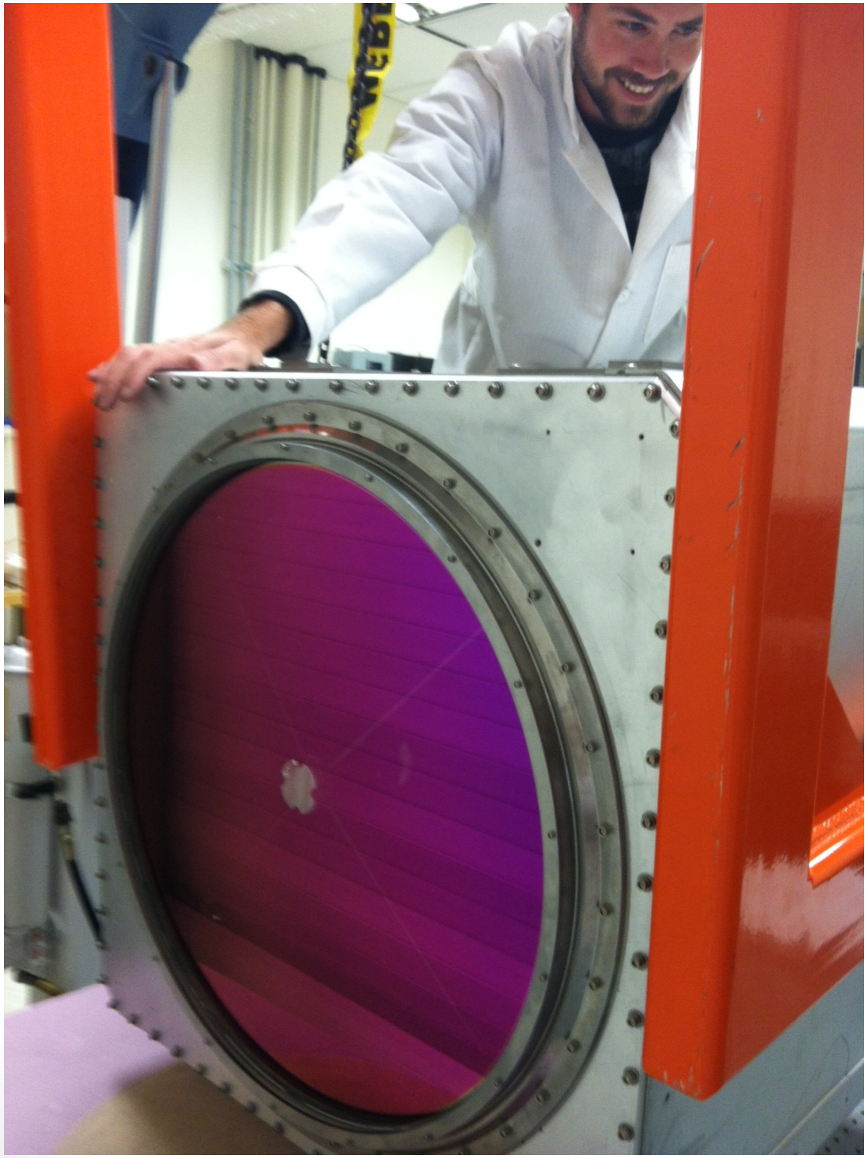

An Introduction to Optical Windows

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OPTI 521

What do windows do

- Windows provide a transparent barrier from the outside environment
- They protect delicate optical elements by separating the inside from the outside
- Can be neglected or overlooked, but a crucial component of almost any optical system

