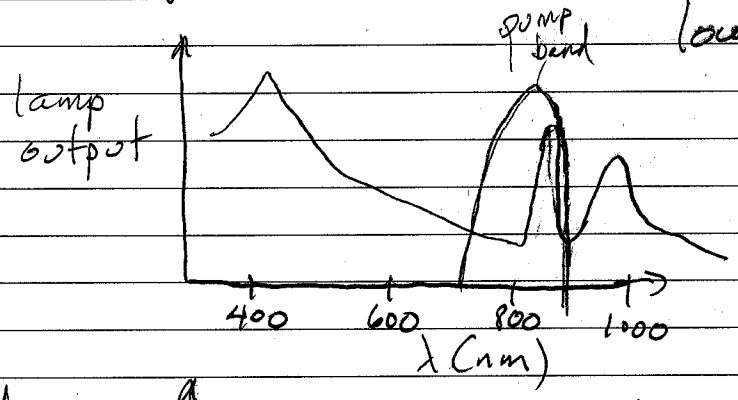
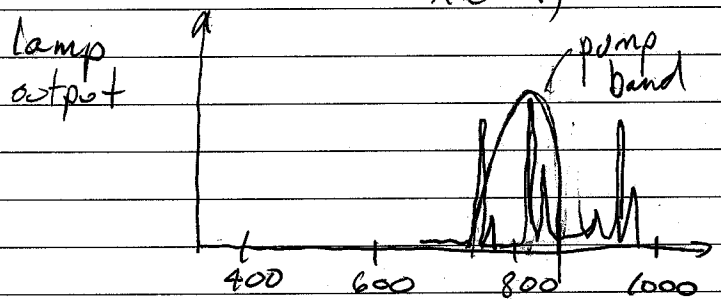
look for high lamp output in the 800 nm absorption bands.



low pressure (500 Torr) Xe flash lamp (pulsed)

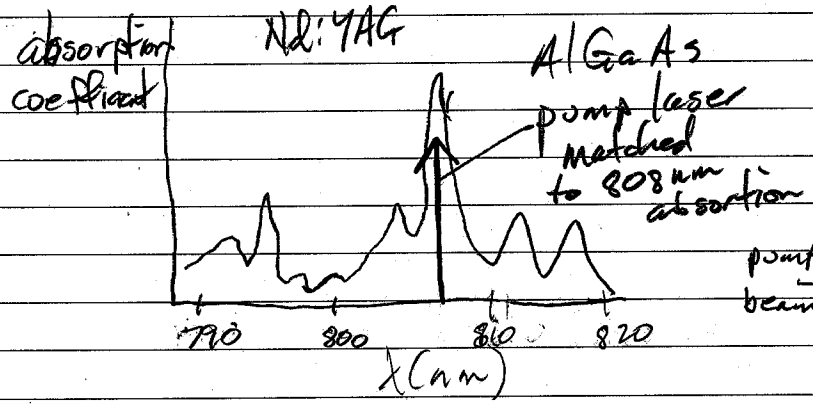


high pressure Kr arc-lamp (cw) (4 atm)

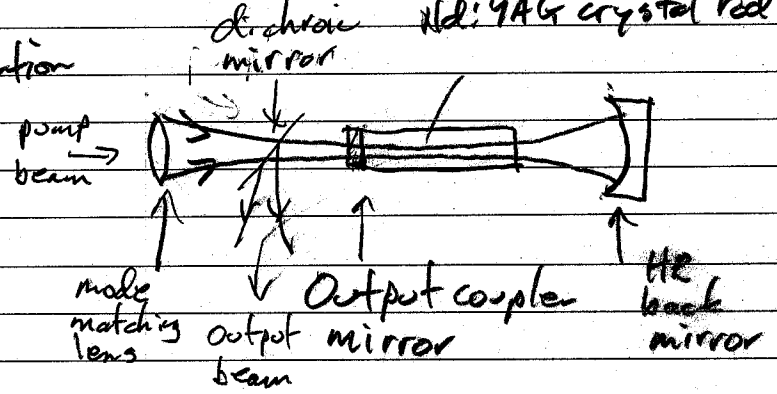
Laser pumping

- spectral matching:
  Laser output spectrum is narrow - if matched to the laser medium absorption - the spectral efficiency can be very high.

