4 0.6	<0.01 <0.01	<0.05 <0.05	<0.05 <0.05	0.2 0.5	<0.03 <0.03	<0.01 <0.01	0.1 <0.1	<0.05 <0.05	<0.02 <0.02	<0.1 <0.1	<0.2 <0.2	<0.003 <0.003	1.1 1.4	0.8 0.2	70 70

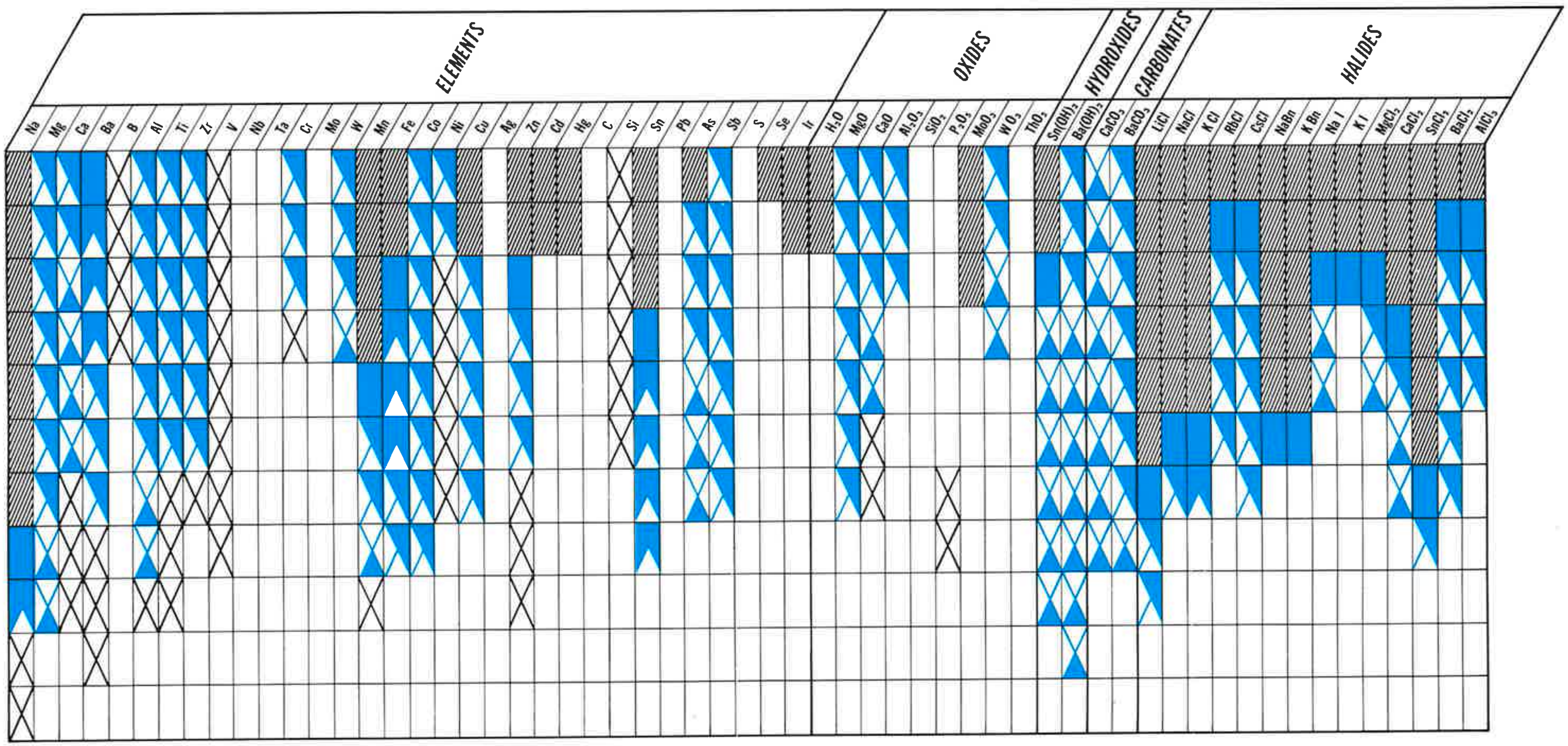
*Types 214 LD and 224 LD may contain a higher amount of surface hydroxyl (OH) ions, but the values represent a bulk average for the total wall thickness.

Reactivity

Most acids, metals, chlorine and bromine are unreactive with fused quartz at ordinary temperatures. It is slightly attacked by alkaline solutions, the reaction rate increasing with temperature and concentration of solution. Phosphoric acid will attack fused quartz at temperatures above about 150 °C. Hydrofluoric acid alone will attack it at all temperatures. Carbon and some metals will reduce fused quartz; basic oxides, carbonates, sulfates, etc., will react with it at elevated temperatures. For general use however, it can be concluded that fused quartz is quite unreactive.

The effects of various elements and compounds on fused quartz at elevated temperatures are observed in a vacuum. Each sample is held at the lowest temperature for one hour, then at the next higher temperature for one hour, and so on. The extent of the reaction is, of course, also time-dependent.

Table XII – Qualitative Guide To Fused Quartz Reaction With Selected Elements And Compounds At Elevated Temperatures



VISUAL INSPECTION RESULTS:

LEGEND: NO CHANGE · NO DEVITRIFICATION–BUT COATED OR STAINED BY TEST MATERIAL · SOME SPOTS OF DEVITRIFICATION · SURFACE DEVITRIFICATION · SEVERE DEVITRIFICATION · FAILURE DUE TO DEVITRIFICATION · NOT TESTED AT THIS TEMPERATURE

Permeability

Fused quartz is essentially impermeable to most gases, but helium, hydrogen, deuterium and neon may diffuse through the glass. The rate of diffusion increases at higher temperatures and differential pressures.

The selective diffusion of helium through fused quartz is the basis for a method of purifying helium by essentially "screening out" contaminants by passing the gas through thin-walled quartz tubes.

The diffusion of helium, hydrogen, deuterium and neon through fused quartz is accelerated with increasing temperature. According to General Electric Research Laboratory, the permeability constants for these gases through fused silica at 700 °C are estimated to be:

Helium 2.1 x 10-8 cc/sec./cm2/mm/cm.Hg

Hydrogen 2.1 x 10^{-9}

Deuterium 1.7 x 10^{-9}

Neon 9.5 x 10^{-10}

Internal Pressure Determination

Since fused quartz is utilized in applications involving internal pressures, it is sometimes helpful to know the maximum pressure which can be applied to a certain size tube. The following formula will approximate this information at room temperature.