Operating environments

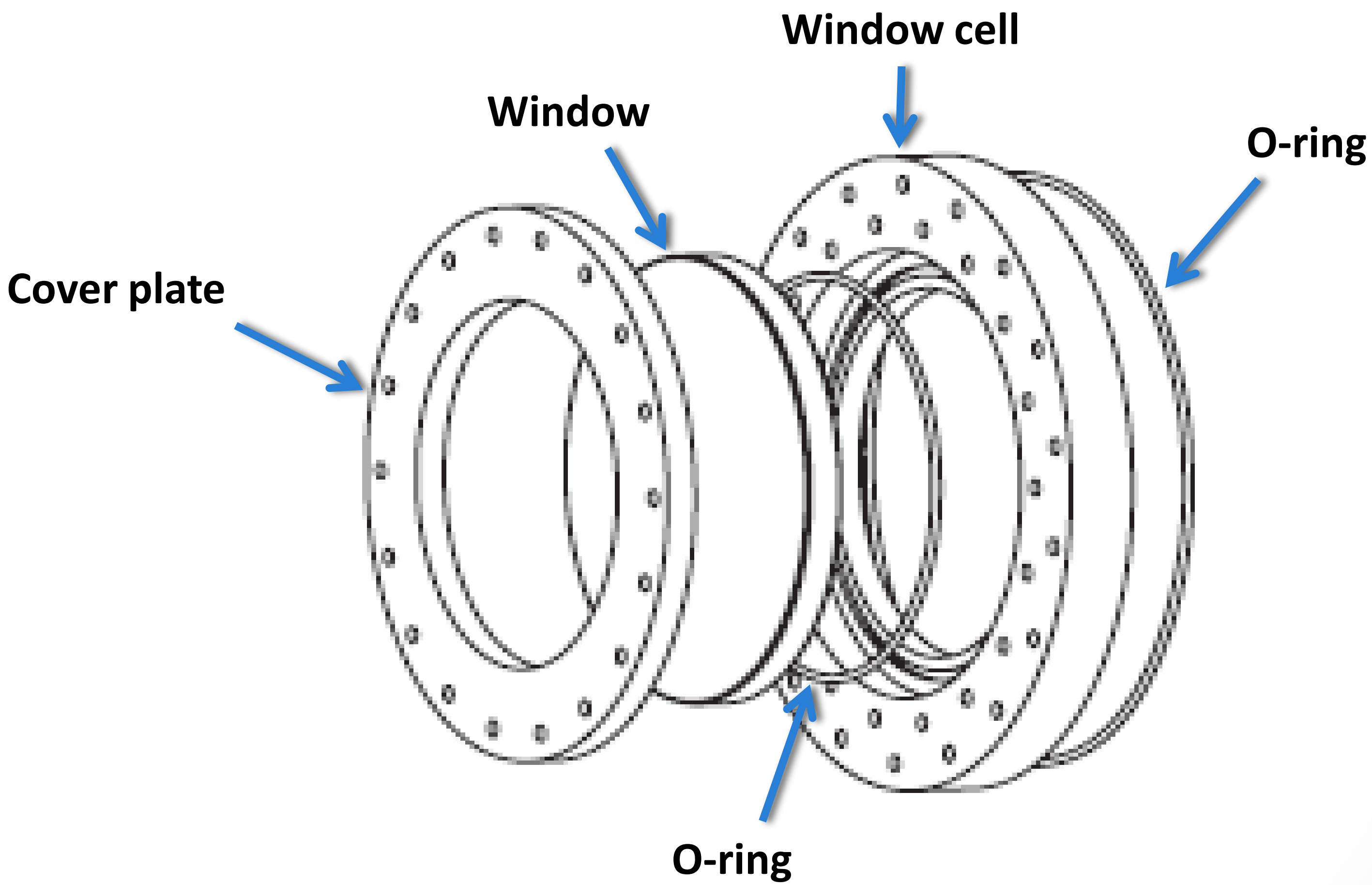
- Pressure differential
- Thermal gradients
- Airborne
- Vibration
- Abrasion and chemical attack
- Impact
- High energy lasers
- Cyrogenic
- **Structure/mounting induced stresses**

Window shapes

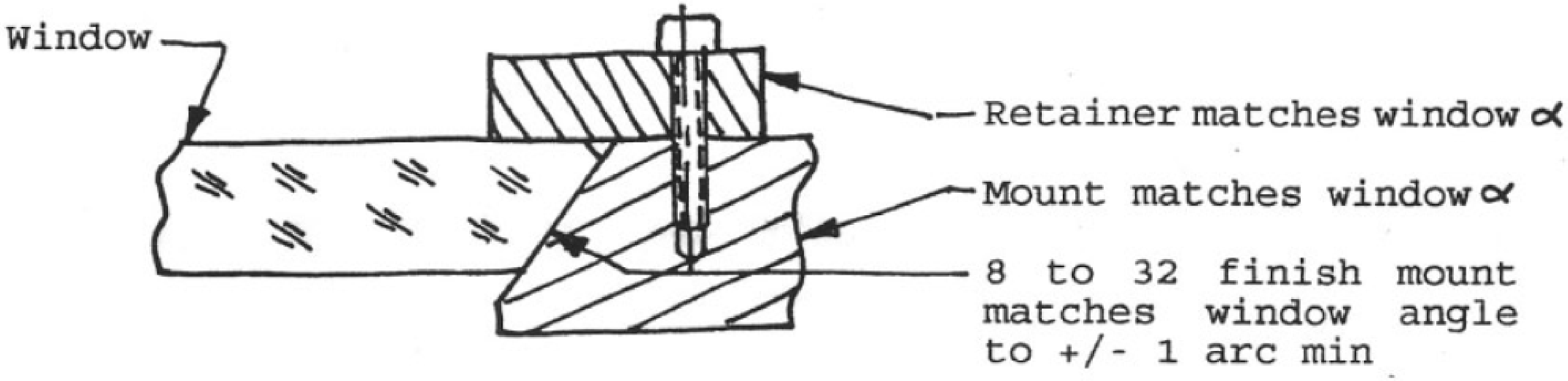
- Circular plane parallel plate is most common
  - Will be the focus of this presentation
- Domes for missiles
  - Better aerodynamic shape

