
Title:
An Yb-based Laser Transmitter

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Outline

1. Review of Yb-based laser media
2. Laser performance in a prism-pump design
3. Calculation of slope efficiency
4. Improvements to the current design

Why Ytterbium?

- Long upper state lifetime \Rightarrow fewer diode lasers needed to achieve required output energy \Rightarrow reduced size, weight, complexity, and cost.
- Small quantum defect \Rightarrow high efficiency and low thermal loading.
- No energy levels above the upper laser manifold \Rightarrow no excited state absorption

Why not Ytterbium?

- ❑ Lower laser level thermally populated at room temperature \Rightarrow quasi-three level laser.
- ❑ Long upper state lifetime can place stringent requirements on the pump diode lasers; i.e., chirp and duty cycle.
- ❑ Material systems not as mature as Nd-based systems.

Yb:S-FAP for High Output Energy

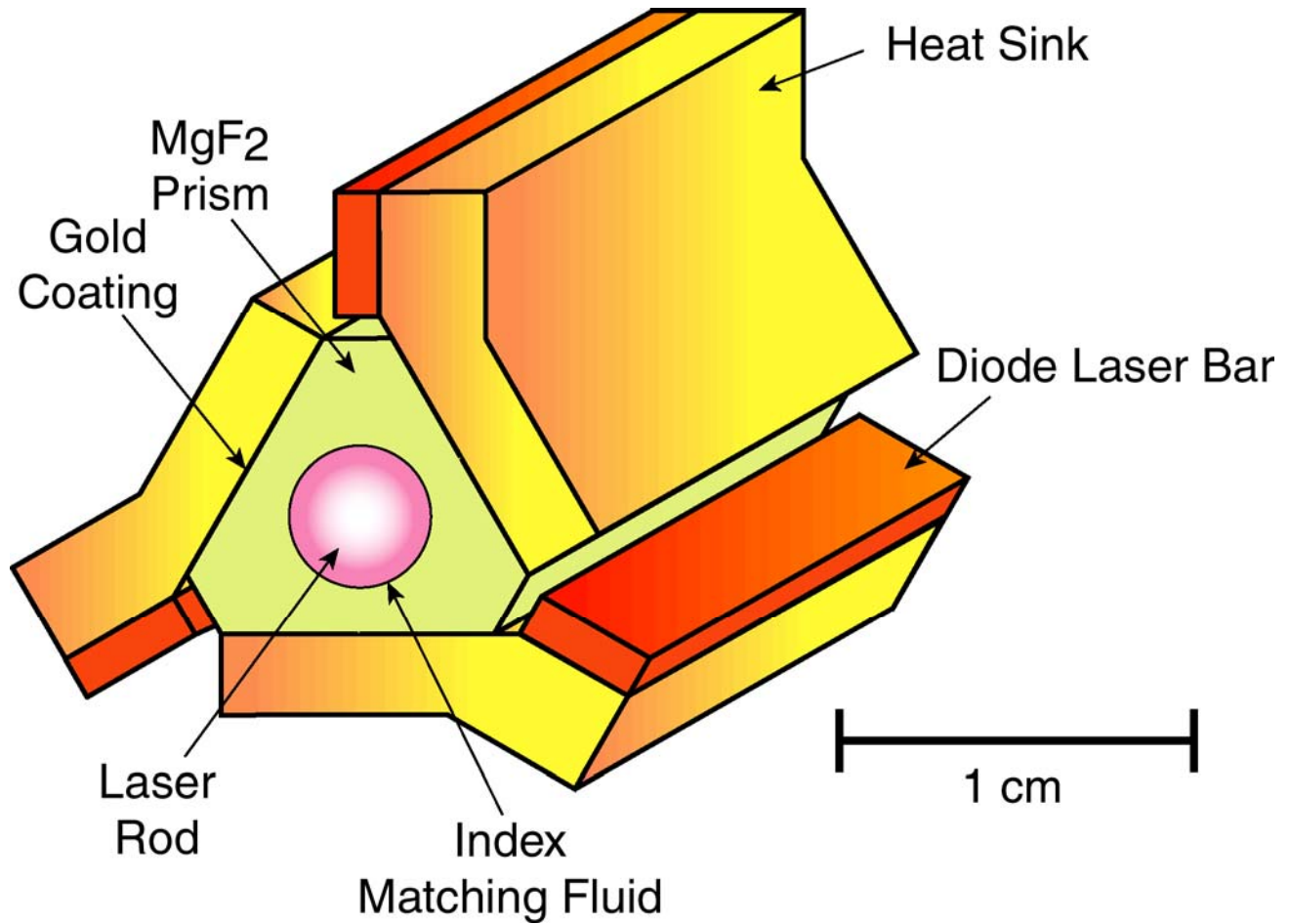
- ❑ Large emission cross section
- ❑ Low pump and laser saturation intensity
- ❑ Uniaxial crystal \Rightarrow no stress-induced birefringence
- ❑ Both Yb:S-FAP and the requisite pump diode lasers are being extensively developed under Lawrence Livermore's Mercury laser project
- ❑ Crystals available from at least 3 different commercial sources.

