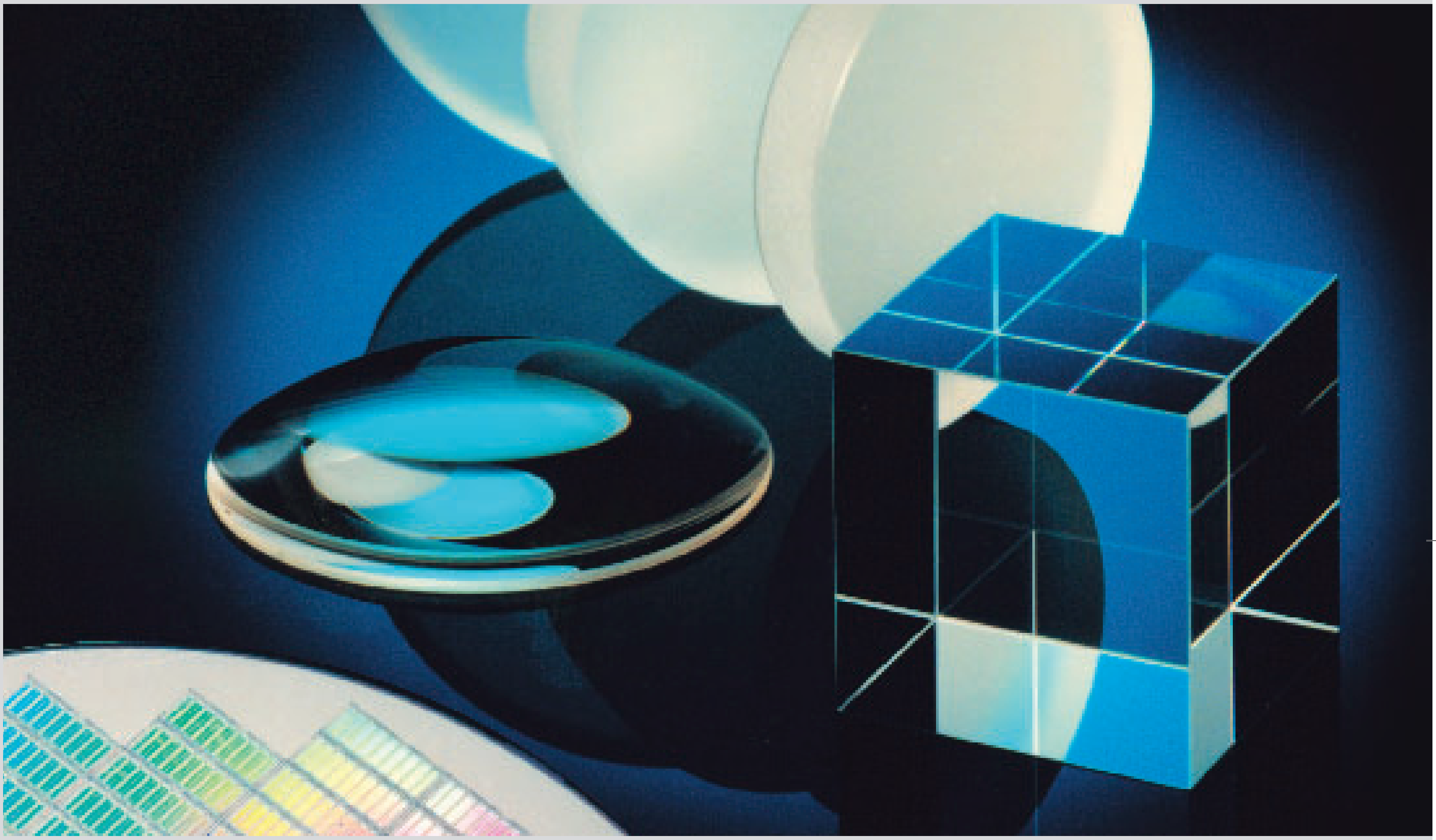
Heraeus



Quartz Glass for Optics
Data and Properties

Heraeus Quarzglas

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[3D] = 3D material, optically isotropic.