CFQ Rupture Formula For Tubing

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

Where:

S = Hoop Stress in Pa

p = Working pressure (Pa)

r = Inside Radius of Tube (mm)

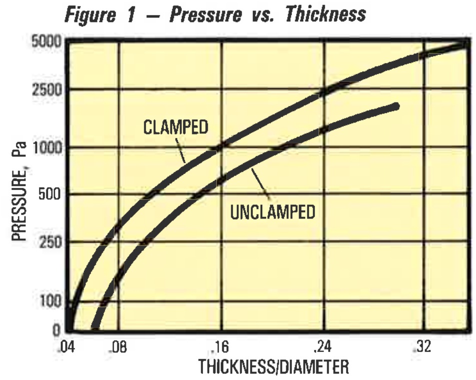
t = Wall Thickness (mm)

This formula is not applicable when the internal pressure exceeds $7x10^5$ Pa (100 psi).

CFQ Rupture Formula For Discs And Plates

Calculating pressure differential is also required for many applications of stressed fused quartz discs, plates, and sight glasses.

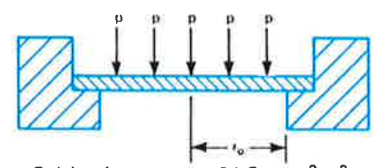
Figure 1 — Pressure vs. Thickness



Maximum pressure versus ratio of thickness to diameter for clamped and unclamped plates. To determine required thickness, multiply diameter of disc by the factor at the bottom corresponding to required pressure. Source: GE

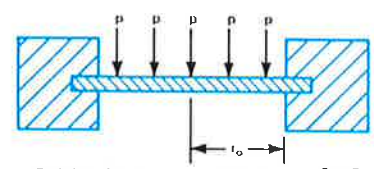
The formulae which follow can be used for room temperature applications of circular parts with either clamped or unclamped edges.

Unclamped Edge



Solving for p: $p = .84\, S_{max}\, t^2/r_o^2$

Clamped Edge



Solving for p: $p = 2.28\, S_{max}\, t^2/r_o^2$

Where:

p = Pressure differential, Pa

r_o = Unsupported disc radius, mm (for plates substitute width)

S_{max} = Maximum stress (approx. 7 to 1 safety factor) 7.0 x 10^6 Pa

t = Disc thickness, mm

However, the following factors will affect the strength of these parts and must be considered when using the formulae:

a. Surface should be highly polished and free of scratches.

b. Means by which a sample is clamped into a pressure device.

c. The gasketing material used.

d. The thermal gradients expected across the surface and between the surfaces.

e. The rate of pressure increase which will be applied.

f. Temperature of specimen.

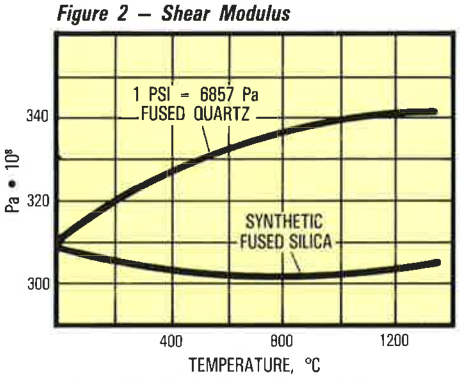
Mechanical Properties

Mechanical properties of fused quartz are much the same as those of other glasses. The material is extremely strong in compression, with design compressive strength of better than 1.1 x 10^9 Pa (160,000 psi).

Surface flaws can drastically reduce the inherent strength of any glass, so tensile properties are greatly influenced by these defects. The design tensile strength for fused quartz with good surface quality is in excess of 4.8 x 10^7 Pa (7,000 psi). In practice, a design stress of .68 x 10^7 Pa (1,000 psi) is generally recommended. Typical mechanical data are shown in Table XIII.

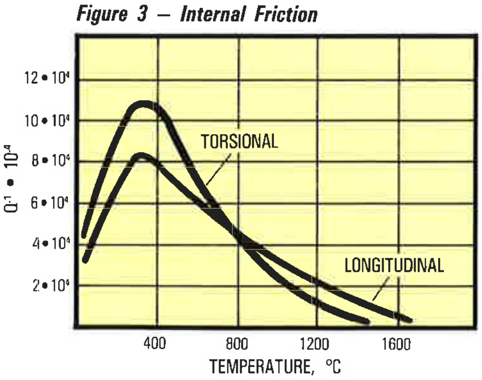
Temperature dependence for various mechanical properties are illustrated in Figures 2 to 8.

Figure 2 — Shear Modulus



Representative shear (rigidity) modulus values for fused quartz. Source: National Bureau of Standards.

Figure 3 — Internal Friction



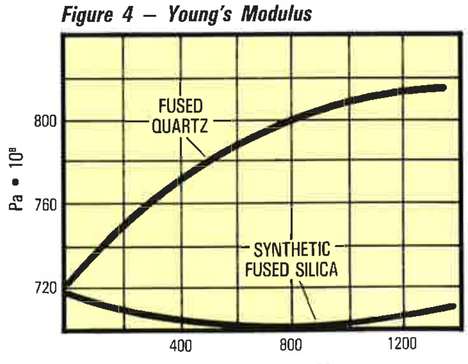
Representative longitudinal and torsional internal friction values for synthetic fused silica. Source: Ibid.

Table XIII - Typical Physical Properties, Type 214 Clear Fused Quartz

Property	Typical Values
Density	2.2×10^3 kg/m³
Hardness	5.5 - 6.5 Mohs' Scale 570 KHN $_{100}$
Design Tensile Strength	4.8×10^7 Pa (N/m²) (7000 psi)
Design Compressive Strength	Greater than 1.1×10^9 Pa (160,000 psi)
Bulk Modulus	3.7×10^{10} Pa (5.3×10^6 psi)
Rigidity Modulus	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	.17
Coefficient of Thermal Expansion (20 °C - 320 °C)	5.5×10^{-7} cm/cm • °C
Thermal Conductivity (20 °C)	1.4 W/m • °C
Specific Heat (20 °C)	670 J/kg • °C
Softening Point	1683 °C
Annealing Point	1215 °C
Strain Point	1120 °C
Electrical Resistivity (350 °C)	7×10^7 ohm cm

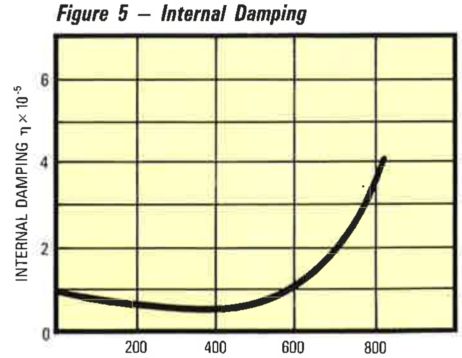
Property	Typical Values
Dielectric Properties (20 °C and 1 MHz)	
Constant	3.75
Strength	5×10^7 V/m
Loss Factor	Less than 4×10^{-4}
Dissipation Factor	Less than 1×10^{-4}
Index of Refraction	1.4585
Constringence (Nu value)	67.56
Velocity of Sound-Shear Wave	3.75×10^3 m/s
Velocity of Sound/ Compression Wave	5.90×10^3 m/s
Sonic Attentuation	Less than 11 db/m MHz
Permeability Constants (700 °C)	(cm³ mm/cm² sec. cm of Hg)
Helium	210×10^{-10}
Hydrogen	21×10^{-10}
Deutrium	17×10^{-10}
Neon	9.5×10^{-10}

Figure 4 — Young's Modulus



Representative elastic (Young's) modulus for fused quartz. Source: Ibid.