- spatial matching
  If the pump laser beam is high quality ("diffraction-limited" or TEM_{00}) it can be perfectly matched to the target laser mode, which gives optimum spatial overlap or efficiency.

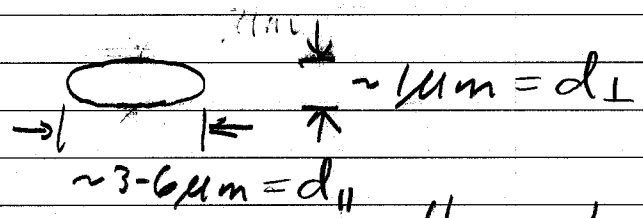


longitudinal pumping

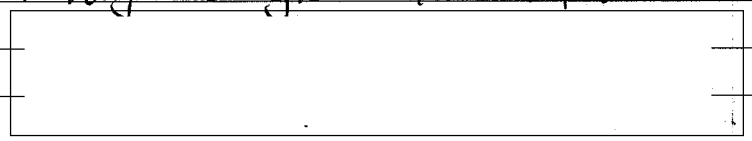


Mode matching for diode lasers

Diode laser output is typically elliptical Gaussian in shape



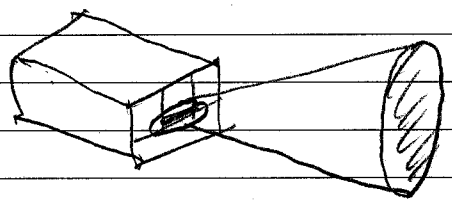
Spot sizes are very small, so beam diverges at high angles in both directions.



($d_\perp = 1\mu m$)

($d_\parallel = 5\mu m$)

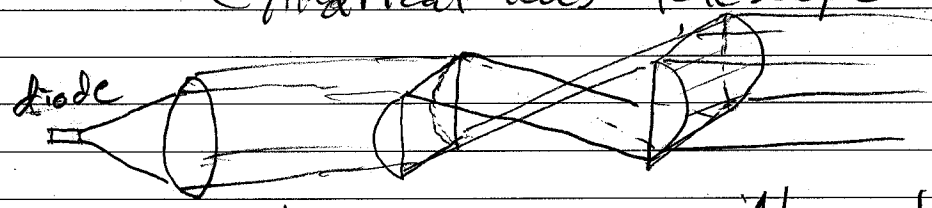
→ Beam diverges more quickly in ⊥ direction, so shape becomes elliptical with larger axis rotated



To match into a circular target laser mode an <u>anamorphic</u> beam expander is needed.

<u>examples</u>

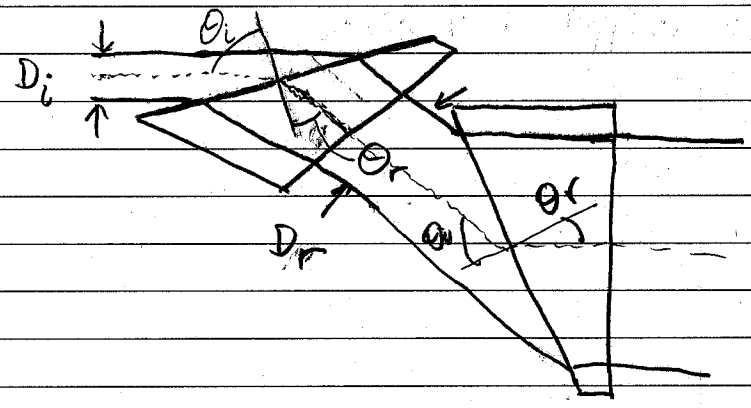
- Cylindrical lens telescope



- Alignment critical
- aberrations
- cost

- Anamorphic prism pair.