In quartz glass, the homogeneity is typically specified in one direction only. Heraeus manufactures quartz glass grades which are controlled and specified in all 3 directions regarding striae, layers and homogeneity. These materials, specified for the most demanding applications, are identified by the 3D symbol.

❶ For raw formed ingots the bubble specification is valid for the area defined by the minimum diameter tolerance. For machined parts it is defined as 100 % of the material.

❷ Bubbles or inclusions ≤ 0.08 mm diameter are not counted.

❸ For non-spherical bubbles the diameter is averaged.

❹ The Δn value is the maximum permissible lateral variation in refractive index (measured by interferometer at 632.8 nm) over 90% of the diameter or edge length of a fine ground piece, or 80% of a raw formed ingot. The maximum test diameter is 430 mm. Larger pieces are measured using overlapping interferograms.

Grade	Bubbles and Inclusions ❶ ❷		Homogeneity ❻		
	The bubble grade is given for every 100 cm^3. Quartzglass from Heraeus is free of inclusions.		Striae class as per DIN ISO 10110	Δn Value	
	DIN 58927	DIN ISO 10110 For different weight intervals (kg). ❸		PV value ❹ (Peak-to-Valley)	Non spherical ❺ proportion Δn (p.s.)
Suprasil® 1 [3D]	0	1 /2*0.10 / ≤ 6	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 2 Grade A	0	1 /1*0.16 / ≤ 6 1 /1*0.25 / 6 - 30	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 2 Grade B	0	1 /1*0.16 / ≤ 6 1 /1*0.25 / 6 - 30	2 / -;5	$\leq 10 \cdot 10^{-6}$	$\leq 5 \cdot 10^{-6}$
Suprasil® 1 ArF* [3D]	0	1 /2*0.10 / ≤ 6	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 2 ArF*	0	1 /1*0.16 / ≤ 6 1 /1*0.25 / 6 - 30	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 1 KrF* [3D]	0	1 /2*0.10 / ≤ 6	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 2 KrF*	0	1 /1*0.16 / ≤ 6 1 /1*0.25 / 6 - 30	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 311 [3D]	0	1 /2*0.10 / ≤ 6	2 / -;5	$\leq 3 \cdot 10^{-6}$	$\leq 1 \cdot 10^{-6}$
Suprasil® 312	0	1 /1*0.16 / ≤ 6 1 /1*0.25 / 6 - 30	2 / -;5	$\leq 4 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Suprasil® 300	0	1 /2*0.16 / ≤ 6	n.sp.	n.sp.	n.sp.
Homosil® 101 [3D]	0	1 /2*0.10 / ≤ 6	2 / -;5	$\leq 3 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Herasil® 102	0	1 /1*0.16 / ≤ 6 1 /1*0.20 / 6 - 30	2 / -;5	$\leq 4 \cdot 10^{-6}$	$\leq 2 \cdot 10^{-6}$
Herasil® 3	2...3	1 /1*0.40 / ≤ 6 1 /1*1.00 / 6 - 30	n.sp.	$\leq 10 \cdot 10^{-6}$	n.sp.
Infrasil® 301 [3D]	0	1 /2*0.16 / ≤ 6	2 / -;5	$\leq 5 \cdot 10^{-6}$	$\leq 4 \cdot 10^{-6}$
Infrasil® 302	0..1	1 /1*0.20 / ≤ 6 1 /1*0.50 / 6 - 30	2 / -;5	$\leq 6 \cdot 10^{-6}$	$\leq 4 \cdot 10^{-6}$
Infrasil® 303	1	1 /2*0.25 / ≤ 6 1 /2*0.63 / 6 - 30	2 / -;5	$\leq 10 \cdot 10^{-6}$	$\leq 6 \cdot 10^{-6}$
HOQ 310	2...3	1 /2*0.63 / ≤ 6 1 /2*1.00 / 6 - 30	n.sp.	n.sp.	n.sp.

* **Suprasil 1, 2 ArF** and **KrF** are optimized for Excimer laser applications. Please ask for our Application Note.

