Errata to *Field Guide to Optomechanical Design and Analysis*

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Corrections to the first printing are on pages 14, 49, 85, 130, and 131.

Corrections to the second printing are on pages 14, 85, 130, and 131.

Corrections to the third printing are on page 49.

corrected units

Stress and Strain

In mechanics, a body can be subjected to many forces. The most common way of defining these forces is by classifying them as a **stress** or a **strain**. Stress σ occurs when a body is subjected to a force or load, which is quantified by dividing the applied force F by the cross-sectional area A on which the force is acting. The units of stress are **psi** (pounds per square inch) or **Pascals** (N/m^2).

Pa = N/m^2

1 psi = 6895 Pa

1 MPa = 145 psi

$$\sigma = \frac{F}{A}$$

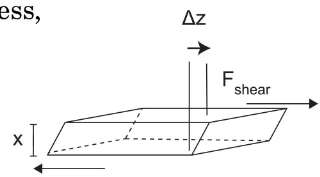
This equation assumes that the force is applied normal to the cross-sectional area; when the force is applied tangential to a surface V, it is called shear stress τ:

$$\tau = \frac{V}{A}$$

Strain ε occurs when a body is subjected to an axial force: it is the ratio of the change in length of the body to the original length.

$$\varepsilon = \frac{\Delta L}{L}$$

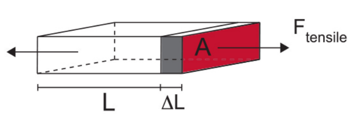
Shear strain γ, which is a function of the shear modulus of the material G, occurs when the body is strained in an angular way. Strain is unitless, whereas shear strain is expressed in radians. Stress and strain can be the result of a **compressive** or **tensile** force.

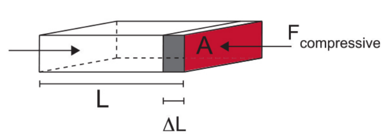


$$\gamma = \frac{\Delta z}{x} \qquad \gamma = \frac{\tau}{G}$$

$$\tau = \frac{dF_{shear}}{dA}$$

$$\varepsilon = \frac{\sigma}{E} \qquad \sigma = \frac{dF_{normal}}{dA}$$





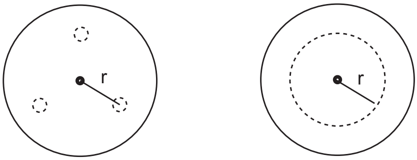
Thermal Stress

The thermal expansion of an adhesive is typically much higher than the substrates it is bonding. The effect due to the large expansion of the adhesive is mitigated by its high compliance, so the substrate expansion dominates. This is not true for very low temperatures where the modulus of the adhesive will increase by orders of magnitude. The maximum shear stress τ_{max} experienced by the adhesive will occur at the farthest point from center and is quantified by

$$\tau_{max} = \frac{\Delta T G(\alpha_1 - \alpha_2)}{Bt} \times \left\{ \frac{1}{1+\nu_1}\left[\frac{1-\nu_1}{Br} - \frac{I_0(Br)}{I_1(Br)}\right] + \frac{1}{1+\nu_2}\left[\frac{1-\nu_2}{Br} - \frac{I_0(Br)}{I_1(Br)}\right]\right\}^{-1}$$

$$B = \left[\frac{G}{t}\left(\frac{1-\nu_1^2}{E_1 h_1} + \frac{1-\nu_2^2}{E_2 h_2}\right)\right]^{\frac{1}{2}}$$

where G is the shear modulus of the adhesive, α_1 and α_2 are the coefficients of thermal expansion of the bonded materials, t is the bond thickness, E_1 and E_2 are the Young's modulus values of the bonded materials, h_1 and h_2 are the height/thicknesses of the bonded materials, and r is the maximum bond dimension from the center to the edge (radius).



This equation assumes flat, circular plates where the bond covers the entire area between the two substrates. The bending of the substrates is included in the equation. For small bonds (with a maximum dimension less than a few mm), this can be estimated by:

$$\tau_{max} = \frac{Gr}{t}(\alpha_1 - \alpha_2)\Delta T$$

Self-Weight Deflection: Parametric Model

There is a **parametric model** that suits both large- and small-aspect-ratio mirrors: the equation below can determine the **rms deflection** δ_{rms} as well as the **peak-to-valley deflection** δ_{P-V} and the **rms** or **peak-to-valley slope error** ($\Delta_{P-V}d$ or $\Delta_{rms}d$, respectively), with or without **low-order curvature (power)**.

$$\delta_{rms}, \delta_{P-V}, (\Delta_{P-V}d), (\Delta_{rms}d) = \gamma\left(\frac{q}{D}\right)\left(\pi r^2\right)^2(1+f)$$

$$f = \frac{A}{\alpha}\cdot e^{-\upsilon} + \frac{B}{\sqrt{\alpha}}\cdot \nu + C$$