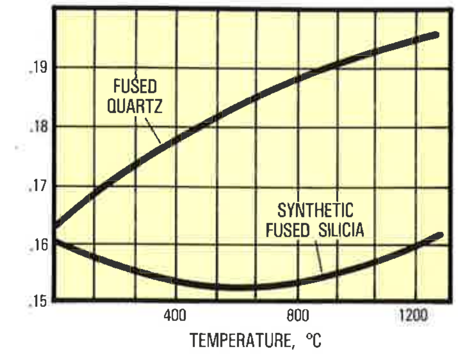
Figure 5 — Internal Damping



Representative internal damping values for fused quartz. Source: Published manufacturer's data.

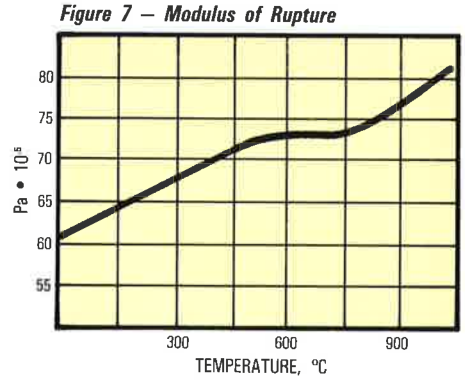
Thermal Properties

Figure 6 — Poisson's Ratio



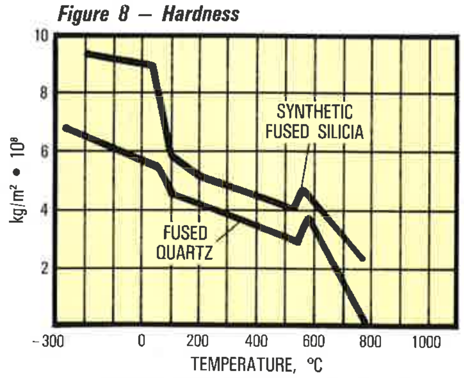
Poisson's ratio for fused quartz. Source: Ibid.

Figure 7 — Modulus of Rupture



Representative modulus of rupture values for fused quartz.
Source: Published manufacturer's data.

Figure 8 — Hardness



Representative hardness values for fused quartz
Source: J.H. Westbrook *Physics and Chemistry of Glasses,* Vol 1, 1960.

One of the most important properties of fused quartz is its extremely low coefficient of expansion: 5.5×10^{-7} mm °C (20-320 °C). Its coefficient is 1/34 that of copper and only 1/7 of borosilicate glass. This makes the material particularly useful for optical flats, mirrors, furnace windows and critical optical applications which require minimum sensitivity to thermal changes.

A related property is its unusually high thermal shock resistance. For example, thin sections can be heated rapidly to above 1500 °C and then plunged into water without cracking. (See figures 9, 10, 11 and 12.)

Empirical Annealing Rates, Fused Quartz

Cooling From Two Sides:

Rate. °C/minute –

$$4274.7 \times \frac{\text{residual stress, Pa}}{(\text{thickness, mm})^2}$$

Cooling From One Side:

Rate. °C/minute =

$$4274.7 \times \frac{\text{residual stress, Pa}}{(2 \times \text{thickness, mm})^2}$$

The residual stress or design, depending on the application, may be in the range of 1.7×10^7 to 20.4×10^7 Pa (25 to 300 psi).

As a general rule, it is possible to cool up to 100 °C/hour for sections less than 25 mm thick.

Effects Of Temperature

Fused quartz is a solid material at room temperature, but at high temperatures, it behaves like all glasses. It does not experience a distinct melting point as crystalline materials do, but softens over a fairly broad temperature range. This transition from a solid to a plastic-like behavior, called the transformation range, is distinguished by a continuous change in viscosity with temperature.

Viscosity

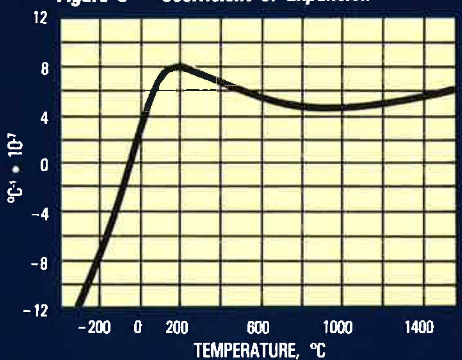
Viscosity is the measure of the resistance to flow of a material when exposed to a shear stress. Since the range in "flowability" is extremely wide, the viscosity scale is generally expressed logarithmically. Common glass terms for expressing viscosity include: strain point, annealing point, and softening point, which are defined as:

Strain Point: The temperature at which the internal stress is substantially relieved in four hours. This corresponds to a viscosity of $10^{14.5}$ poise, where poise = dynes/cm² sec.

Annealing Point: The temperature at which the internal stress is substantially relieved in 15 minutes, a viscosity of $10^{13.2}$ poise.

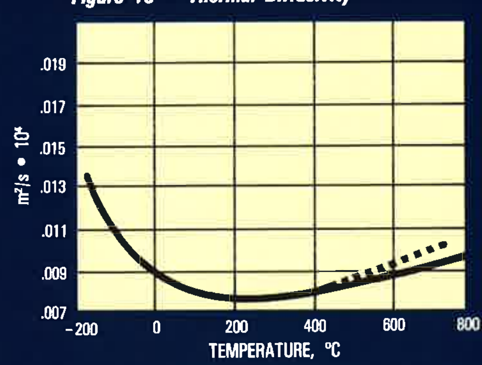
Softening Point: The temperature at which glass will deform under its own weight, a viscosity of approximately $10^{7.6}$ poise. The softening point of fused quartz has been variously reported from 1500 °C to 1670 °C, the range resulting from differing conditions of measurement. (See tables XIII and XIV and Figures 13 and 14.)

Figure 9 — Coefficient of Expansion



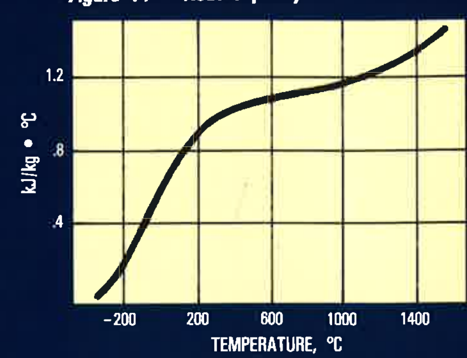
Representative coefficient of expansion of fused quartz.
Source: Published manufacturer's data.

