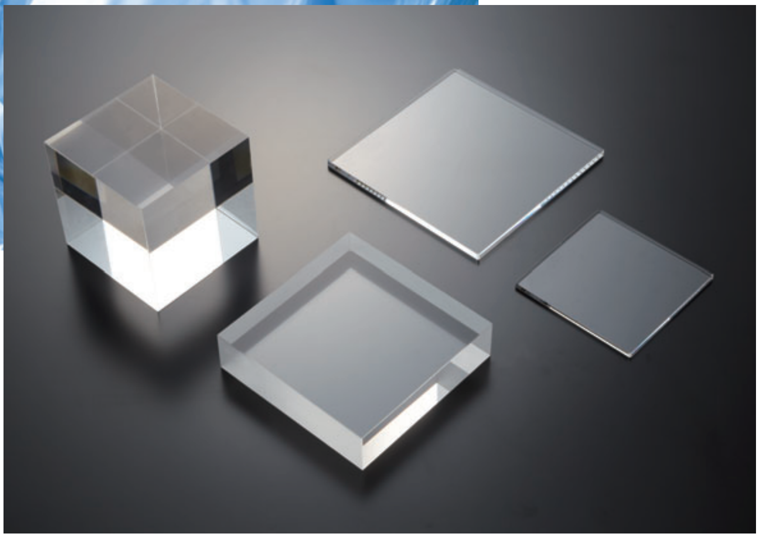
TOSOH

Optical Silica Glass

ES Series



ES ingots are manufactured from high-purity $SiCl_4$ using an oxy-hydrogen flame in a verneuil type process.

For very large parts, such as LCD photomasks, ES ingots are reflown into large rectangular blocks.

ES ingots have a typical purity that exceeds the detection limit of 10ppb in all elements, and are virtually free of bubbles and inclusions.

As a result, ES is the material of choice for LCD photomasks up to Gen. 10, and selected subgrades are widely used in leading edge stepper (KrF and ArF) and optics applications.

Grade

Grades	Features	Application	Available size(sidexside. Diameter)
ES	Standard optical grade for planar optics	LCD Mask, Mirror&window substrate	1,800x1,700mm *1
ESL-1	Standard optical grade with 1D striae free	General Optics & laser Optics	1,300x1,000mm *1
ESL-1000	Enhance excimer durability for ESL-1	Stepper lens (illumination)	1,300x1,000mm *1
ESL-2	Good homogeneity with 3D striae free	High precision optics	~Φ450mm
ESL-2000	Enhance excimer durability for ESL-2	Stepper lens (Projection)	~Φ450mm

*1 Reflown ingots

Optical Properties

(Typical values)

Grades	Striae *2	Homogeneity *3 Δn(x10⁻⁶) within CA	Strain (nm/cm)	Fluorescence *4	Excimer Durability	Applicable Wavelength *6 (nm)	Bubble Class *7
ES	n.sp.	n.sp.	1~20	n.sp.	n.sp.	180~2100	Class 0
ESL-1	1D	5~15(CA:Φ500mm) 3~10(CA:Φ300mm)	1~10	None	n.sp.	180~2100	Class 0
ESL-1000	1D	5~15(CA:Φ500mm) 3~10(CA:Φ300mm)	1~10	None	sp. *5	180~2100	Class 0
ESL-2	3D	<10(CA:Φ300mm)	1~10	None	n.sp.	180~2100	Class 0
ESL-2000	3D	<10(CA:Φ300mm)	1~10	None	sp. *5	180~2100	Class 0

n.sp. = not specified

*2 Striae specification is defined as below and confirmed by interferometric measurement.
1D : 1 direction free 3D : 3 direction free

*3 Homogeneity means refractive index homogeneity and is expressed as Δn(PV) within effective area.

*4 Fluorescence is checked with excitation at 254nm using an Hg-lamp.