[5] Δn (p.s.) (power subtracted) is calculated by subtracting from a measured Δn distribution the proportion that gives an exactly spherical aberration of an originally plane optical phase-front.
[6] Does not apply to drawn rods.
[7] Quartz glass is free from visible fluorescence at excitation wavelengths $\lambda \geq 290$ nm.
[8] Lower values available on request.

[9] The residual strain values refer to the measured stress induced birefringence per cm light path. The edge zone is defined as the outer 10% (for raw formed ingots and rods, the edge zone is defined as the outer 15%) of diameter or side-length.
n.sp. = not specified

Refractive index

at 20°C and 1 bar

The given values are interpolated from measured values having an accuracy of $\pm 3 \cdot 10^{-5}$.

In contrast to other optical glasses, quartz glass shows very little difference in refractive index from melt to melt.

	Residual Strain [9]		Fluorescence [7]	OH Content
PV value by special request	In the center [6] nm/cm	At the edges nm/cm	With excitation using a Hg lampe at λ = 254 nm and UG 5-filter	ppm (µg/g)
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1000
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1000
-	≤ 5	5...15	free	≤ 1000
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1200
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1200
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1200
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	≤ 1200
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	ca. 200
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	free	ca. 200
-	≤ 5	5...15	slight blue	≤ 1
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	blue-violet	ca. 150
$\leq 1 \cdot 10^{-6}$	≤ 5	5...15	blue-violet	ca. 150
-	≤ 10	10...15	blue-violet	ca. 150
$\leq 2 \cdot 10^{-6}$	≤ 5	5...15	blue-violet	≤ 8 [8]
$\leq 3 \cdot 10^{-6}$	≤ 5	5...15	blue-violet	≤ 8 [8]
-	≤ 10	10...20	blue-violet	≤ 8 [8]
-	≤ 10	10...20	blue-violet	ca. 30

	Wavelength nm	Suprasil	Homosil/ Herasil/ Infrasil/HOQ
	190	1.56572	-
ArF	193.4	1.56077	-
	200	1.55051	-
	202.54	-	1.54729
	220	1.52845	1.52870
	232.94	-	1.51834
	240	1.51334	1.51359
KrF	248,4	1.50855	-
	260	1.50239	1.50264
4 x Nd:YAG	266	1.49968	1.49993
	274.87	1.49607	1.49634
	280	1.49416	1.49439
	300	1.48779	1.48800
XeCl	308	1.48564	1.48583
	320	1.48274	1.48292
HeCd	325	1.48164	1.48182
N_2	337	1.47921	1.47938
	340	1.47865	1.47881
	360	1.47529	1.47544
(n_i)	365.48	1.47447	1.47462
	380	1.47248	1.47262
	400	1.47012	1.47025
(n_h)	404.65	1.46962	1.46975
(n_g)	435.83	1.46669	1.46681
HeCd	441.6	1.46622	1.46634
Kr	447.1	1.45661	1.46591
(n_F)	486.13	1.46313	1.46324
Ar	488	1.46301	1.46313
Ar	514.5	1.46156	1.46166
2 x Nd:YAG	532	1.46071	1.46081
(n_e)	546.07	1.46008	1.46018
(n_d)	587.56	1.45846	1.45856
HeNe	632.8	1.45702	1.45711
(n_c)	656.27	1.45637	1.45646
Ruby	694.3	1.45542	1.45552
Kr	752.5	1.45419	1.45428
	800	1.45332	1.45341
	850	1.45250	1.45259
	900	1.45175	1.45185
GaAs	905	1.45168	1.45177
	1000	1.45042	1.45051
Nd:YAG	1064	1.44963	1.44972
HeNe	1153	1.44859	1.44868
	1200	1.44805	1.44815
Nd:YAG	1319	1.44670	1.44680
	1400	1.44578	1.44589
	1600	1.44342	1.44353
	1800	1.44087	1.44099
	2000	1.43809	1.43821
	2200	1.43501	1.43515
	2400	1.43163	1.43177
	2600	1.42789	1.42804
	2800	1.42377	1.42393
	3000	1.41925	1.41941
	3200	1.41427	1.41444
	3400	1.40881	1.40897

