Optical Materials

Name	Special Properties	Difficulty Properties	Wavelength Range [microns]	Refractive Index	Density [g/cm3]	Young's Modulus [GPa]	CTE [ppm/oC]	Thermal Conductivity [W/m-K]	Stress Optic Coefficient	Application
BK7	Can be machined at high qualities for low costs and is easy to get a hold of	Very practical, but only for applications in the visible spectrum	0.34-2.5	1.5168	2.51	82	7.1	1.114	2.77	Good for everyday use in the visible and Near IR spectrum
Fused Silica	Composition levels can easily adjusted to provide different characteristics and refractive indices. Large wavelength range and low CTE	Has a higher temperature-dependent refractive index	0.18-2.5	1.4584	2.2	72	0.5	1.31	3.4	High powered laser applications. Fused Silica is the most common material for optical fibers in telecomm.
Calcium Flouoride	Has a very large transmission range and relatively low dispersion characteristics	Large CTE, not the most durable material, and expensive	0.35-7	1.4338	3.18	75.8	18.85	9.71	2.15	Common for use in the IR and UV range. Used for filters, windows, and prisms
P-PK53	Similar properties as BK7 but much easier toinjection mold	Refractive index can change depending on how it is molded	0.4-1	1.5269	2.83	59	13.3	0.64	2.06	Used for glass molding and can make inexspensive aspheres
Acrylic (PMMA)	Can be injection molded, making it very cheap and easily repeatable to manufacture	Bad thermal characteristics and can have stress from the molding process	0.4-1	1.492	1.18	3.3	70	0.2	-3	Small, everyday optics such as phone camera lenses or eyeglasses
Sapphire	Very high Young's modulus reulting in a very tough and durable material. Also transmits a large range of wavelengths	It is difficult and expensive to machine because of its rigidity	0.17-5.5	1.7545	3.97	335	5.3	27.21	-	Used for windows and shields in the IR or UV spectrum. Also good for semiconductor processing, electrical, and microwave applications
ZnSe	Low absorption coefficient and high resistance to thermal shock. Transmits well in the IR range	Soft material and large temperature-dependent refractive index	0.6-16	2.403	5.27	67.2	7.1	18	-1.6	Lenses and windows for thermal imaging and FLIR. Ideal for integration with CO_2 lasers
ZnS	Good imaging quality in the IR and UV spectrums	Twice as hard as ZnSe, but still a soft material and large temperature-dependent rafractive index	0.4-12	2.2008	4.09	74.5	6.5	27.2	0.804	IR lenses and windows, particularly in high speed aircraft and vacuum applications
Germanium	Low dispersion, high thermal conductivity and good for use in the IR	Dense material and temperature-dependent refractive index	2 to 14	4.0026	5.33	102.7	6.1	58.61	-1.56	ATR prisms, CO_2 lasers, optical coatings for beam splitters and other IR applications
Magnesium Fluoride	Very large Young's modulus and has a wide transmission range	Very birefringent and it's large CTE is anisotropic	0.12-7	1.413	3.18	138	13.7	21	-	Common for anti-reflection coatings and UV optics