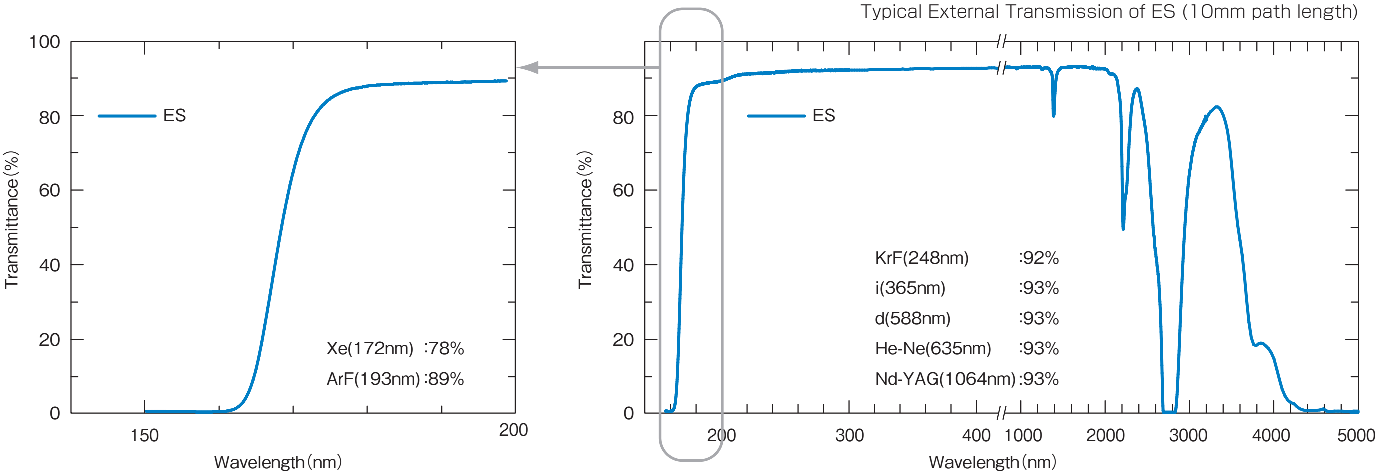
*5 Excimer durability is specified with Tosoh's KrF and ArF excimer laser damage tests.

*6 Applicable wavelength is defined as the wavelength range where external transmittance is more than 80%/cm.

*7 Bubble class is as per DIN 58927.

Spectral Transmission

Typical External Transmission of ES (10mm path length)



Optical Properties

λ (μm)		Refractive Index*1
n_{1530}	1.53000	1.44428
n_{1064}	1.06400	1.44965
n_t	1.01398	1.45027
n_s	0.85211	1.45249
$n_{A'}$	0.76819	1.45392
n_{708}	0.70820	1.45514
n_{691}	0.69075	1.45554
n_{672}	0.67164	1.45600
n_C	0.65627	1.45640
$n_{C'}$	0.64385	1.45674
$n_{He\text{-}Ne}$	0.63299	1.45704
n_{623}	0.62344	1.45733
n_D	0.58929	1.45844
n_d	0.58773	1.45849
n_{577}	0.57696	1.45888
n_e	0.54623	1.46011
n_{492}	0.49161	1.46284
n_F	0.48613	1.46317
$n_{F'}$	0.47999	1.46354
n_g	0.43596	1.46673
n_h	0.40477	1.46966
n_i	0.36512	1.47458
n_{334}	0.33415	1.47983
n_{313}	0.31266	1.48454
n_{289}	0.28936	1.49107
n_{270}	0.26988	1.49814
n_{254}	0.25373	1.50557
n_{248}	0.24800	1.50865
n_{229}	0.22887	1.52121
n_{215}	0.21451	1.53378
n_{194}	0.19423	1.55899
n_{185}	0.18495	1.57511

Refractive Index	
n_d	1.45849
n_e	1.46011

Abbe No.	
ν_d	67.72
ν_e	67.58

Dispersion	
n_F-n_C	0.00677
$n_{F'}$-$n_{C'}$	0.00681

Partial Dispersion	
n_C-n_t	0.00613
n_C-$n_{A'}$	0.00248
n_d-n_C	0.00209
n_e-n_C	0.00371
n_g-n_d	0.00824
n_g-n_F	0.00356
n_h-n_g	0.00293
n_i-n_g	0.00785
$n_{C'}$-n_t	0.00647
n_e-$n_{C'}$	0.00337
$n_{F'}$-n_e	0.00344
n_i-$n_{F'}$	0.01104

