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

**Pump Band**
- low pressure (500 Torr)
- Xe flash lamp (pulsed)

**Lamp Output**

**Pump Band**
- high pressure Kr arc-lamp (cw)

4 atm

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**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 TEMs), it can be perfectly matched to the target laser mode, which gives optimum spatial overlap or efficiency.

**Absorption coefficient**

Nd:YAG

AlGaAs

Longitudinal pumping

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**Diagram:**
- Nd:YAG crystal rod
- Mirror
- Pump beam
- Output coupler
- Matching output mirror
- HE beams
Mode matching for diode lasers

Diode laser output is typically elliptical Gaussian in shape.

\[ \sim 1 \mu m = d_\perp \]

\[ \sim 3-6 \mu m = d_\parallel \]

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

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

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

\( \Rightarrow \) Beam diverges more quickly in \( \perp \) direction, so shape becomes elliptical with larger axis rotated.

To match into a circular target, laser mode an anamorphic beam expander is needed.

- Cylindrical lens telescope

- Spherical lens

- 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 to amplifier system. For these larger aperture systems, transverse pumping is preferred.
  - For longer amplifier length - laser ion concentration is higher
  - Can use non-diffractive 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 assem
bled 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.

\[ \text{Nd:YAG slab} \]

\[ \text{fibers} \]

\[ \text{focusing beam} \]

**Effective pump rate \& efficiency - Longitudinal pumping**

Take pump beam intensity

\[
I_p(r,z) = I_p(0,0) \exp\left[-\left(\frac{2r^2}{w_p^2}\right)\right]\exp(-2z)
\]

\[
I_p(0,0) = \frac{2P_{\text{p}}}{\pi w_p^2}, \quad P_{\text{p}} = \text{incident pump power}
\]

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

The spatial dependence of the pump rate is

\[
R_p(r,z) = \frac{2}{hv_p} \exp\left[-\left(\frac{2r^2}{w_p^2}\right)\right]\exp(-2z)
\]

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 \( b_0 = \frac{2\pi w_0^2}{\lambda} \).

Then:

\[
\langle R_p \rangle = \frac{P_{tp}}{h\nu P} \frac{2\alpha}{\Pi \nu \alpha} \frac{\int \exp\left[-2r^2/\left(\frac{1}{w_0^2} + \frac{1}{\alpha^2}\right)\right] \exp(-\alpha z) \cos^2 k z \cos^2 \left(\frac{2\pi}{\lambda} r z\right) dr dz}{\int \exp\left[-2r^2/\left(\frac{1}{w_0^2} + \frac{1}{\alpha^2}\right)\right] \cos^2 k z \cos^2 \left(\frac{2\pi}{\lambda} r z\right) dr dz}
\]

\[
= \frac{P_{tp}}{h\nu} \frac{2[1 - e^{-\alpha l}]}{\Pi \left(\frac{1}{w_0^2} + \frac{1}{\alpha^2}\right) l}
\]

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

Pump rate maximizes for \( \nu_p \to 0 \). Why?

For \( \nu_p \to 0 \), \( b_0 \) also shrinks to zero, and our assumption eventually breaks down. The optimum condition is to make \( b_0 \), or \( 2R_p = \frac{\lambda}{2} \).