tructural Materials

Name	Special Properties	Difficulty Properties	Density [g/cm^3]	Young's Modulus [Gpa]	Poisson Ratio	CTE [ppm/°C]	Thermal Conductivity [W/m-K]	Hardness	Application
Steel (1010 mild)	Lox cost, high strength, and excellent weldability	Heavy material, not resistant to corrosion, and difficult to machine	7.8	200	0.29	11.5	65.2	Rockwell B-76	Used for frame support or optical mounts
nless Steel (17-4 CI	Very stiff and good for corrosion prevention	Heavy material and poor thermal properties	7.8	198	0.27	11	18	Rockwell C-35	For outdoor use such as telescope structrues where corrosion needs to be avoided
Beryllium	Lightweight and has a high specific stiffness	Hazardous to work with. It is expensive to manufacture because of this	1.84	303	0.29	11.5	216	Rockwell B-80	Cryogenic applications and parts for satellites in orbit
Titanium	CTE is comparable to glass and is very strong and sturdy	Difficult to machine and weld and is expensive	4.5	108	0.31	8.6	7	Rockwell B-80	Very strong for structural support and framing in telescope designs or high-performance mounts
Copper	Resistant to corrosion and has a high thermal conductivity	Heavy and has a low micro-yield strength	8.53	110	0.38	20	120	Rockwell F-54	Almost all wires are made from copper and can be used for heat sinks
Invar 36	Very low CTE	Difficult to manufacture, not corrosion resistant, and not very stiff	8	148	0.29	1.3	14	Rockwell B-90	Used for athermaizing and precision instruments
raphite Epoxy (CFR	Extremely low CTE and very strong	Reactive to moisure and unstable in humidity	1.7	180	-	0.02	11.5	-	Used to bond low CTE materials such as telescope trusses
Silicon Carbide	Very light and very stiff	Expensive and not very common	3.1	410	0.14	4	120	Knoop 2800	Can be used for mirror materials in astronomy
Molybdenum	Great weldability and resistant to corrosion	Most commonly used with other materials, not independently	10.2	320	0.31	5	138	Brinell 1500 Mpa	Aircraft parts or engines are often made from this
Teflon	Low friction and non-reactive with other materials	At high temperatures, it can become toxic	2.2	0.5	0.46	59	0.23	-	Non-stick applications, contact between interfaces on structures

luminum Alloys

Name	Special Properties	Difficulty Properties	Density [g/cm^3]	Young's Modulus [Gpa]	Poisson Ratio	CTE [ppm/^{o}C]	Thermal Conductivity [W/m-K]	Yield Strength [Mpa]	Application
6061-T6	Easy to machine, inexpensie, and lightweight. It is a good acceptor of coatings and has a high resistance to corrosion	Fairly soft material and has high CTE in comparison to other metals	2.68	68.2	0.33	23.6	167	276	Camera lens mounts, magneto parts, electrical fittings & connectors, aircraft fittings, and couplings
1100	Excellent forming characteristics, good thermal properties, especially for cold working. Easily machineable and weldable	Does not respond well to heat treatment and difficult to anneal	2.71	68.9	0.33	23.6	220	34-152	Commonly used in sheet metal work, cooking utensils, rivets & reflectors, and for decorative parts
A356	This alloy is very castable, it is resistant to heat cracking and solidification shrinkage. Godd resistance to corrosion	Slightly more difficult to machine, requires sharper cutting tools.	2.67	72.4	0.33	23.2	151	165	Structural parts requiring high strength, aircraft & missile components, andmachine parts.

IR Lenses

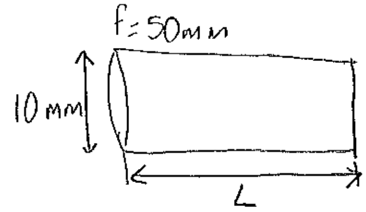
Vendor	Part Number	Material	Wavelength Range [mircons]	Size [mm]	Cost	Special Issues
Newport	SAPX010	Sapphire	0.15-5	25.4	$506	Suitable for high-power, high-pressure, or corrosive atmosphere applications. This lens is extremely hard, has a high compressive strength, and excellent thermal conductivity.
Newport	ZNPA10	Zinc Selenide	0.6-6	25.4	$2,010	This lens has a large transmission range, low absorption coefficient, and high resistance to thermal shock. Its aspheric surface provides diffraction limited focusing performance
Newport	CAPX11	Calcium Fluoride	0.18-8	25.4	$262	This lens has high verage transmission and low chromatic aberration. In the NIR regime, this lensexhibits very low GVD.