Partial Dispersion Ratio	
$\theta_{C,t}$	0.9056
$\theta_{C,A'}$	0.3665
$\theta_{d,C}$	0.3093
$\theta_{e,C}$	0.5480
$\theta_{g,d}$	1.2167
$\theta_{g,F}$	0.5260
$\theta_{h,g}$	0.4323
$\theta_{i,g}$	1.1600
$\theta'_{C',t}$	0.9499
$\theta'_{e,C'}$	0.4952
$\theta'_{F',e}$	0.5046
$\theta'_{i,F}$	1.6209

Sellmeier Dispersion Formula for Refractive Index

$$n^2-1 = A_1\lambda^2/(\lambda^2-B_1^2)+A_2\lambda^2/(\lambda^2-B_2^2)+A_3\lambda^2/(\lambda^2-B_3^2)$$

Constants of Sellmeier Dispersion Formula			
A1	0.6961852	B1	0.0685886
A2	0.4079779	B2	0.1162043
A3	0.8974798	B3	9.8961609

Differential Temperature Coefficients of the Refractive Index

Temp. range (℃)	dn/dT absolute ($\times10^{-6}$/℃)				dn/dT relative ($\times10^{-6}$/℃)			
	e (546.1nm)	g (435.8nm)	h (404.7nm)	i (365.0nm)	e (546.1nm)	g (435.8nm)	h (404.7nm)	i (365.0nm)
-40~-20	7.8	8.2	8.4	8.7	9.8	10.2	10.5	10.8
-20~0	8.2	8.6	8.9	9.2	9.9	10.4	10.7	11.0
0-20	8.7	9.1	9.4	9.7	10.1	10.6	10.9	11.2
20~40	9.1	9.5	9.8	10.2	10.6	10.8	11.1	11.5
40~60	9.5	9.9	10.2	10.6	10.6	11.1	11.4	11.7
60~80	9.8	10.3	10.5	10.9	10.8	11.3	11.6	12.0

Internal Transmission	
λ(nm)	t=10mm
170	77
175	95
180	98
190	98
200	99
210	100
220	100
230	100
240	100
250	100
260	100
270	100
280	100
290	100
300	100
350	100
400	100
450	100
500	100
600	100
700	100
800	100
900	100
1000	100
1200	100
1400	93
1600	100
1800	100
2000	99
2100	98
2200	66

*1 All refractive indices are calculated from values measured under dry N2 at 25℃, 1013hPa

Mechanical Properties

Item		Value
Density	(g/cm^3)	2.2
Young's modulus	(GPa)	74
Shear modulus	(GPa)	31
Poisson's ratio		0.18
Bending strength*2	(MPa)	65~95
Compressive strength	(MPa)	1,130
Tensile strength*2	(MPa)	49
Torsion strength	(MPa)	29
Vickers hardness	(MPa)	8,900

Thermal Properties

Item	Value
Strain point($\eta=10^{14.5}$) (°C)	980
Annealing Point($\eta=10^{13}$) (°C)	1,080
Softening Point($\eta=10^{7.6}$)*3 (°C)	(1,720)
Thermal Conductivity (W/mK) at 20℃	1.38
Specific heat (J/kg·K) at 20℃	749
Thermal diffusivity ($\times10^{-7}m^2/s$) at 20℃	8.5
Coefficient of thermal expansion ($\times10^{-7}$/℃)	
α:30℃~100℃	5.2
α:30℃~200℃	5.8
Viscosity log η (Poise) at 1,200℃	11.4

Electrical Properties

Item	Value
Dielectric constant at 500MHz	3.9
Dielectric loss factor(tan δ) at 500MHz	$<1\times10^{-3}$
Resistivity (Ω)	5×10^{15}
Volume resistivity ($\Omega\cdot$cm)	1×10^{17}

*2 Bending and Tensile strengths are affected by surface conditions.

