The Design of Pressure Windows

CRYSTRAN
UV · VISIBLE · IR SPECIALIST OPTICS

Notes to calculate thickness of optical windows used in vacuum or pressure applications

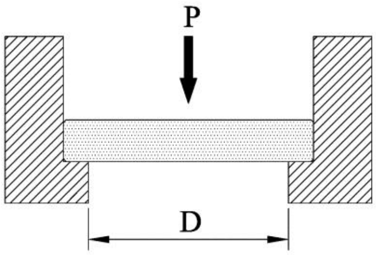
The maximum stress S_{max} on a uniformly loaded window is given by:

S_{max} = $(K \,.\, D^2 \,.\, P) / (4 \,.\, T^2)$ *and also* $S_{max} = F_a / SF$ *(See Safety Factor Box)*

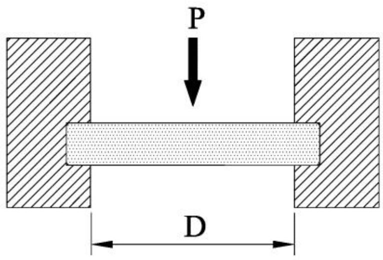
and then solving for thickness T

$T = D \,.\, \sqrt{(SF \,.\, K / 4)} \,.\, \sqrt{(P / F_a)}$ *(CIRCULAR WINDOWS)*

$T = L \,.\, \sqrt{(SF \,.\, K / 2)} \,.\, \sqrt{(P / (F_a \,.\, (1 + R^2)))}$ *(RECTANGULAR WINDOWS)*



Unclamped, S_{max} at centre



Clamped, S_{max} at edge

CLAMPED

Circular Window (Safety Factor of 4 & K_c = 0.75)

$$T = 0.866\, D \sqrt{(P / F_a)}$$

Rectangular Window (Safety Factor of 4 & K_c = 0.75)

$$T = 1.23\, L \sqrt{(P / (F_a \,.\, (1 + R^2)))}$$

UNCLAMPED

Circular Window (Safety Factor of 4 & K_u = 1.125)

$$T = 1.06\, D \sqrt{(P / F_a)}$$

Rectangular Window (Safety Factor of 4 & K_u = 1.125)

$$T = 1.50\, L \sqrt{(P / (F_a \,.\, (1 + R^2)))}$$

DEFINITIONS

S_{max}	=	Maximum stress
SF	=	Safety Factor
F_a	=	Apparent Elastic Limit
	=	or Rupture Modulus
K	=	Empirical Constant
D	=	Unsupported Ø for circular window
L,W	=	Length & Width for rectangular window
R	=	L / W
T	=	Thickness of window
P	=	Load per unit area

CONSTANT K

The value of **K** depends on the method of support, upon the force introduced in clamping and upon the brittle / ductile character of the window material involved.

Empirically, a **K** value of 0.75 is found suitable for most optical crystals when the perimeter is clamped, and a value 50% greater when unclamped.

K_c = 0.75
K_u = 1.125

SAFETY FACTOR

To avoid plastic deformation, the maximum stress (**S_{max}**) should be less than the Apparent Elastic Limit (**F_a**) by an appropriate Safety Factor (SF)

$$S_{max} = F_a / SF$$

A modest safety factor of 4 (i.e., maximum stress equals one quarter of the elastic limit) seems to suffice for many laboratory applications where the operating conditions are reasonably under control. Severe conditions such as thermal shock require special consideration and may even result in a decision to use a *reduced* thickness. The published Apparent Elastic Limit of some materials may not be completely reliable. Crystals vary and cleavage may occur according to grain boundaries or the particular cut of the ingot. Ultimately, the final design thickness must be a carefully considered decision and may need to be empirically tested. Crystran Ltd can accept no responsibilty for the adoption of these calculations and recommendations.

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Worked Examples

COMMON APPARENT ELASTIC LIMITS

Al_2O_3 (Sapphire)	=	276Mpa	=	45000psi
BaF_2	=	26.9MPa	=	3900psi
BK7 glass	=	63.5Mpa	=	9210psi
CaF_2	=	36.5MPa	=	5300psi
Germanium	=	89.6MPa	=	13000psi
KRS5	=	26.2Mpa	=	3800psi
LiF	=	11.2MPa	=	1620psi
MgF_2	=	49.6MPa	=	7200psi
Silica glass	=	55.0Mpa	=	7980psi
ZnS (FLIR)	=	103.4MPa	=	15000psi
ZnSe	=	55.1MPa	=	8000psi

CaF_2 window 50mm Ø with 1 atmosphere P.D
Safety factor of 4
T = 2.8mm unclamped
T = 2.3mm clamped

CaF_2 window 52mm x 20mm with 1 atmosphere P.D
Safety factor of 4
T = 1.5mm unclamped
T = 1.2mm clamped

Sapphire window 25mm Ø with 3800 psi P.D
Safety factor of 4
T = 7.7mm unclamped
T = 6.3mm clamped
With sapphire, for pressures above 500psi it is recommended to use windows with the axis of the crystal parallel to the axis of the window. (Perpendicular to the surface)

KRS5 window 40 Ø with 1 atmosphere P.D
Safety factor of 4
T = 2.6mm unclamped
T = 2.2mm clamped

Fused silica window 100mm Ø with 1000 kPa P.D
Safety factor of 10
T = 22.6mm unclamped
T = 18.5mm clamped

ZnSe window 80mm Ø with 1 atmosphere P.D
Safety factor of 4
T = 3.6mm unclamped
T = 3.0mm clamped

NORMAL ATMOSPHERIC PRESSURE

Traditionally measured in:
(1) pounds/sq inch 14.7 psi
(2) inches of mercury 29.9213"
(3) mm of mercury 760 mm
(4) millibar 1013.240 mBar
Now measured in SI units:
(5) Pascals 101.324 kPa

(2) and (3) are straightforward measures of a column of mercury supported by 1 atmosphere.

1" = 25.4mm 1mm = 0.03937"

(4) and (5) are actual measures of pressure (force/area) and take account of the density of mercury (13.595gm/cc at 0°degC) and the acceleration due to gravity (980.665 cm/sec^2) when converting from a mercury barometer reference.

Pressure at 1 atmosphere
$= 0.76\text{m} \times 13595\ \text{kgm.m-3} \times 9.80665\ \text{m} . \text{s}^{-1}$
$= 101324\ \text{Pa}\ (\text{N/m}^2)\ (\text{m}^{-1}.\text{kgm.s}^{-1})$
$= 101.324\text{kPa}$

NOTES:

- A carefully designed window may still break before any significant loading if the mounting introduces any localised stress.
- Mismatch of expansion coefficients generally dictates the use of resilient material between window and mounting.
- Thermal outgassing used in UHV systems should be undertaken with caution with crystal windows as thermal shock may initial cleavage in some crystals
- The constant for clamped mounting allows for no flexure at the wall. The use of soft gaskets may allow flexure so the formula for the "unclamped" condition should be used.

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