Internal Transmission (%)

Typical values of internal transmission at selected UV wavelengths per 10 mm sample thickness

Internal Transmission (%)			
Wave-length	Suprasil ArF/KrF	Suprasil	Homosil 101 Herasil 102
nm			
193.4	≥ 99.30	98.50	92.00
248.4	≥ 99.80	99.50	99.00
266	99.90	99.90	99.50

Refractive Index Dispersion

Dispersion constants (Sellmeier)		
	Suprasil	Homosil/ Herasil/ Infrasil/HOQ
B_1	$4.73115591 \cdot 10^{-1}$	$4.76523070 \cdot 10^{-1}$
B_2	$6.31038719 \cdot 10^{-1}$	$6.27786368 \cdot 10^{-1}$
B_3	$9.06404498 \cdot 10^{-1}$	$8.72274404 \cdot 10^{-1}$
C_1	$1.29957170 \cdot 10^{-2}$	$2.84888095 \cdot 10^{-3}$
C_2	$4.12809220 \cdot 10^{-3}$	$1.18369052 \cdot 10^{-2}$
C_3	$9.87685322 \cdot 10^{1}$	$9.56856012 \cdot 10^{1}$

Sellmeier Equation:
$n^2 - 1 = B_1\lambda^2/(\lambda^2 - C_1) + B_2\lambda^2/(\lambda^2 - C_2) + B_3\lambda^2/(\lambda^2 - C_3)$
Wavelengths λ in µm at 20°C

Relative temperature coefficients of the refractive index in 10^{-6} K^{-1}

Wave-length	Suprasil		Homosil/ Herasil/ Infrasil/HOQ	
nm	0...20°C	20...40°C	0...20°C	20...40°C
237.8	14.6	14.9	15.2	15.3
365.0	11.0	11.2	11.5	11.6
546.1	9.9	0.1	10.6	10.7
587.6	9.8	10.0	10.5	10.6
643.8	9.6	9.8	10.4	10.5

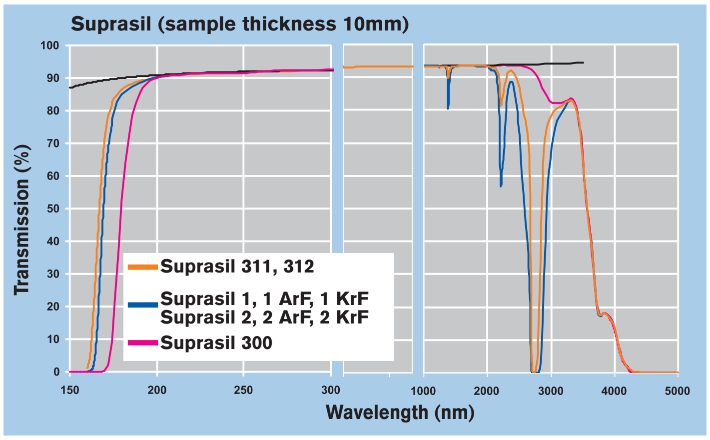
Abbe constant

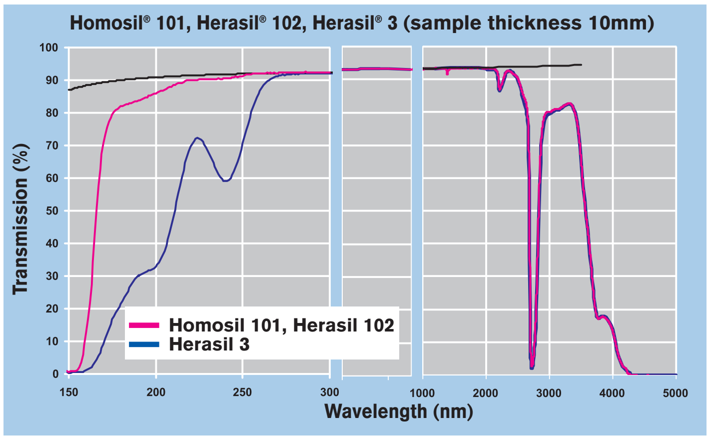
$\nu_d = \frac{n_d - 1}{n_F - n_c}$	67.8 ± 0.5	67.6 ± 0.5