*3 Estimate from extrapolation

NOTE : Unless otherwise stated, all values represent typical data at 25℃

ED-H

ED-H ingots are manufactured from high-purity $SiCl_4$ in a VAD process.

ED-H ingots have a typical purity that exceeds the detection limit of 10ppb in all elements, and are virtually free of bubbles and inclusions.

Thanks to an OH content less than 100ppm, ED-H material exhibits superior transmission characteristics in the deep UV and is a material of choice for VUV applications down to 170nm.

Grade

Grade	Feature	Application	Available size (Diameter)
ED-H	Good homogeneity with 3D striae free	High precision optics	Φ180mm

Optical Properties

(Typical values)

Grade	Striae *1	Homogeneity *2 Δn(x10⁻⁶) within CA	Strain (nm/cm)	Fluorescence *3	Excimer Durability	Applicable Wavelength *4 (nm)	Bubble Class *5
ED-H	3D	5～10 (CA : Φ180mm)	1～10	None	n.sp.	170～2,600	Class 0

n.sp. = not specified

*1 Striae specification is defined as below and confirmed by interferometric measurement.
1D : 1 direction free 3D : 3 direction free

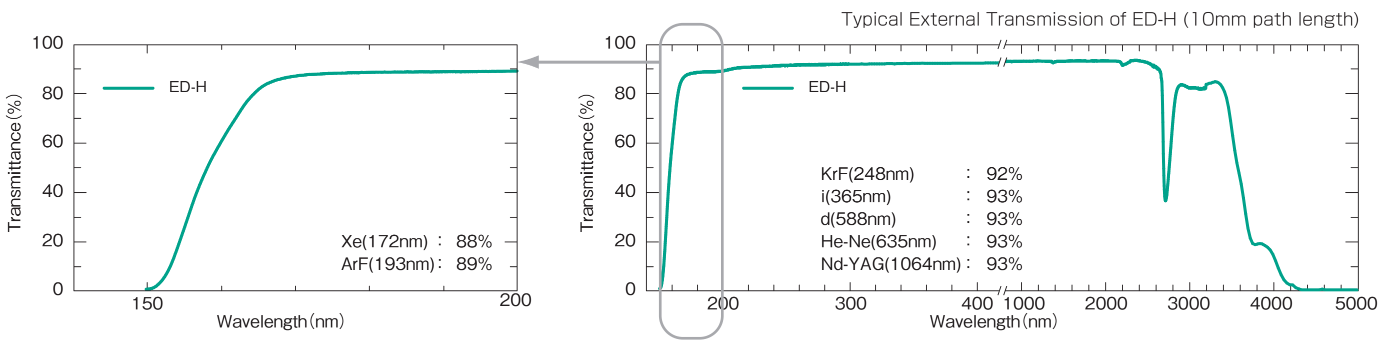
*2 Homogeneity means refractive index homogeneity and is expressed as Δn(PV) within effective area.

*3 Fluorescence is checked with excitation at 254nm using an Hg-lamp.

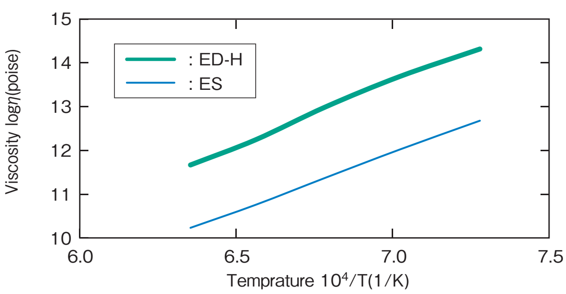
*4 Applicable wavelength is defined as the wavelength range where external transmittance is more than 80%/cm.

*5 Bubble class is as per DIN 58927.