OPTI 421/521

Introductory Opto-Mechanical Engineering

Homework 9

2) Thermal defocus



F=50mm

a) PMMA plastic

$CTE = \alpha = 60$ ppm/°C

$n = 1.492$

$dn/dt = -8.5 \times 10^{-5}/°C$

b) Change in focal length of the lens

$\Delta f = \beta f \Delta t$

$f = 50$ mm

$\Delta t = 25°C$

$$\beta = \alpha - \frac{1}{n_r - 1}\frac{dn_r}{dT} = (60 \times 10^{-6}/°C) - \left[\frac{1}{0.492}(-8.5 \times 10^{-5}/°C)\right]$$

$\beta = 2.327 \times 10^{-4}/°C$

$\Delta F = \beta f \Delta t = (2.327 \times 10^{-4}/°C)(50\,mm)(25°C)$

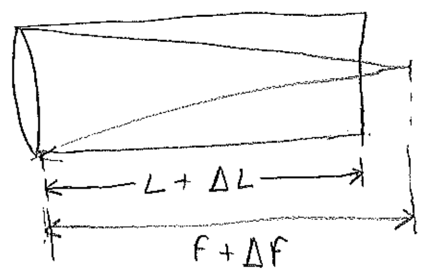
$\Delta f = 0.2909\,mm$

c) Change in length of the tube

$\Delta L = \alpha \Delta T L = (60 \times 10^{-6}/°C)(25°C)(50\,mm)$

$\Delta L = 0.075\,mm$

d) Resulting focus error from the combined effect



Resulting error = $(f+\Delta f)-(L+\Delta L) = (50mm + 0.2909mm)-(50mm+0.075mm)$

Resulting error = $50.2909 - 50.075 = 0.2159$ mm

$\delta z = 0.2159$ mm

e) Lens made of BK7
mount made of aluminum

BK7

$\beta = \alpha - \frac{1}{n-1}\frac{dn}{dT}$

$\beta = 7\times10^{-6} - \frac{1}{0.5168}(1.1\times10^{-6})$

$\beta = 4.87\times10^{-6}/°C$

$\Delta f = f\beta\Delta t = (50mm)(4.87\times10^{-6})(25)$

$\Delta f = 0.0061$ mm

Aluminum

$\alpha_{AL} = 24\times10^{-6}/°C$

$L = 50$ mm

$\Delta T = 25°C$

$\Delta L = \alpha\Delta T L = (24\times10^{-6}/°C)(25°C)(50mm)$

$\Delta L = 0.03$ mm

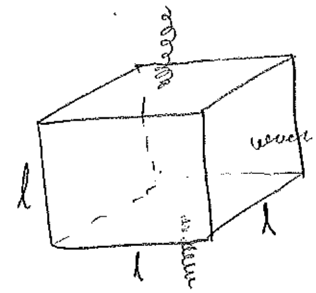
$\delta z = (F+\Delta F)-(L+\Delta L) = (50+0.0061)-(50+0.03)$

$\delta z = -0.0239$ mm

$\delta z = -23.9\,\mu m$

3) Shock Loading

$l = 10$ inch
$W = 10$ lb
$h = 20$ inch
$A_g = 5$ G's



a) Calculate self weight deflection

$$A_g = \sqrt{\frac{h}{\delta_{selfweight}}} \Rightarrow \delta_{selfweight} = \frac{h}{A_g^2}$$

$$\delta_{selfweight} = \frac{20 \text{ inch}}{(5G)^2} = \frac{20}{25}$$

$$\delta_{selfweight} = 0.8 \text{ inch}$$

b) Calculate force from expected shock load

$$m = \frac{W}{g} = \frac{10 \text{ lb}}{386 \text{ inch/s}^2} \qquad F = ma = m \cdot A_g g = \left(0.026 \frac{\text{lb}\cdot\text{s}^2}{\text{inch}}\right)(5)\left(386 \frac{\text{inch}}{\text{s}^2}\right)$$