- Lower cost
- easier alignment



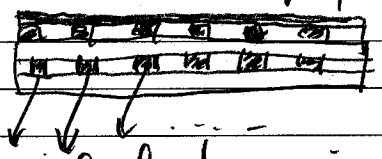
If Prism is designed so output is perpendicular to output face, then

magnification

Second prism has same magnification. Net magnification is M^2.

- For higher power systems, larger aperture multimode or unstable resonator systems are used. Alternative is low power oscillator → amplifier system. For these larger aperture systems, transverse pumping is preferred.
  - For longer amplifier length - laser ion concentration is higher
  - Can use non-diffraction limited pump beam

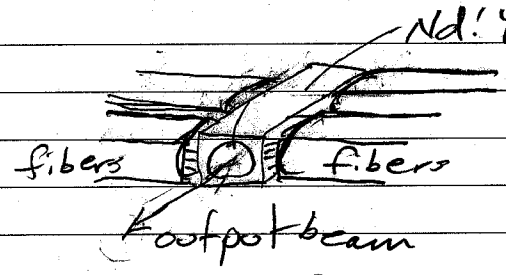
- Diode laser arrays
  - monolithic stripe array



individual emission spots merge to form large beam ~ 10-20 W

- stacked bar array – Monolithic stripe arrays can be assembled together to make 2D arrays. Heat extraction problems make cw operation difficult, but pulsed operation is possible, with peak powers of hundreds of Watts

Array outputs typically coupled into single multimode fiber or fiber bundles.



<u>Effective pump rate + efficiency – Longitudinal pumping</u>

Take pump beam intensity

$$I_p(r,z) = I_p(0,0)\exp[-(2r^2/\omega_p^2)]\exp(-\alpha z)$$

$I_p(0,0) = 2P_{ip}/\pi\omega_p^2$ $\quad P_{ip}$ = incident pump power

ω_p: pump beam spot size

- Assume laser medium is short compared to pump beam confocal parameter

The spatial dependence of the pump rate is

$$R_p(r,z) = \frac{\alpha I_p(r,z)}{h\nu_p} = \frac{P_{ip}}{h\nu_p}\frac{2\alpha}{\pi\omega_p^2}\exp[-(2r^2/\omega_p^2)]\exp(-\alpha z)$$

The "average" pump rate over the laser mode is

$$\langle R_p\rangle = \frac{\int R_p(r,z)\,|u(r,z)|^2\,dV}{\int |u(r,z)|^2\,dV}$$

with the integral taken over the laser medium volume

$u(r,z)$ is the field amplitude for the cavity mode

This also assumes the beam waist of the cavity mode is in the medium, and the medium is short compared to the confocal parameter $b_0 = \frac{2\pi\omega_0^2}{\lambda}$

Then:

$$\langle R_p \rangle = \frac{P_{ip}}{h\nu_p}\frac{2\alpha}{\pi\omega_p^2}\frac{\int \exp\left[-2r^2\left(\frac{1}{\omega_0^2}+\frac{1}{\omega_p^2}\right)\right]\exp(-\alpha z)(2\pi r)\,dr\,dz}{\int \exp[-2r^2/\omega_0^2]\cos^2 kz\,(2\pi r)\,dr\,dz}$$

$$= \frac{P_{ip}}{h\nu_p}\frac{2[1-e^{-\alpha l}]}{\pi(\omega_0^2+\omega_p^2)l}$$

define absorption efficiency $\eta_a = 1-e^{-\alpha l}$

Pump rate maximizes for $\omega_p \to 0$. Why?

For $\omega_p \to 0$, b_p also shrinks to zero, and our assumption eventually breaks down. The optimum condition is to make b_p, or $z_{R_p} \cong l$