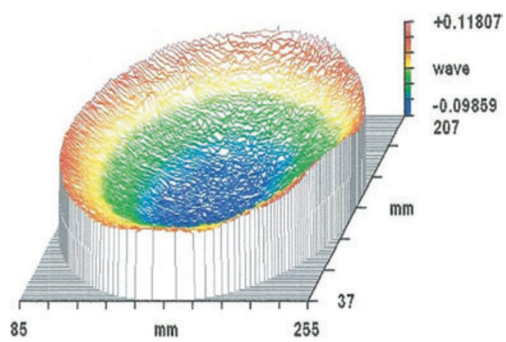
Spectral Transmission



High temperature viscosity



Homogeneity (Typical mapping data)



Optical Properties

λ (μm)		Refractive Index*1
n_{1530}	1.53000	1.44440
n_{1064}	1.06400	1.44977
n_t	1.01398	1.45038
n_s	0.85211	1.45260
$n_{A'}$	0.76819	1.45403
n_{708}	0.70820	1.45525
n_{691}	0.69075	1.45565
n_{672}	0.67164	1.45611
n_C	0.65627	1.45651
$n_{C'}$	0.64385	1.45685
$n_{He\text{-}Ne}$	0.63299	1.45716
n_{623}	0.62344	1.45744
n_D	0.58929	1.45855
n_d	0.58773	1.45861
n_{577}	0.57696	1.45899
n_e	0.54623	1.46022
n_{492}	0.49161	1.46296
n_F	0.48613	1.46328
$n_{F'}$	0.47999	1.46366
n_g	0.43596	1.46684
n_h	0.40477	1.46977
n_i	0.36512	1.47469
n_{334}	0.33415	1.47994
n_{313}	0.31266	1.48465
n_{289}	0.28936	1.49118
n_{270}	0.26988	1.49825
n_{254}	0.25373	1.50568
n_{248}	0.24800	1.50876
n_{229}	0.22887	1.52132
n_{215}	0.21451	1.53389
n_{194}	0.19423	1.55910
n_{185}	0.18495	1.57522

Refractive Index	
n_d	1.45861
n_e	1.46022

Abbe No.	
ν_d	67.75
ν_e	67.61

Dispersion	
n_F-n_C	0.00677
$n_{F'}-n_{C'}$	0.00681

Partial Dispersion	
n_C-n_t	0.00613
$n_C-n_{A'}$	0.00248
n_d-n_C	0.00209
n_e-n_C	0.00371
n_g-n_d	0.00823
n_g-n_F	0.00356
n_h-n_g	0.00293
n_i-n_g	0.00785
$n_{C'}-n_t$	0.00647
$n_e-n_{C'}$	0.00337
$n_{F'}-n_e$	0.00344
$n_i-n_{F'}$	0.01104

Partial Dispersion Ratio	
$\theta_{C,t}$	0.9056
$\theta_{C,A'}$	0.3665
$\theta_{d,C}$	0.3094
$\theta_{e,C}$	0.5481
$\theta_{g,d}$	1.2166
$\theta_{g,F}$	0.5259
$\theta_{h,g}$	0.4324
$\theta_{i,g}$	1.1600
$\theta'_{C',t}$	0.9502
$\theta'_{e,C'}$	0.4954
$\theta'_{F',e}$	0.5046
$\theta'_{i,F}$	1.6213

Sellmeier Dispersion Formula for Refractive Index

$$n^2-1 = A_1\lambda^2/(\lambda^2-B_1{}^2)+A_2\lambda^2/(\lambda^2-B_2{}^2)+A_3\lambda^2/(\lambda^2-B_3{}^2)$$

Constants of Sellmeier Dispersion Formula			
A1	0.6963511	B1	0.0685337
A2	0.4081467	B2	0.1162167
A3	0.8974786	B3	9.8961611

Internal Transmission	
λ(nm)	t =10 mm
170	98
175	99
180	99
190	99
200	99
210	99
220	100
230	100
240	100
250	100
260	100
270	100
280	100
290	100
300	100
350	100
400	100
450	100
500	100
600	100
700	100
800	100
900	100
1000	100
1200	100
1400	99
1600	100
1800	100
2000	100
2200	98
2400	100
2600	97
2800	71

*1 All refractive indices are calculated from values measured under dry N2 at 25℃, 1013hPa