Figure 10 — Thermal Diffusivity



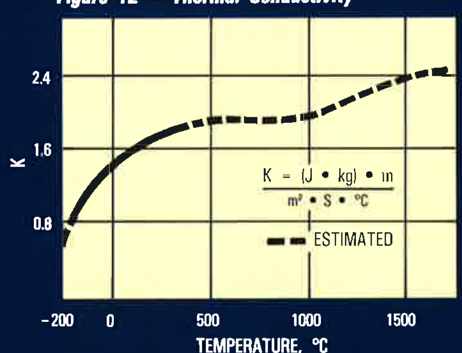
Representative thermal diffusivity of fused quartz.
Source: ibid.

Figure 11 — Heat Capacity



Representative heat capacity of fused quartz.
Source: R.B. Sosman, *The Properties of Silica, 1927.*

Figure 12 — Thermal Conductivity



Representative thermal conductivity of fused quartz.
Source: Published manufacturer's data.

Figure 13 — Viscosity Test

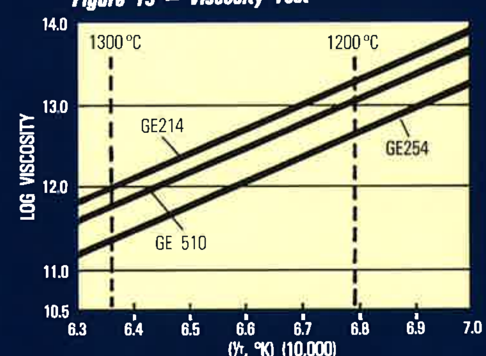
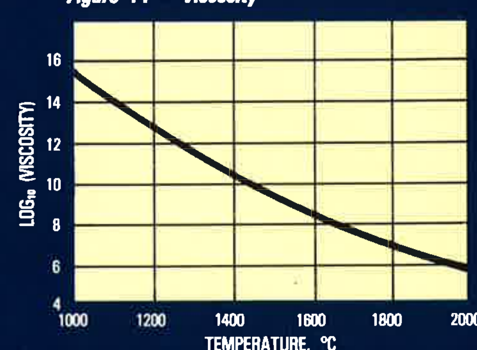


Figure 14 — Viscosity



Representative viscosity of fused quartz.
Source: GE.

Table XIV · Log Viscosity of GE Fused Quartz

	Type 214	Type 219	Type 254
Log Viscosity: @1100 °C	14.88	14.75	14.11
@1200 °C	13.22	13.28	12.66
@1300 °C	11.76	11.98	11.38
ANNEALING POINT	1215 °C	1204 °C	1163 °C
STRAIN POINT	1122 °C	1106 °C	1066 °C
ACTIVATION ENERGY	155.11 kcal/mol/°K	141.84 kcal/mol/°K	135.56 kcal/mol/°K

Type 214 TEMP. °K	1/T x 10⁴	VISC. LOG	Type 219 TEMP. °K	1/T x 10⁴	VISC. LOG	Type 254 TEMP. °K	1/T x 10⁴	VISC. LOG
1393	7.18	13.40	1564	6.39	12	1524	6.56	12.01
1433	6.98	13.30	1558	6.43	12.11	1516	6.6	12.08
1473	6.79	13.24	1542	6.48	12.29	1502	6.66	12.29
1493	6.70	12.91	1529	6.54	12.48	1489	6.72	12.46
1513	6.61	12.59	1515	6.60	12.68	1475	6.78	12.64
1533	6.52	12.29	1501	6.68	12.85	1461	6.84	12.81
1553	6.44	12.05	1488	6.72	13.02	1448	6.91	12.99
1573	6.36	11.77	1474	6.78	13.22	1431	6.99	13.27

Thermal Properties, cont.

Devitrification

Devitrification and particle generation are limiting factors in the high temperature performance of fused quartz. Devitrification is a two step process of nucleation and growth. In general, the devitrification rate of fused quartz is slow for two reasons: the nucleation of the crystobalite phase is possible only at the free surface, and the growth rate of the crystalline phase is low.

Nucleation in fused quartz materials is generally initiated by surface contamination from alkali elements and other metals. This heterogeneous nucleation is slower in non-stoichiometric fused quartz, such as GE quartz, than in stoichiometric quartz materials.

Crystobalite Growth

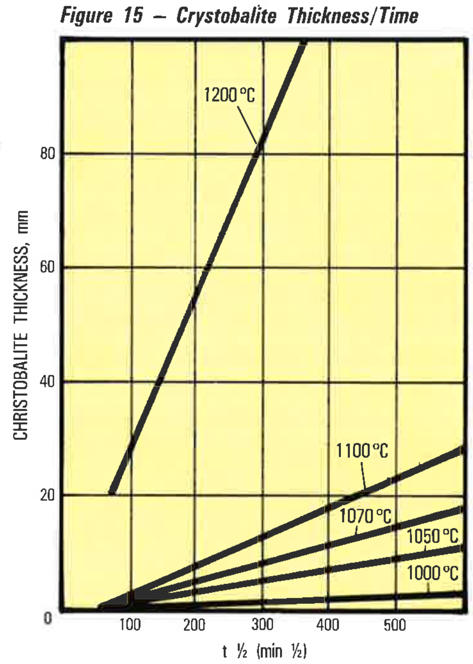
The growth rate of crystobalite from the nucleation site depends on certain environmental factors and material characteristics. Temperature and quartz viscosity are the most significant factors, but oxygen and water vapor partial pressures also impact the crystal growth rate. Consequently, the rate of devitrification of fused quartz increases with increasing hydroxyl (OH^-) content, decreasing viscosity and increasing temperature. High viscosity, low hydroxyl fused quartz materials produced by GE Quartz, therefore, provide an advantage in devitrification resistance.

Photo courtesy of Pacific Western Systems, Mountain View, CA

The thermal properties of fused quartz are critical in the high temperature processing of semiconductor wafers.

The phase transformation to β–crystobalite generally does not occur below 1000°C. This transformation can be detrimental to the structural integrity of fused quartz if it is thermally cycled through the crystallographic α - β inversion temperature range (~250°C). This inversion is accompanied by a large change in density and can result in spalling and possible mechanical failure (see Figure 15).

Figure 15 – Crystobalite Thickness/Time



GE Type 204 fused quartz. Qualitatively similar behavior is observed for type 214.

An Advantage

In certain applications, devitrification can be put to the user's advantage since the crystobalite tends to inhibit sag of the fused quartz.

For example, if a diffusion furnace tube is to be used at high temperatures for extended periods of time, and is not subject to thermal cycling below the β to α crystobalite transformation, rotation procedures described on page 24 have been found to be beneficial.

Contamination

Contamination in almost any form is detrimental. Alkaline solutions, salts, or vapors are particularly deleterious. Handling of fused quartz with the bare hands deposits sufficient alkali from perspiration to leave clearly defined fingerprints upon devitrification. Drops of water allowed to stand on the surface will collect enough contamination from the air to promote devitrified spots and water marks.