$$m = 0.026 \text{ lbs}^2/\text{inch} \qquad F = 50.18 \text{ lb}$$

c) Calculate required stiffness

$$K = \frac{F}{\delta_{sw}} = \frac{50.18 \text{ lb}}{0.8 \text{ inch}}$$

$$K = 62.725 \text{ lb/inch}$$

d) Mount w/ spring model

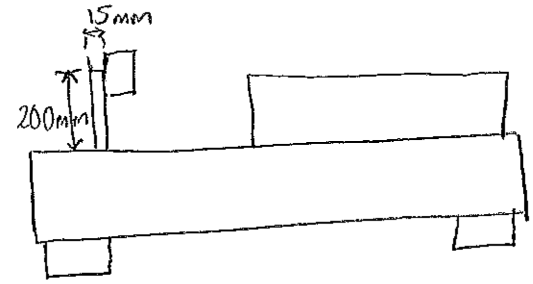
Each pair of springs must provide $K_{Tot} = 3860$ lb/inch

since they are in parallel

$$K_1 + K_2 = K_{Total}$$

$$K_{spring} = 31.36 \text{ lb/inch}$$

4) Vibration analysis



$M_{post} + m_{mirror} = 1\,kg$ $\qquad C_R = 0.05$

$Q = 40$ $\qquad PSD = 10^{-8}\,G^2/Hz$

$M_{assembly} = 100\,Kg$

$\delta_{iso} = 2\,mm = 0.002\,m$

a) i) Calculate Resonant Freq

$$\omega_{assembly} = \omega_{iso} = \sqrt{\frac{g}{\delta_{iso}}} = \sqrt{\frac{9.8\,m/s^2}{0.002\,m}} = 70\ rad/s$$

$$f = \frac{\omega_{iso}}{2\pi} = \frac{70}{2\pi} = 11.14\ Hz$$

ii) Post (steel $E = 200\,GPa = 200 \times 10^9\,Pa$)

$$K_{post} = \frac{F}{\delta_{post}} \quad \text{where} \quad \delta = \frac{FL^3}{3EI} = \frac{F(0.2\,m)^3}{3(200 \times 10^9\,Pa)(2.485 \times 10^{-9}\,m^4)}$$

$$I = \frac{\pi}{64}(0.015\,m)^4 = 2.485 \times 10^{-9}\,m^4$$

$$K_{pos} = \frac{F}{\frac{FL^3}{3EI}} = \frac{3EI}{L^3} = 186{,}375\ N/m$$

$$\omega_{post} = \sqrt{\frac{K}{m}} = \sqrt{\frac{186\,375\,N/m}{1\,Kg}} = 431.71\ rad/s^2$$

$$F_{post} = \frac{1}{2\pi}\omega_{post} = 68.70\ Hz$$

b) Determine Transmissibility

$$T(f) = \sqrt{\frac{1 + \left(2 \frac{\omega_{post}}{\omega_{assembly}} C_r\right)^2}{\left(1 - \frac{\omega_{post}^2}{\omega_{assembly}^2}\right)^2 + \left(2 \frac{\omega_{post}}{\omega_{assembly}} C_r\right)^2}}$$

$$T(f) = \sqrt{\frac{1 + \left(2 \frac{431.71}{70} 0.05\right)^2}{\left(1 - \left(\frac{431.71}{70}\right)^2\right)^2 + \left(2 \frac{(431.71)}{70}(0.05)\right)^2}}$$

$$T(f) = \sqrt{\frac{1.38}{1371.62 + 0.38}} = 0.03171$$

$$T(f) = 0.03171$$

c) Determine Mirror Displacement

$$\delta_{rms} = g \cdot T(f) \sqrt{\left(\frac{1}{32\pi^3}\right)\left(\frac{Q}{F_{post}^3}\right) PSD}$$

$$= (9.8)(0.03171)\sqrt{\left(\frac{1}{32\pi^3}\right)\left(\frac{40}{(68.70)^3}\right) 10^{-8}}$$

$$\delta_{rms} = 1.096 \times 10^{-8} \text{ mm} = 10.96 \text{ nm}$$

Requirements are

$$\frac{488 \text{ nm}}{40} = 12.2 \text{ nm}$$

$$\delta_{rms} < 12.2 \text{ nm}$$

meet the specifications!