Mechanical Properties *2

Item		Value
Density	(g/cm^3)	2.2
Young's modulus	(GPa)	74
Shear modulus	(GPa)	31
Poisson's ratio		0.18
Bending strength*2	(MPa)	65~95
Compressive strength	(MPa)	1,130
Tensile strength*2	(MPa)	49
Torsion strength	(MPa)	29
Vickers hardness	(MPa)	8,900

Thermal Properties

Item		Value
Strain point(η=$10^{14.5}$)	(°C)	1,090
Annealing Point(η=10^{13})	(°C)	1,190
Softening Point(η=$10^{7.6}$)*3	(°C)	(1,720)
Thermal Conductivity	(W/mK) at 20℃	1.38
Specific heat	(J/kg・K) at 20℃	749
Thermal diffusivity	($\times10^{-7}$m^2/s) at 20℃	8.5
Coefficient of thermal expansion ($\times10^{-7}$/℃)		
	α:30℃~100℃	5.2
	α:30℃~200℃	5.8
Viscosity log η (Poise)	at 200℃	13.0

Electrical Properties

Item		Value
Dielectric constant	at 500MHz	3.9
Dielectric loss factor(tan δ)	at 500MHz	<1x10^{-3}
Resistivity	(Ω)	8 x 10^{15}
Volume resistivity	(Ω・cm)	5 x 10^{17}

*2 Bending and Tensile strengths are affected by surface conditions.
*3 Estimate from extrapolation
NOTE : Unless otherwise stated, all values represent typical data at 25℃

Impurity Level of Optical Silica Glass (Typical Value)

Unit(ppm)

Grades	Al	Ca	Cu	Fe	Na	K	Li	Mg	OH
ES	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1000
ED-H	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<100

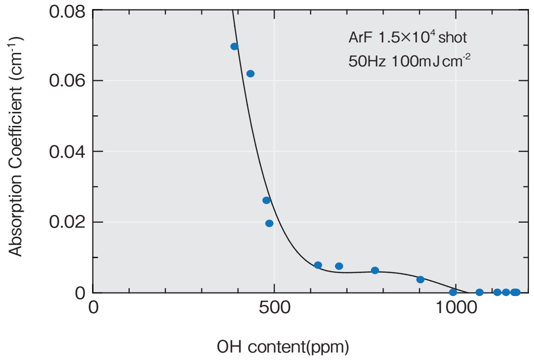
Fluorescence Property of ES series

ES Series do not show fluorescence when irradiating with 254nm light from a low pressure lamp.
However, when irradiating with a strong light source such as X-ray and excimer lasers, fluorescence may occur.
The following indicates the fluorescence seen in ES Series when irradiated with X-ray and UV lights.

Irradiated Light	Excitation Wavelength (nm)	Condition	Shot Number	Absorption Band	Visible Fluorescence
Low pressure Hg	254	Continuously,2mW/cm²	10,000	None	None
KrF excimer laser	248	25Hz, 200mJ/cm²	10,000	None	None
ArF excimer laser	193	125Hz, 500mJ/cm²	10,000	None	light red
ArF excimer laser	193	100Hz, 150mJ/cm²	10,000	None	blue
ArF excimer laser	193	100Hz, 400mJ/cm²	10,000	None	blue & slight red
X-ray	—	W, 50KV, ca 1E+6 rad	—	*1	—

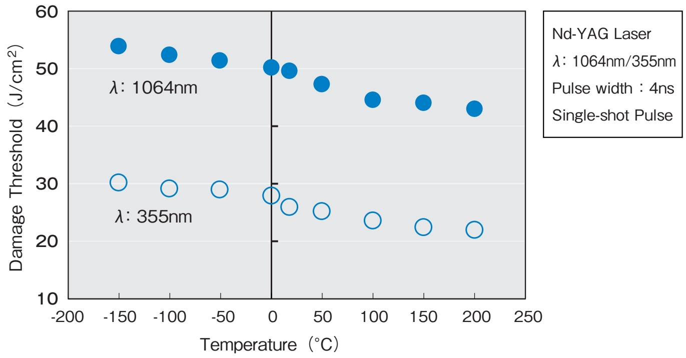
*1 Transmittance decrease less than 1% in the 200 to 300nm wavelength