Surface contamination affects devitrification in two ways. First, the contaminant promotes nucleation of the crystobalite. Second, it acts as a flux to enhance the crystobalite to β (high) tridymite transformation.

Under some conditions, the tridymite devitrification will grow deeply and rapidly into the interior of the fused quartz.

Heating fused quartz to elevated temperatures (ca. 2000 °C) causes the SiO_2 to undergo dissociation or sublimation. This is generally considered to be: $SiO_2 \rightarrow SiO + \frac{1}{2} O_2$. Consequently, when flame-working fused quartz, there is a band of haze or smoke which forms just outside the intensely heated region. This haze presumably forms because the SiO recombines with oxygen from the air (and perhaps water) and condenses as extremely small particles of amorphous SiO_2. The haze can be removed from the surface by a gentle heating in the oxy-hydrogen flame.

The dissociation is greatly enhanced when the heating of fused quartz is carried out in reducing conditions. For example, the proximity or contact with graphite during heating will cause rapid dissociation of the SiO_2.

Resistance To Sag

The most significant chemical factor effecting the sag resistance of fused quartz is the hydroxyl (OH^-) content. GE controls the OH^- content in its quartz to meet the specific needs of its customers.

To maximize the performance of tubes used in high temperature semiconductor processes, it is important to understand the impact of changes in diameter and wall thickness.

In one study using GE 214LD fused quartz tubing, it was found that the sag rate decreases as the wall thickness of the tube is increased. Generally, as the wall thickness doubles, the sag rate decreases by a factor of approximately 3.

Also, it was shown that with a fixed wall thickness, the sag rate decreases as the tube diameter decreases (see Figures 16 and 17).

Figure 16 – Diffusion Tubing, Collapse vs. Time For Tube ID

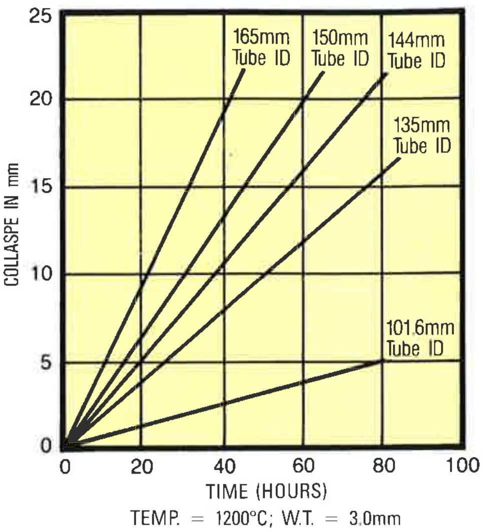
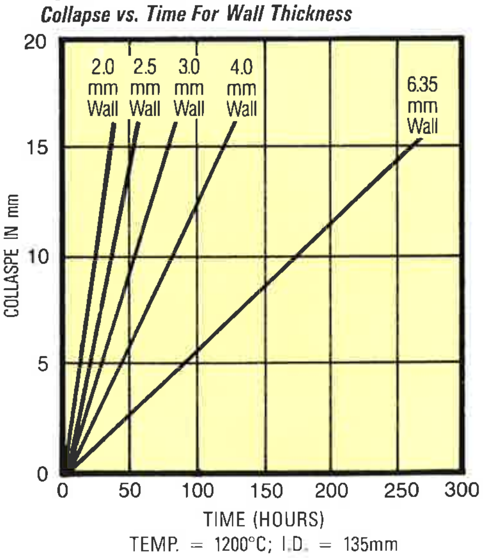


Figure 17 – Diffusion Tubing, Collapse vs. Time For Wall Thickness



Electrical Properties

Since electrical conductivity in fused quartz is ionic in nature, and alkali ions exist only as trace constituents, fused quartz is the preferred glass for electrical insulation and low loss dielectric properties.

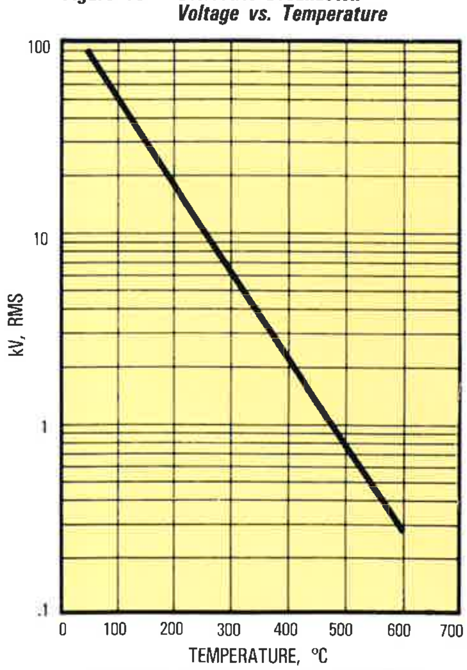
In general, the electrical insulating properties of clear fused quartz are superior to those of the opaque or translucent types. Both electrical insulation and microwave transmission properties are retained at very high temperatures and over a wide range of frequencies.

Typical electrical property values for clear fused quartz include:

Electrical Resistance:
.7 x 10^9 ohm-cm at 350 °C

Dielectric Loss Factor:
Less than .0004 at 20 °C, 1 MHz

Figure 18 — Dielectric Breakdown Voltage vs. Temperature



Representative values of the dielectric breakdown voltage of fused quartz, 0.75 mm thick samples.

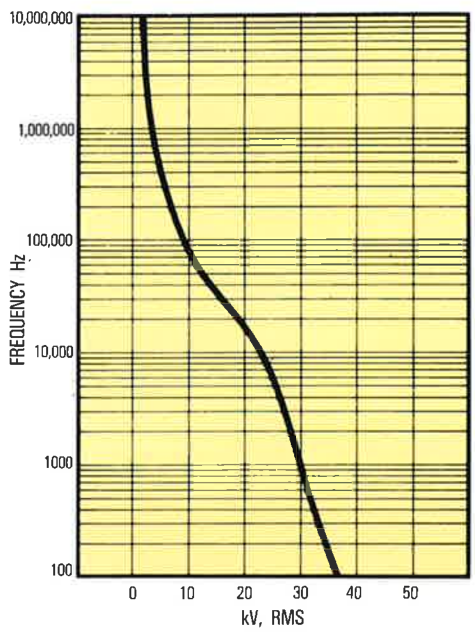
Dielectric Constant:
3.75 at 20 °C, 1 MHz

Specific Resistivity:
10^{18} ohm/cm^3 at 20 °C

Dissipation Factor:
Less than .0001 at 20 °C. 1 MHz

The temperature dependencies of many of these properties are shown in Figures 18 through 23.

Figure 19 — Dielectric Breakdown Voltage vs. Frequency



Representative values of the dielectric breakdown voltage of fused quartz, 0.75 mm thick samples.