- Segmented windows
- Filters are a special case
  - Much easier to mount and do not require environmental seal

Typical design

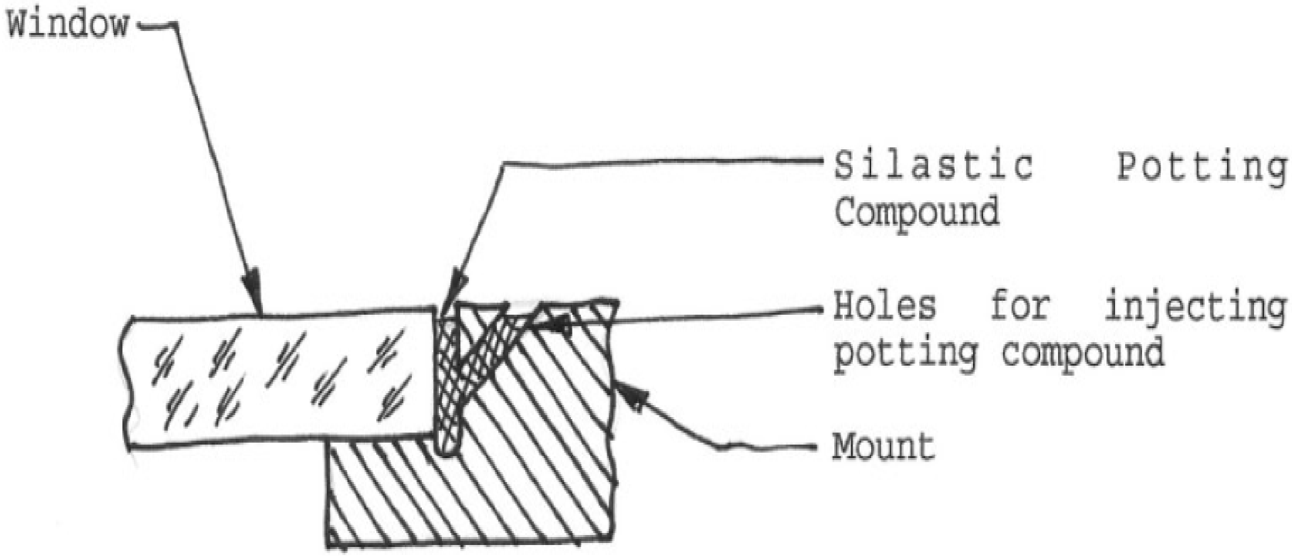