Advantages of the Prism Pump Cavity

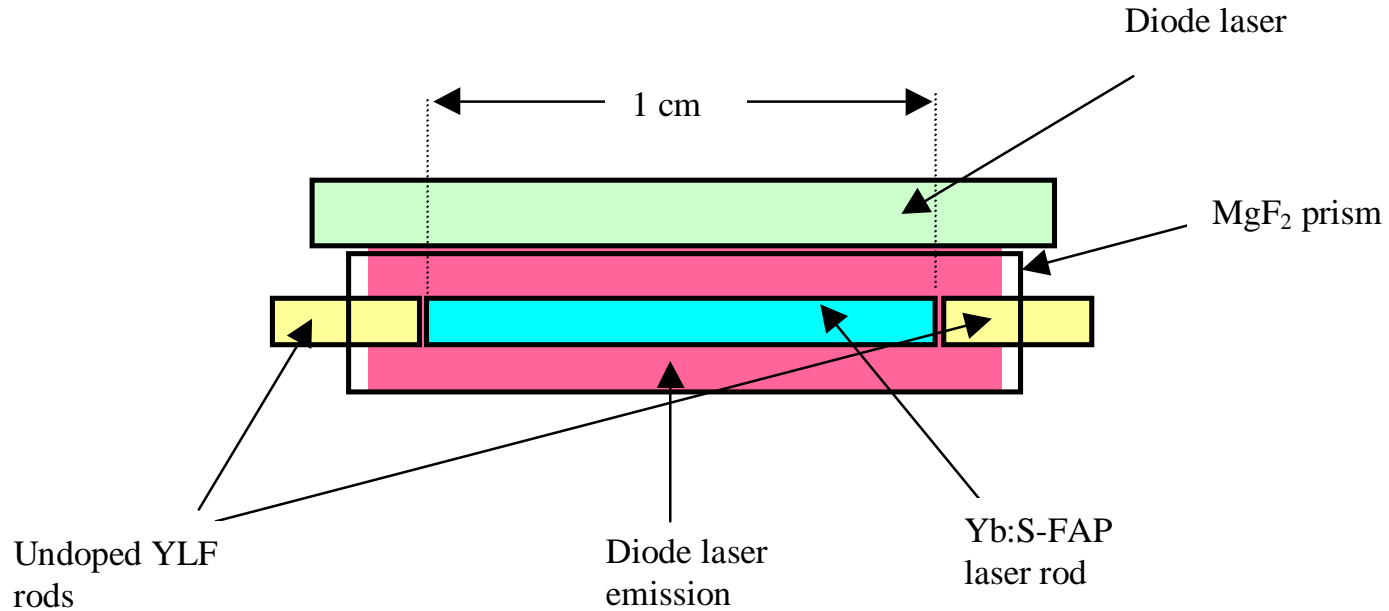
- High efficiency has been demonstrated with a Nd:YLF prism pump cavity by Hirano et al.* (43% optical to optical efficiency) in QCW operation. We obtained 40% slope efficiency for a Nd:YLF laser.
- The same Japanese group has demonstrated 48 mJ from a Q-switched prism pump cavity oscillator. We obtained 100 mJ energy per pulse.
- The pump cavity can be conductively-cooled
- Small and compact