Figure 20 — Resistivity

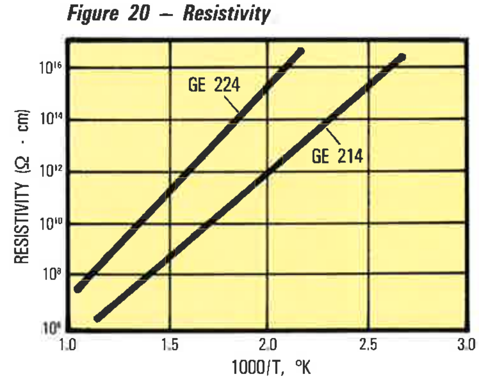
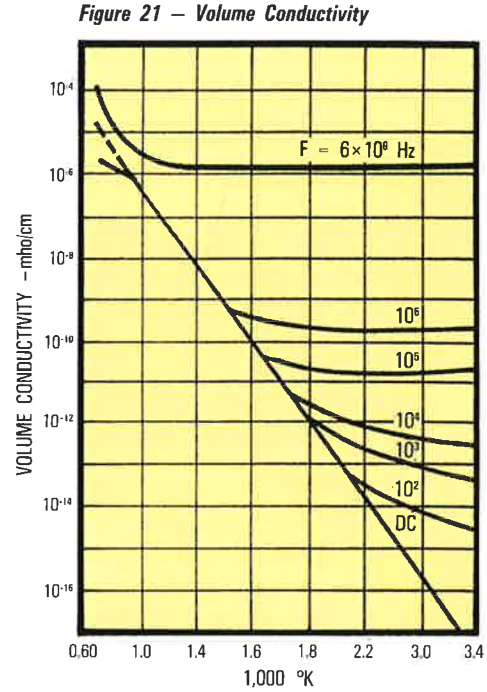


Figure 21 — Volume Conductivity



Volume conductivity of fused quartz. Source: Ibid.

Figure 22 — Dissipation Factor

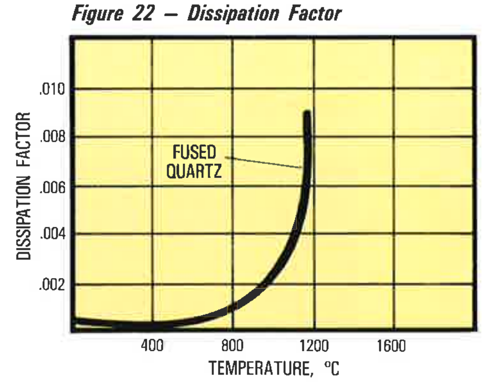
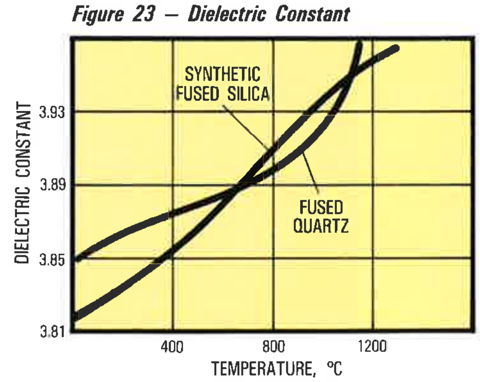


Figure 23 — Dielectric Constant



Optical Properties

Optical transmission properties provide a means for distinguishing among various types of vitreous silica as the degree of transparency reflects material purity and the method of manufacture.

Specific indicators are the UV cutoff and the presence or absence of bands at 245 nm and 2.73 μm. The UV cutoff ranges from ~ 155 to 175 nm for a 10 mm thick specimen and for pure fused quartz is a reflection of material purity.

The presence of transition metallic impurities will shift the cutoff toward longer wavelengths. When desired, intentional doping, e.g., with Ti in the case of Type 219, may be employed to increase absorption in the UV. The absorption band at 245 nm characterizes a reduced glass and typifies material made by electric fusion. If a vitreous silica is formed by a "wet" process, either flame fusion or synthetic material, for example, the fundamental vibrational band of incorporated structural hydroxyl ions will absorb strongly at 2.73 μm.

UV Cutoff

As the transmission curve in Figure 24 illustrates, GE Type 214 fused quartz has a UV cutoff (1 mm thickness) at <160 nm, a small absorption at 245 nm and no appreciable absorption due to hydroxyl ions. Type 219, which contains approximately 100 ppm Ti, has a UV cutoff at ~ 230 nm for a 1 mm thick sample. The IR edge falls between 4.5 and 5.0 μm for a 1 mm thick sample. Tables XV and XVI detail the percent transmittance for Types 214 and 124 fused quartz, including the losses caused by reflections at both surfaces. Values represent a 1 mm thick Type 214 sample and a 10 mm thick Type 124 sample.

Type 124 fused quartz is a very efficient material for the transmission of infrared radiation. Its infrared transmission extends out to about 4 micrometers with little absorption in the "water band" at 2.73 μm.

Conversion to other thicknesses can be accomplished with the following formula: $T = (1\text{-}R)^2 e[\text{-}\alpha_t]$

Where T = percent transmission expressed as a decimal

R = surface reflection loss for one surface

e = base of natural logarithms

α = absorption coefficient, cm^{-1}

t = thickness, cm

Figure 24 — Fused Quartz Average Transmittance Curves

Type 124, 10 mm thickness; all others, 1 mm thickness (Includes Surface Reflection Losses)