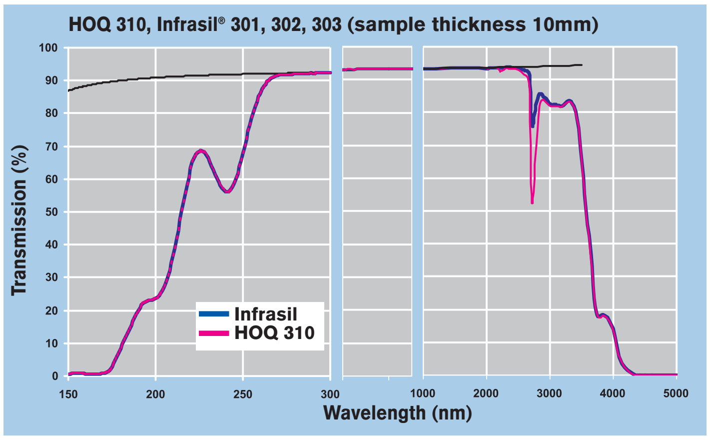
Birefringence constant

$\frac{nm}{cm \cdot bar}$	3.54 ± 0.05	3.61 ± 0.05

Measured transmission including Fresnel reflection losses $(1-R)^2$







The uppermost curves in the transmission graphs indicate the calculated Fresnel reflection losses for two uncoated surfaces.

Technical properties

		Suprasil	Homosil/ Herasil/ Infrasil/HOQ
Mechanical data			
Density	g/cm³	2.201	2.203
Mohs hardness		5.5.........6.5	
Micro hardness	N/mm²	8600.........9800	
Knoop hardness	N/mm²	5800.........6200	
Modulus of elasticity (at 20°C)	N/mm²	$7.25 \cdot 10^4$	$7.0 \cdot 10^4$
Modulus of torsion	N/mm²	$3 \cdot 10^4$	$3.1 \cdot 10^4$
Poisson´s ratio		0.17	0.17
Compressive strength	N/mm²	1150	1150
Tensile strength	N/mm²	50	50
Bending strength	N/mm²	67	67
Torsional strength	N/mm²	30	30
Sound velocity	m/s	5720	5720
Thermal data			
Softening temperature	°C	1600	1730
Annealing temperature	°C	1120	1180
Strain temperature	°C	1025	1075
Max. working temperature	°C		
continuous		950	1150
short-term		1200	1300
Mean specific heat J/kg · K	0...100°C	772	
	0...500°C	964	
	0...900°C	1052	
Heat conductivity W/m · K	20°C	1.38	
	100°C	1.46	
	200°C	1.55	
	300°C	1.67	
	400°C	1.84	
	950°C	2.68	
Mean termal expansion coefficient K^{-1}	0...100°C	$5.1 \cdot 10^{-7}$	
	0...200°C	$5.8 \cdot 10^{-7}$	
	0...300°C	$5.9 \cdot 10^{-7}$	
	0...600°C	$5.4 \cdot 10^{-7}$	
	0...900°C	$4.8 \cdot 10^{-7}$	
	-50...0°C	$2.7 \cdot 10^{-7}$	
	0...-160°C	0	

Electrical data of quartz glass

Resistivity in Ω·m	
20°C	10^{16}
400°C	10^8
800°C	$6.3 \cdot 10^4$
1200°C	$1.3 \cdot 10^3$
Dielectric strength in kV/mm (sample thickness ≧ 5 mm)	
20°C	25...40
500°C	4... 5
Dielectric loss angle (tg δ)	
1kHz	0.0005
1...1000MHz	0.0001
$3 \cdot 10^4$MHz	0.0004
Dielectric constant (ε)	
20°C 0...1 MHz	3.70
23°C $9 \cdot 10^2$ MHz	3.77
23°C $3 \cdot 10^4$ MHz	3.81