Hard mount

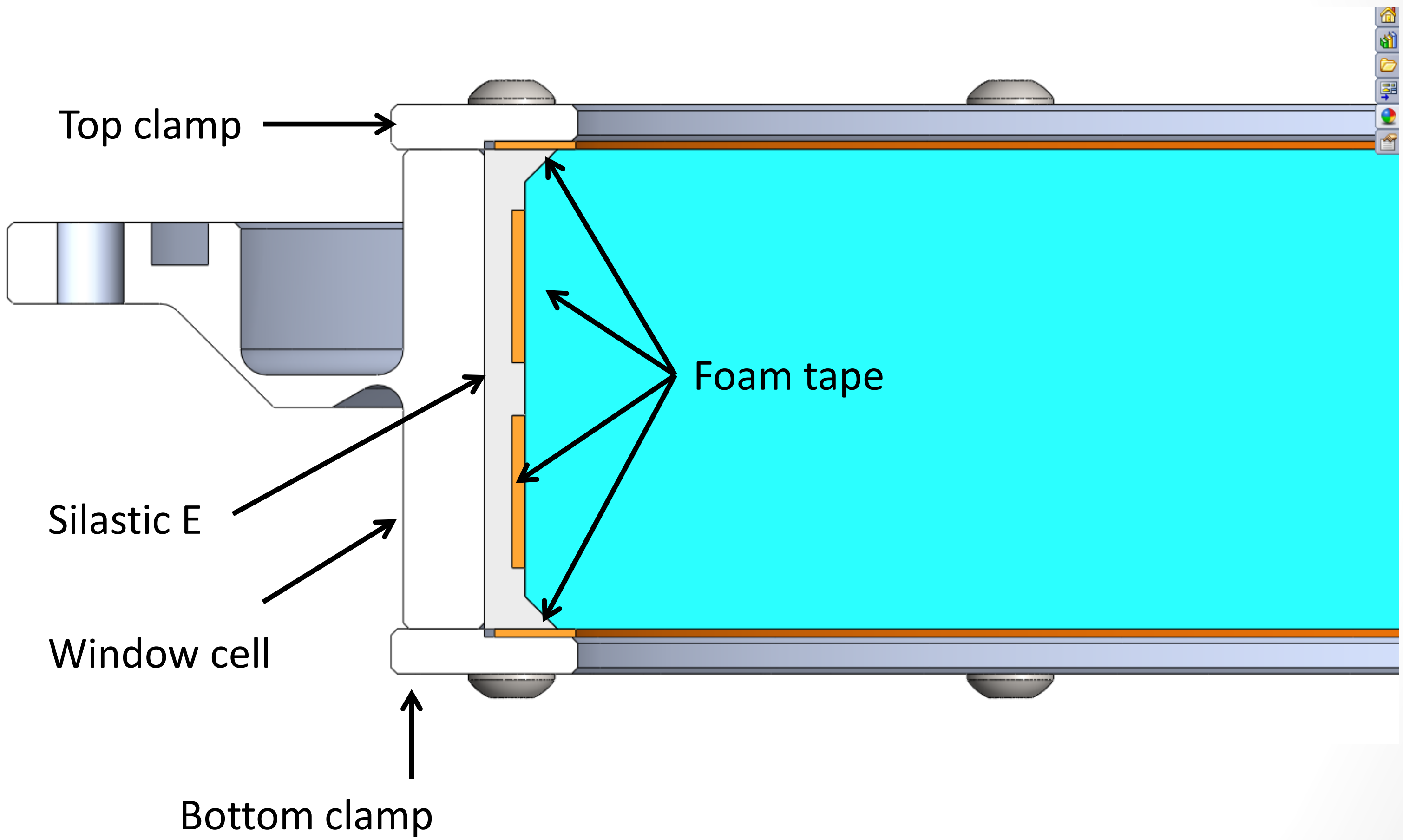


Window
Retainer matches window ∝
Mount matches window ∝
8 to 32 finish mount matches window angle to +/- 1 arc min