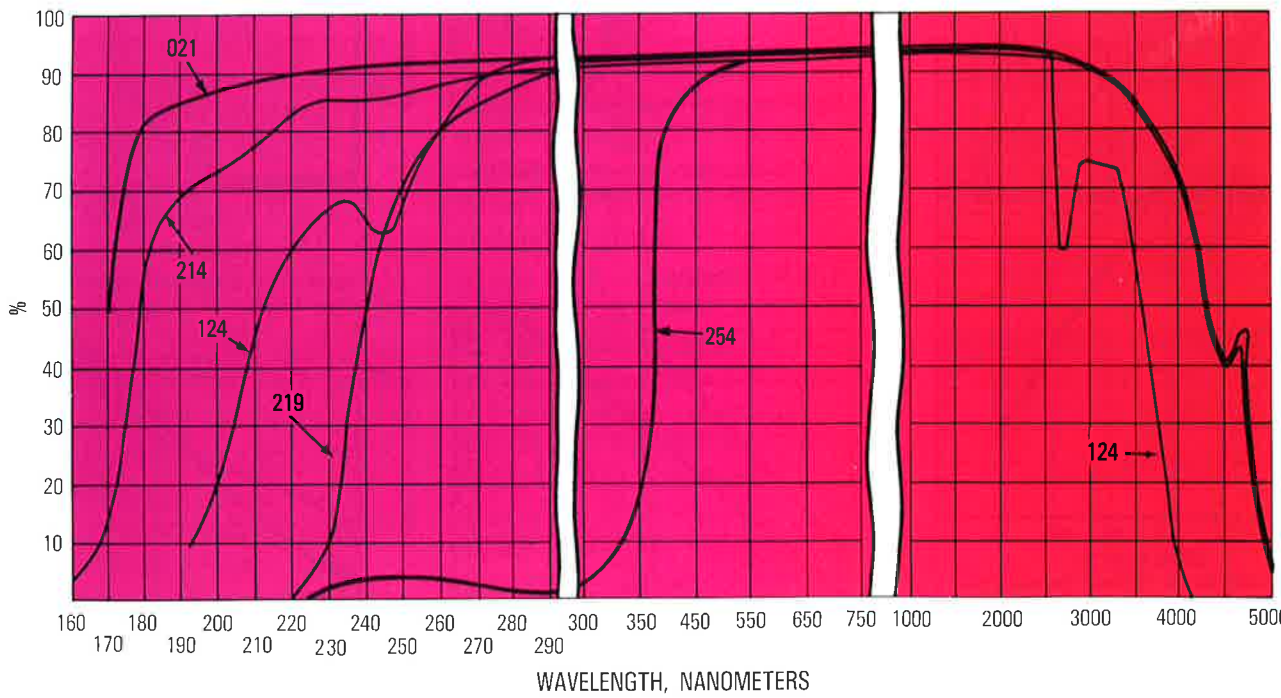
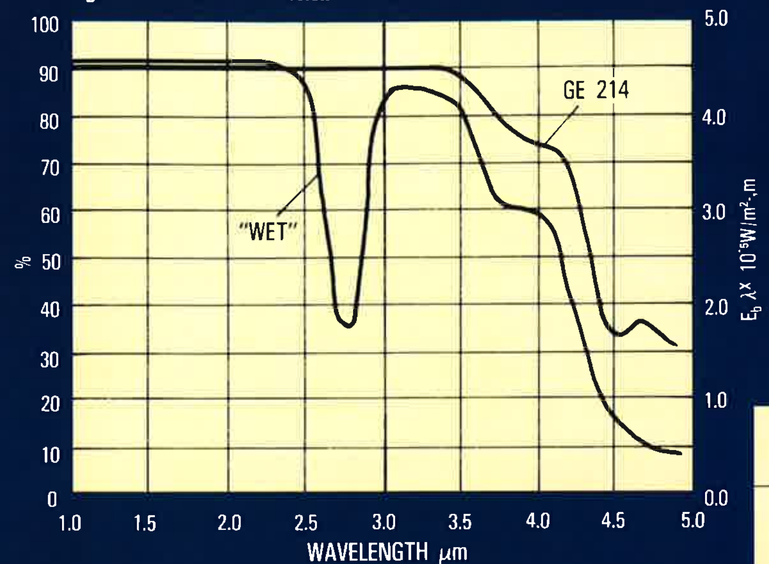


Figure 25 – IR Transmission



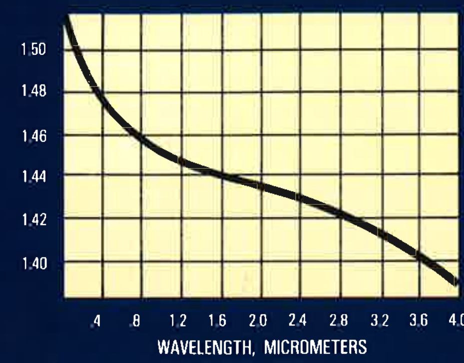
This chart shows how low OH^- content GE fused quartz transmits more energy compared to "wet" varieties of the material. The IR energy transmission of fused quartz is affected by the presence or absence of OH^- absorption band at 2.73μm. The overall effect is an increase in the efficiency of IR heating through the quartz.

Table XV – Type 124 Fused Quartz, Transmittance Standard

THICKNESS – 10MM (Includes Surface Reflection Losses)

Wavelength Micrometers	Average Transmittance in Percent	Average Absorption Coefficient 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	∞

Figure 26 – Index of Refraction



Index of refraction of fused quartz. Source: Rodney and Spindler. *Journal of the Optical Society of America,* Sept. 1954.

Table XVI – Type 214 Fused Quartz, Transmittance Standard

THICKNESS – 1MM (Includes Surface Reflection Losses)

Wavelength in Micrometers	Average Transmittance in Percent	Avg. Absorption Coefficient CM^{-1}
.160	4.6	29.57
.162	5.8	27.33
.164	7.4	24.89
.166	8.4	23.64
.168	10.9	21.04
.170	18.5	15.75
.175	43.6	7.22
.180	60.4	4.01
.185	66.1	3.12
.190	70.4	2.52
.195	71.3	2.41
.200	73.4	2.14
.205	76.1	1.80
.210	79.4	1.39
.220	85.3	.69
.230	87.3	.49
.240	86.5	.60
.245	86.6	.57
.250	87.7	.48
.260	89.5	.28
.270	90.2	.21
.280	90.7	.17
.290	90.9	.16
.300	91.1	.15
.350	91.7	.11
.450	92.2	.09
.550	92.5	.07
.650	92.7	.06
.750	92.9	.04
1.00	93.1	.03
1.50	93.2	.03
2.00	93.5	.02
2.50	93.4	.05
2.65	93.5	.04
2.75	92.9	.11
2.80	93.0	.10
2.90	92.9	.12
3.00	92.7	.15
3.10	92.7	.16
3.20	92.8	.17
3.30	92.8	.18
3.43	92.7	.20
3.80	81.2	1.62
3.92	81.0	1.66
4.20	67.5	3.62
4.25	66.0	3.92
4.30	57.5	5.40
4.45	43.1	8.56
4.58	49.7	6.97
4.70	36.1	10.61

Guidelines for Users of Fused Quartz

Like any material that is expected to provide a design life at high temperatures, fused quartz demands some care in handling and use to achieve maximum performance from the product.

Storage

Space permitting, fused quartz should be stored in its original shipping container. If that is not practical, at least the wrapping should be retained. In the case of tubing, the end coverings should be kept in place until the product is used. This protects the ends from chipping and keeps out dirt and moisture which could compromise the purity and performance of the tubing.

Cleaning

For applications in which cleanliness is important, General Electric recommends the following procedure:

The product, particularly tubing, should be washed in deionized or distilled water with a degreasing agent added to the water. The fused quartz should then be placed in a 7% (maximum) solution of ammonium bifluoride for no more than ten minutes, or a 10 vol % (maximum) solution of hydrofluoric acid for no more than five minutes. Etching of the surface will remove a small amount of fused quartz material as well as any surface contaminants. To avoid water spotting which may attract dirt and cause devitrification upon subsequent heating, the fused quartz should be rinsed several times in deionized or distilled water and dried rapidly.

To further reduce the possibility of contamination, care should be used in handling fused quartz.

The use of clean cotton gloves at all times is essential.