Excimer Laser Durability of ES grades



Dependence of ArF Laser durability on OH Content

Nd: YAG laser damage threshold of ES



(K.Mikami, T.Jitsuno, et.al., 56th JSAP conference 2009)

Chemical properties

Mass Loss of Clear Fused Quartz by Selected Acids

Solution	Conditions			Mass Loss (g/m²)
	Conc. (%)	Temp. (℃)	Time (hr)	
H_2SO_4	96	20	240	0.016
		205	24	0.06
HNO_3	65	20	240	0.06
		115	24	0.11
HCl	37	20	240	0.18
		66	24	0.14

Mass Loss of Clear Fused Quartz by Selected Alkalis

Solution	Conditions			Mass Loss (g/m²)
	Conc. (%)	Temp. (℃)	Time (hr)	
NH_4OH	10	25	72	0.06
		50	72	0.32
NaOH	5	25	96	0.135
		100	10	15
KOH	10	25	72	0.14
		100	10	11.3

Chemical reactivity towards other materials

Metals and nonmetals		Gases	
Al, Ag	Rapid reaction at 700-800℃	CO, SO_2	No reaction
Au, Ag, Pt	No reaction	N_2, O_2	No reaction
Zn, Sn, Pb	No reaction	Cl_2	No reaction
Si	Slight reaction when fused	F_2	No reaction with dried gases under 300℃
Ge	No reaction at 900℃	H_2	No reaction
Mo, W	No reaction	HCl	No reaction
Oxides		**Salts**	
Al_2O_3	Gradual reaction over 900℃	$BaCl_2$	Reaction when fused
CaO	Reaction over 900℃	$BaSO_4$	Reaction over 700℃
CuO	Reaction over 800℃	$CaCl_2$	Slight reaction when fused at 800℃
Fe_2O_3	Reaction over 900℃	KCl	Acceleration of devitrification at high temp.
PbO	Intense reaction with fusion	KF	Intense reaction when fused
MgO	Slight reaction at 900℃	NaCl	Reaction visually recognized over 800℃
ZnO	Reaction over 420℃	Na_2SO_4	No reaction

Devitrification

When silica glass is exposed to high temperatures, the pure SiO_2 structure changes from a glass state (amorphous) to a stable crystalline state called cristobalite. This structural change is known as devitrification and generally occurs at temperatures over 1,150℃ for clean clear fused quartz. Devitrification may also occur at temperatures below 1,000℃ in the presence of impurities such as metal. The relation between the devitrification rate of clear fused quartz and temperature in various atmospheres is indicated below.

Gas composition	Temp.(℃)	Time(h)	Degree of devitrification	Devitrification thickness(μm)
Air	1,300	72	Surface completely devitrified	250
Dried oxygen	1,300	72	Devitrification of 50% of the surface	100～150
Industrial nitrogen	1,300	72	Surface devitrified	—
Nitrogen(O_2 and H_2O removed)	1,300	72	No devitrification	—
Hydrogen(O_2 and H_2O removed)	1,300	72	No devitrification	—

Handling Precautions

Care must be taken to avoid direct hand contact with silica glass. The skin's natural salts contain alkali such as sodium, potassium and other impurities that accelerate devitrification. All sources of metal contaminants should be avoided.

As a further precaution, fused silica should be washed in pure or distilled water, then either air dried in a clean area or wiped dry with an alcohol-soaked clean cloth. For more rigorous cleaning, a very thin surface layer of the glass can be removed by etching, prior to water washing, in a 5% - 10% hydrofluoric acid solution.

Usage Precautions

* Always clean silica glass prior to use.
* Dry product completely before using at high temperature.
* Pay attention to devitrification due to atmospheric exposure.
* Please refer to the thermal properties for your application. Fused silica can resist sudden heating and quenching, but it does have its limits.
* Always consider fused silica's very low thermal expansion when the glass is used with other materials to avoid failure due to the differences in thermal expansion.
* Take caution during prolonged usage at temperatures approaching the annealing point.
* Be aware that slow sagging may occur under high temperature.

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