Typical trace impurities in quartz glass

Impurity	Suprasil ppm	Herasil 102/ Homosil 101 ppm	Herasil 3/ Infrasil/ HOQ ppm
Al = Aluminium	≤ 0,010	10	20
Ca = Calcium	≤ 0,015	1	1
Cr = Chromium	≤ 0,001	0.1	0.1
Cu = Copper	≤ 0,003	0.1	0.1
Fe = Iron	≤ 0,005	0.2	0.8
K = Potassium	≤ 0,010	0.1	0.8
Li = Lithium	≤ 0,001	1	1
Mg = Magnesium	≤ 0,005	0.1	0.1
Na = Sodium	≤ 0,010	1	1
Ti = Titanium	≤ 0,005	0.1	1

SI units and their conversion

In the SI system there are 7 base units:	SI-Base Unit Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	Mol	mol
Luminous intensity	Candela	cd

Conversion between SI and former units:

1 N = 0.1019716 kp
1 J = 0.1019716 kp · m = 0.238846 cal = $6.2418 \cdot 10^{18}$ eV
1 W = 0.1019716 kp · m/s = 0.859855 kcal/h
1 Pa = 10^{-5} bar = $1.019710 \cdot 10^{-5}$ kp/cm²
1 atm = 1.033 kp/cm² = 760 Torr = $1.01325\ 10^5$ Pa = 1.01325 bar

Temperature:

$T_K = 273{,}15 + T_C$ — T_K = Temperature in Kelvin
$T_C = 5/9\ (T_F—32)$ — T_C = Temperature in °Celsius
$T_F = 1{,}8\ (T_K—459{,}67)$ — T_F = Temperature in °Fahrenheit

Quantity	Unit Name	Symbol	Definition
Force	Newton	N	1 N = 1kg · m/s²
Work / Energy / Heat quantity	Joule	J	1 J = 1 W · s = 1 Nm
Power	Watt	W	1 W = 1 J/s = 1 Nm/s = 1 V · A
Pressure / Mechanical stress / Strength	Pascal (bar)	Pa (bar)	1 Pa = 1 N/m² = 1 kg/(m · s²) 10^5 Pa = 1 bar
Temperature	Kelvin (° Celsius)	K °C	1 K (base unit) 0°C = 273.15 K

Conversion between American, British and SI units:

1 m = 39.3701 in = 3.281 ft = 1.0936 yd
1 m³ = $6.1023 \cdot 10^4$ in ³ = $3.3814 \cdot 10^4$ fluid ounces = 264.172 US Gallons
1 N = 0.22481 lb.wt.
1 J = $9.4805 \cdot 10^{-4}$ BTU (mean) = 0.73756 ft.lb.wt.
1 W = 3.413 BTU/h = $2.65522 \cdot 10^3$ lbf.ft.wt.
1 Pa = $1.4503 \cdot 10^{-4}$ lb.wt./in²(psi) = $2.0885 \cdot 10^{-2}$ lbf/ft²

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	Suprasil Grades										Herasil Grades			Infrasil Grades			
	Suprasil® 1	Suprasil® 2 Grade A	Suprasil® 2 Grade B	Suprasil® 1 ArF	Suprasil® 2 ArF	Suprasil® 1 KrF	Suprasil® 2 KrF	Suprasil® 311	Suprasil® 312	Suprasil® 300	Homosil® 101	Herasil® 102	Herasil® 3	Infrasil® 301	Infrasil® 302	Infrasil® 303	HOQ 310
Highest UV transmittance	●	●	●	●	●	●	●	●	●	●							
Highest IR transmittance										●				●	●	●	
Highest purity	●	●	●	●	●	●	●	●	●	●							
Low bubble content	●	●	●	●	●	●	●	●	●	●	●	●		●	●		
Highest homogeneity in all three directions	●			●		●		●			●			●			
Highest homogeneity in functional direction	●	●		●	●	●	●	●	●		●	●		●	●		
Without striae in all three directions	●			●		●		●			●			●			
Without striae in functional direction	●	●	●	●	●	●	●	●	●		●	●		●	●	●	
Very high resistance against high energy radiation				●	●	●	●	●	●	●							
Very high resistance against excimer UV radiation				●	●	●	●										
Most economic grade			●										●			●	●

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