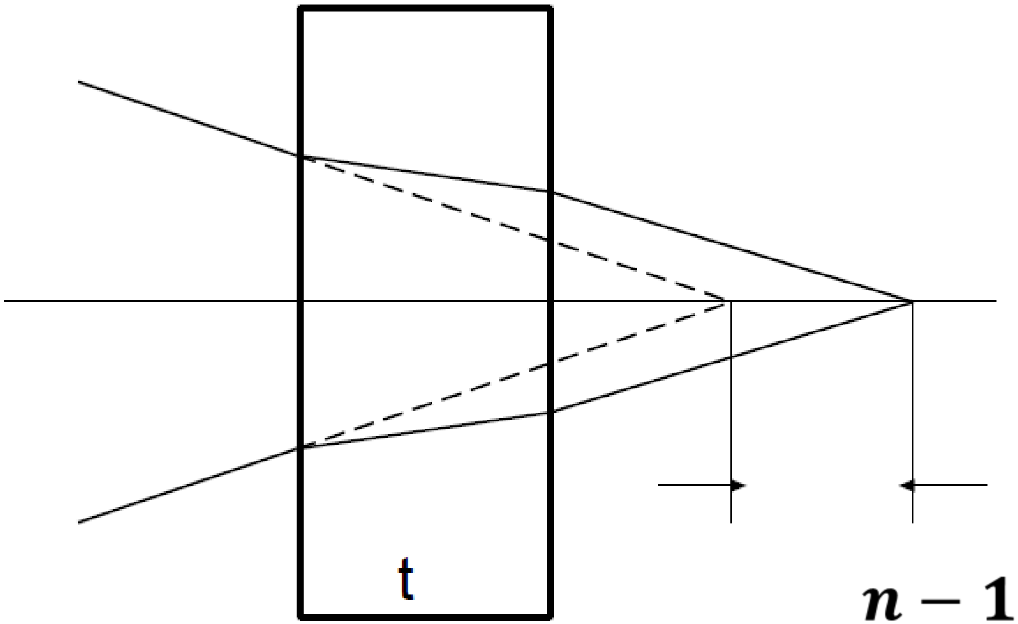
Potted window



K2 CLS exit window



Optical effects



$$\Delta z = \frac{n-1}{n} t$$

Focal shift in the presence of converging beam

- Spherical aberration, coma, astigmatism and chromatic aberrations in the presence of diverging or converging beam

Thermal effects

- Thermal gradients will cause the window to deform
- For an axial thermal gradient the induced power can be estimated as:

$$P = \frac{1}{f} = \frac{n-1}{n}\left(\frac{\alpha}{k}\right)^2 t q^2$$

n = refractive index, α = CTE, k = thermal conductivity
t = thickness, q = incident heat flux per unit area

Pressure differential

- A uniform pressure differential on the front surface of the window will cause a change in transmitted OPD

$$OPD = (8.89\ x\ 10^{-3})\frac{(n-1)\Delta P^2 d^6}{E^2 h^5}$$

n = refractive index, ΔP = pressure differential, d = window diameter
E = Young's modulus, h = thickness

Self-weight deflection

- Windows, like mirrors, will sag under their own weight
- If both surfaces sag the same amount then the resulting shape will be like a meniscus
- The maximum self weight deflection for a window normal to the gravity vector, supported by a ring at its outer edge is

$$\text{deflection} = (0.828)\frac{\rho g r^4}{E h^2}(1-\upsilon^2)$$

ρ = density, g= acceleration due to gravity, r = window radius, E = Young's modulus, h = thickness, v = Poisson's ratio

- This will cause a OPD change in the system

Combined effects

- Proper finite element analysis will provide accurate window shape due to deformations
- FEA data can then be used to determine Zernikes and RMS surface error
- Optical analysis using Zemax or Code V will give induced aberrations and OPD
  - Can be corrected by other elements in the system if designed properly

Window materials

Material	Index @µm	Wavelength range (µm)	Young's modulus (GPa)	CTE (10^{-6}/C)	Thermal conductivity (W/m-k)	Poisson's ratio
N-BK7	1.5168@d	0.35-2.5	82	7.1	1.11	0.206
Sapphire	1.7545@1.06	0.17-5.5	335	5.3	27.21	0.25
ZnSe	2.403@10.6	0.6-16	67.2	7.1	18	0.28
CLEARTRAN	2.2008@10	0.37-14	74.5	7.0	27.2	0.28
Germanium	4.0026@11	2-14	102.7	6.1	58.61	0.28
Silicon	3.4223@5	1.2-15	131	2.6	163.3	0.266
CaF2	1.4338@d	0.35-7	5.8	18.85	9.71	0.26
Fused silica	1.4584@d	0.18-2.5	72	0.5	1.31	0.17

Choosing the proper material is crucial

- There are dozens of materials to choose from
- Wavelength range, strength, thermal properties, birefringence
- Cost and manufacturability will also drive material decision

Fused silica

- Great material for UV to NIR applications
- Strong material with low CTE
- Does have a higher dn/dT than BK7
- Stronger than borosilicate crown glass windows

Sapphire

- UV to MWIR applications
- Very hard and scratch resistant
- Difficult to machine and expensive
- New market for consumer applications

    GT Advanced Technologies http://optics.org/news/4/11/10

Cleartran

- Manufactured by DOW
- Form of CVD Zinc Sulfide
- High optical quality, non-hygroscopic, easy to machine
- Visible to LWIR applications
- Very Important for braodband applications

Coatings

- Coatings usually get damaged before the window substrate
- The application will determine the type of coating
- Anti-reflection (or reflection), high transmission, notch, diamond-like hard carbon

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Optomech website

- http://fp.optics.arizona.edu/optomech/

Questions?