This equation applies to flat mirrors (with no curvature or holes). It has less than 10% error for mirrors with a Poisson ratio ν of 0.1–0.35.

where α is the mirror aspect ratio (diameter-to-thickness ratio), D is the flexural rigidity, and γ, A, B, and C are parametrically determined constants. Parametric variables for a three-point, six-point, and continuous ring support:

Support	Optimal target & position	Optical performance metric	γ ($\times 10^{-6}$)	A	B	C ($\times 10^{-2}$)
3-pt	δ_{rms}	δ_{P-V}	246.7	0.50	4.10	−2.79
		δ_{rms}	58.58	1.27	2.93	−6.56
		$\Delta_{P-V}\cdot d$	396.7	0.78	3.91	−6.39
	66.3%	$\Delta_{rms}\cdot d$	264.3	1.20	2.70	−5.38
6-pt	δ_{rms}	δ_{P-V}	36.59	6.12	3.57	−24.4
		δ_{rms}	8.380	6.04	4.37	−36.7
		$\Delta_{P-V}\cdot d$	116.5	4.74	2.30	−27.9
	68.5%	$\Delta_{rms}\cdot d$	67.17	3.68	1.14	−21.0
Ring	δ_{rms}	δ_{P-V}	29.33	6.55	4.09	−29.2
		δ_{rms}	7.574	6.54	4.36	−39.0
		$\Delta_{P-V}\cdot d$	91.94	5.12	2.53	−31.9
	68.5%	$\Delta_{rms}\cdot d$	59.98	3.31	0.74	−21.2

The second column lists the optimized parameter and the diameter percentage at which the supports should be placed. The third column lists the parameter calculated. The slope variable provides the amount of deflection for a unit diameter, but the result must be divided by the diameter to obtain the actual slope value (see Ref. 5).

Glass Properties

Material	n_d	Transmission range (μm)	E (GPa)	α (×10⁻⁶ /°C)
N-BK7	1.5168	0.2–2.5	82	7.1
Borofloat 33 borosilicate	1.4714	0.35–2.7	64	3.25
Calcium fluoride	1.4338	0.35–7.0	75.8	21.28
Clearceram®-Z (CCZ) HS	1.546	0.5–1.5	92	0.02
Fused silica	1.4584	0.18–2.5	72	0.5
Germanium	4.004 (@ 10 μm)	2.0–14.0	102.7	6.1
Magnesium fluoride	1.3777 (n_o) 1.3895 (n_e)	0.12–7.0	138	13.7 (∥) 8.9 (⊥)
P-SK57	1.5843 (after molding)	0.35–2.0	93	7.2
Sapphire	1.7659 (n_o) 1.7579 (n_e)	0.17–5.5	400	5.6 (∥) 5.0 (⊥)
SF57	1.8467	0.4–2.3	54	8.3
N-SF57	1.8467	0.4–2.3	96	8.5
Silicon	3.148 (@ 10.6 μm)	1.2–15.0	131	2.6
ULE® (Corning 7972)	1.4828	0.3–2.3	67.6	0.03
Zerodur®	1.5424	0.5–2.5	90.3	0.05 (Class 1)
Zinc selenide (CVD)	2.403 (@ 10.6 μm)	0.6–16	67.2	7.1
Zinc sulfide (Cleartran)	2.2008 (@ 10 μm)	0.4–14.0	74.5	6.5

Glass Properties (cont.)

Material	**ρ (g/ cm³)**	***dn/dT* (absolute) (×10⁻⁶/°C)**	**ν**	**λ (W /mK)**	***K* (10⁻¹² /Pa)**
N-BK7	2.51	1.1	0.206	1.11	2.77
Borofloat 33 borosilicate	2.2	–	0.2	1.2	4
Calcium fluoride	3.18	–11.6	0.26	9.71	–1.53 @ 546 nm ($q_1 - q_2$)
Clearceram®-Z (CCZ) HS	2.55	–	0.25	1.54	–
Fused silica	2.2	11	0.17	1.35	3.5
Germanium	5.33	396	0.28	58.61	–
Magnesium fluoride	3.18	1.1 (n_o)	0.271	11.6	–
P-SK57	3.01	1.5	0.249	1.01	2.17
Sapphire	3.97	13.1	0.27	46	–
SF57	5.51	6	0.248	0.62	0.02
N-SF57	3.53	–2.1	0.26	0.99	2.78
Silicon	2.33	130	0.279	137	–
ULE® (Corning 7972)	2.21	10.68	0.17	1.31	4.15
Zerodur®	2.53	15.7	0.243	1.6	3
Zinc selenide (CVD)	5.27	61 @ 10.6	0.28	18	–1.6
Zinc sulfide (Cleartran)	4.09	40 @ 10.6 54.3 @ 0.632	0.28	27.2	–