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WINTER COLLEGE ON LASERS, ATOMIC AND MOLECULAR PHYSICS

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Lecture I

Limitations to Performance of Solid State Lasers

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Limitations to performance of solid state lasers

Energy per pulse

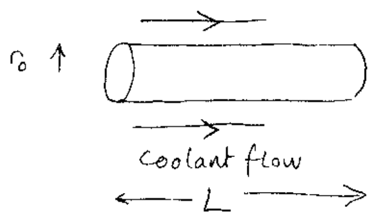
1. Optically-induced damage (lower damage threshold if mode-locked)
2. Amplified spontaneous emission
3. Available size of laser medium

Average output

1. Thermally-induced optical distortion of the laser medium
2. Thermally-induced fracture of the laser medium

Thermal effects in laser rods

(See W Koechner, Solid State Laser Engineering, Springer Series in Optical Sciences, Vol 1, 1976)



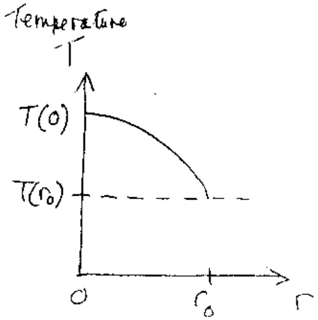
Assume uniform heat deposition Q per unit volume /sec

$$Q = \frac{P_a}{\pi r_0^2 L}$$

where P_a is the total heat dissipated by the rod.

$$T(r) = T(r_0) + \frac{Q}{4K}(r_0^2 - r^2)$$

↑ Thermal conductivity



- Temperature gradient is independent of $T(r_0)$, but $T(0)$ does depend on $T(r_0)$ and hence on cooling efficiency

Fracture occurs when maximum stress in the laser rod,

$$\frac{2^{1/2}\alpha E}{8\pi K(1-\nu)} \cdot \frac{P_a}{L}$$

equals the tensile strength.

(see Koechner)

- α, thermal expansion coefficient
- E, Young's Modulus
- ν, Poisson's ratio
- K, thermal conductivity

	K ($W\,cm^{-1}\,K^{-1}$)	
Ruby	0.42	@ 300K
YAG	0.13	"
glass	~0.01	"

} expansion coefficient, Young's modulus etc are similar

Nd:YAG ruptures when ~100W/cm are dissipated

glass ruptures at less than ~10W/cm

(Typically ~5% of electrical power to the lamp is dissipated as heat in the laser medium)

Thermal lensing in cylindrical laser rods

$$n(r) = n_0 + \Delta n(r)_T + \Delta n(r)_{stress}$$

$n(r)$: refractive index; $\Delta n(r)_T$: dominant term

$$\Delta n(r)_T = -\frac{\Phi}{4K}\frac{dn}{dT} \cdot r^2 ,$$

a quadratic variation, hence equivalent to a spherical lens.

(If $n(r) = n_0\left(1 - \frac{2r^2}{b^2}\right)$ then $f \sim \frac{b^2}{4n_0 L}$)

f: focal length; L: length of medium

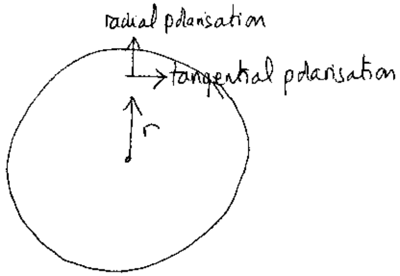
$$\text{So } f = \frac{2KA}{P_a \, dn/dT}$$

ie $f \propto 1/P_{input}$

e.g. for Nd YAG, 6 mm diameter rod,

find 0.5 $\times 10^{-3}$ dioptres / watt (1 kW ⇒ 2m focal length)

Photoelastic effects

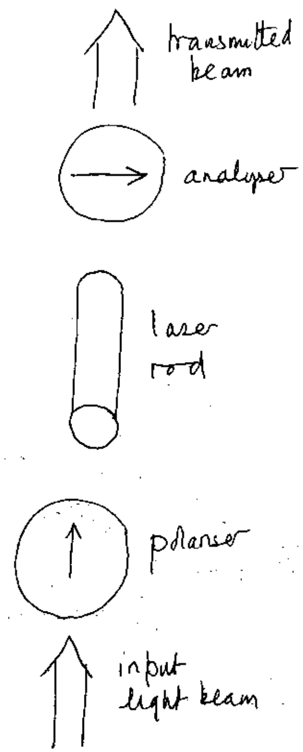


Δn_r is the refractive index change for light polarised in a radial direction,

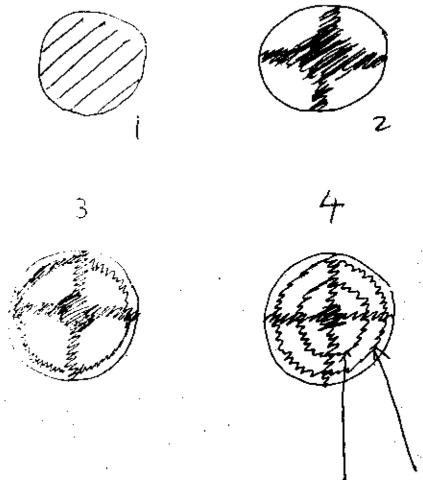
Δn_ϕ for light polarised in a tangential direction

$\Delta n_r, \Delta n_\phi \propto 1/K$ (hence much greater for glass)

For Nd YAG, $\Delta n_\phi - \Delta n_r = 3 \times 10^{-6} \Phi r^2$



1–4, (increasing lamp power) show pattern of transmitted beam. Hatched region has low transmission



$\frac{L}{\lambda}(\Delta n_\phi - \Delta n_r) = 1, 2$