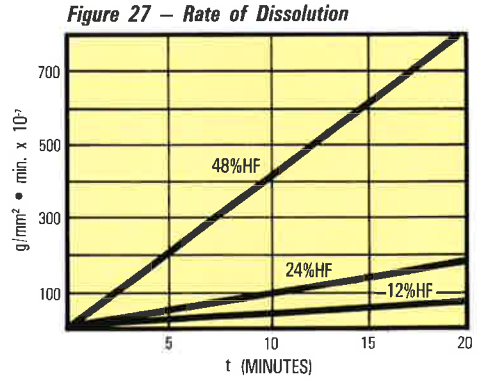
Washing of translucent tubing is not recommended because the water or acid solution tends to enter the many capillaries in the material. This may cause the quartz to burst if the pieces are subsequently heated rapidly to very high temperatures.

Rotation Procedures For Fused Quartz Furnace Tubes

The following procedure has been used to create an even layer of crystobalite on diffusion tubes in order to increase resistance to devitrification.

Place the tube in a furnace at 1200 °C, and rotate it 90 ° every two hours for the first 30 hours. If the working schedule does not permit adherence to this procedure, the following suggestion is offered. Place the tube in a furnace at 1200 °C and rotate it 90 ° every two hours for the first 8 hours, then reset the furnace to operating temperature.

Figure 27 – Rate of Dissolution



Solarization

Fused quartz made from natural raw material solarizes or discolors upon prolonged irradiation by high energy radiation (such as short UV, x-rays, gamma rays and neutrons). Resistance to this type of solarization increases with the purity of fused quartz. Hence, synthetic fused silica is highly resistant to solarization. Solarization in fused quartz can be thermally bleached by heating it to about 500 °C.

Fluorescence

Fused quartz made from natural sand exhibits a strong fluorescence when exposed to shortwave length UV radiation (253.7 nm). The intensity of the fluorescence depends on the processing conditions and purity of the fused quartz. Generally, the intensity decreases with increased purity. Synthetic fused quartz is essentially free of fluorescence induced by short UV radiation.

Technical Support

An important consideration for today's users of fused quartz is the availability of technical product support. GE Quartz backs its products with fully equipped analytical and development laboratories and a staff of materials and fusion experts available to support customer requirements. State-of-the-art analytical equipment assures optimal production quality and also enables certification and subsequent verification of GE Quartz product compliance with stringent industry standards.

Manufacturing & Quality Control

From its manufacturing plants in the United States and Europe, GE produces quartz products for users around the world. These modern and efficient facilities are supported by well equipped laboratories and highly qualified engineering personnel.

Because purity is a yardstick by which our product is measured, every step in the production process, from raw material purification to final packaging, is closely monitored and controlled.

Throughout production, GE quartz products are repeatedly inspected for visual and dimensional quality using a variety of modern instruments. These include an infrared spectrophotometer for detecting residual hydroxyl ion (OH^-) content and a beam bending viscometer for measuring viscosity.

In addition, raw material and fused quartz samples are routinely analyzed for trace impurities using a number of detection techniques. These include induction coupled plasma, neutron activation, atomic absorption, x-ray fluorescence, SEM/EDX, and electron spin resonance.

GE Quartz manufacturing plants. From top to bottom, Geesthact, Germany; Willoughby, Ohio, and Newark, Ohio.

Above: gas chromotography. Below: atomic absorption spectroscopy.

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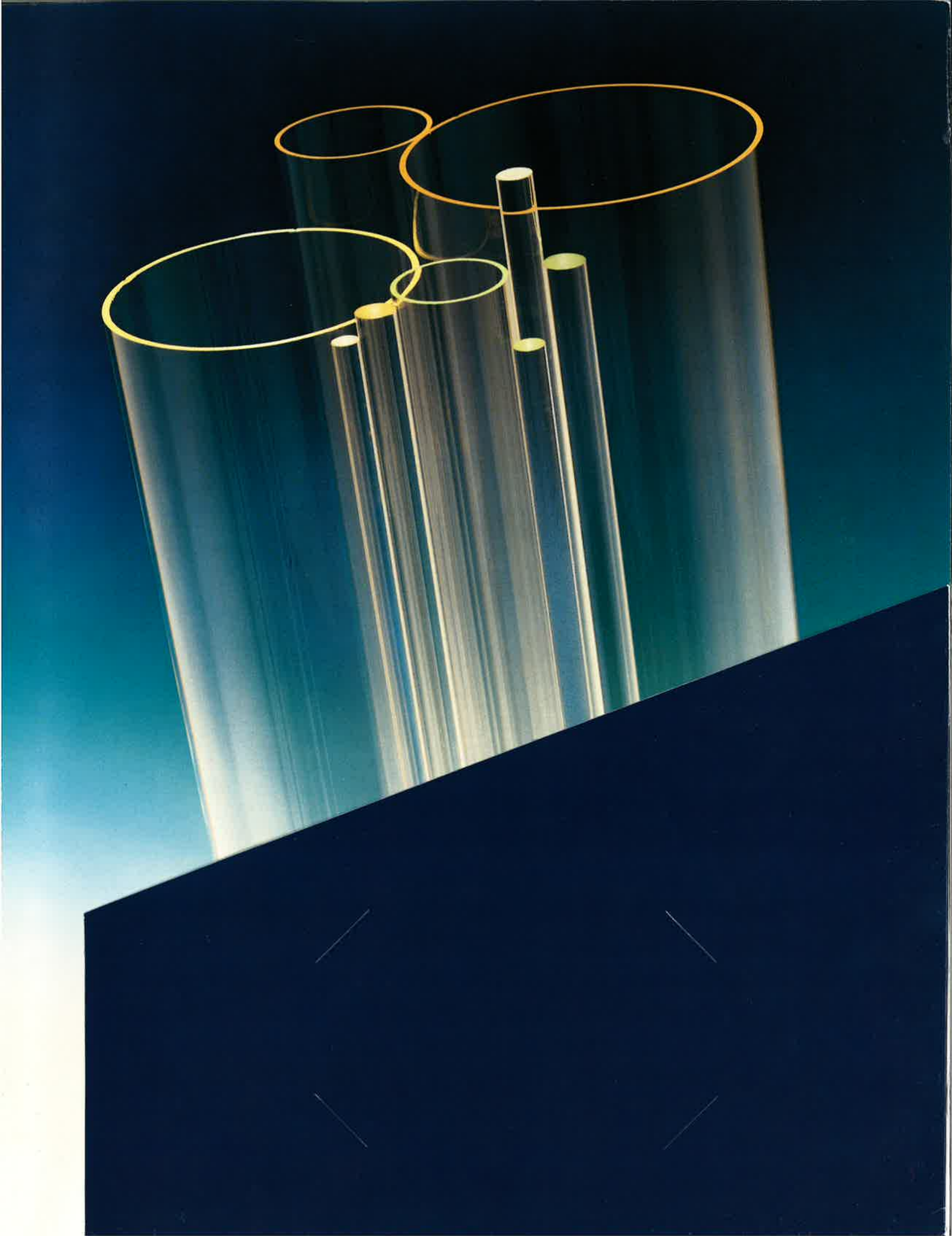

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