*Y. Hirano, T. Yanagisawa, S. Ueno, T. Tajime, O. Uchino, T. Nagai, and C. Nagasawa, "All solid-state high-power conduction cooled Nd:YLF rod laser," Opt. Lett. 25, 1168 (2000).

The Prism Pump Cavity Approach

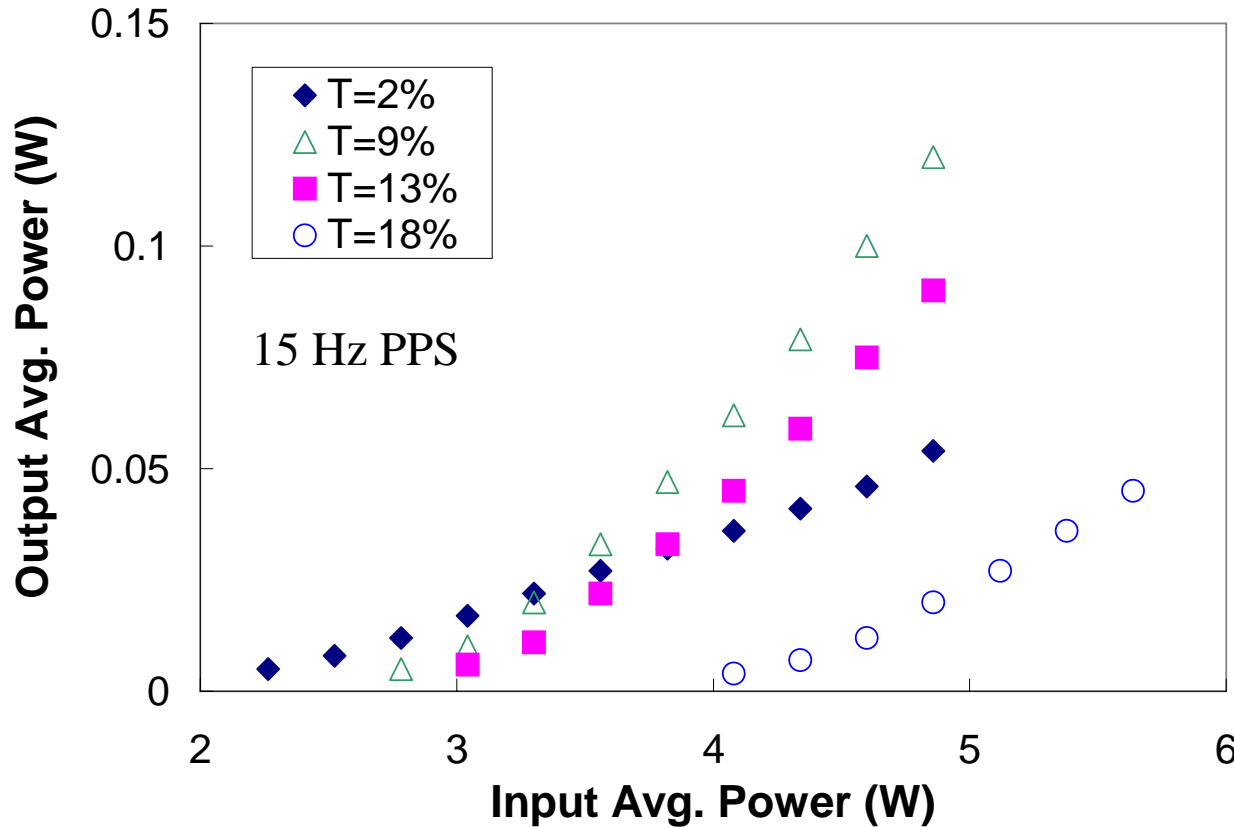


A Side View of the Prism-Pump Cavity



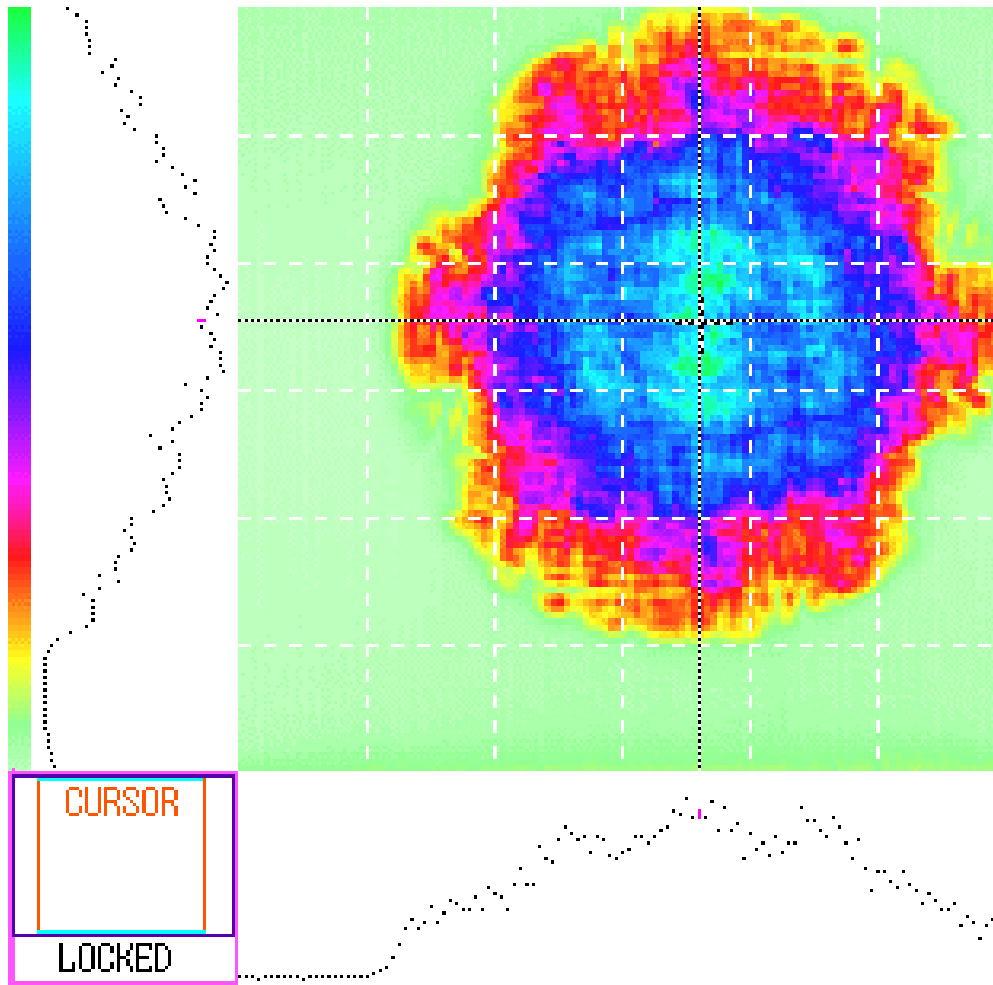
- The length of the laser rod is same as the length of the diode laser emitters.
- Undoped YLF provides a means of sealing index matching fluid between the laser rod and the prism.

I-O Curves for Different Output Couplers



- Maximum slope efficiency of 8% was obtained for $T = 9\%$ output coupler.
- Only four data points were used to calculate the slope efficiency.
- The slope efficiency increased with the input power.

Laser Beam Profile at Maximum Output Power



- Camera was approximately 10-cm away from the output coupler.
- Beam profile was recorded for $T = 9\%$ output coupler at maximum output power.
- Maximum intensity is at the center of the rod.
- M^2 of the laser was measured to be 22.

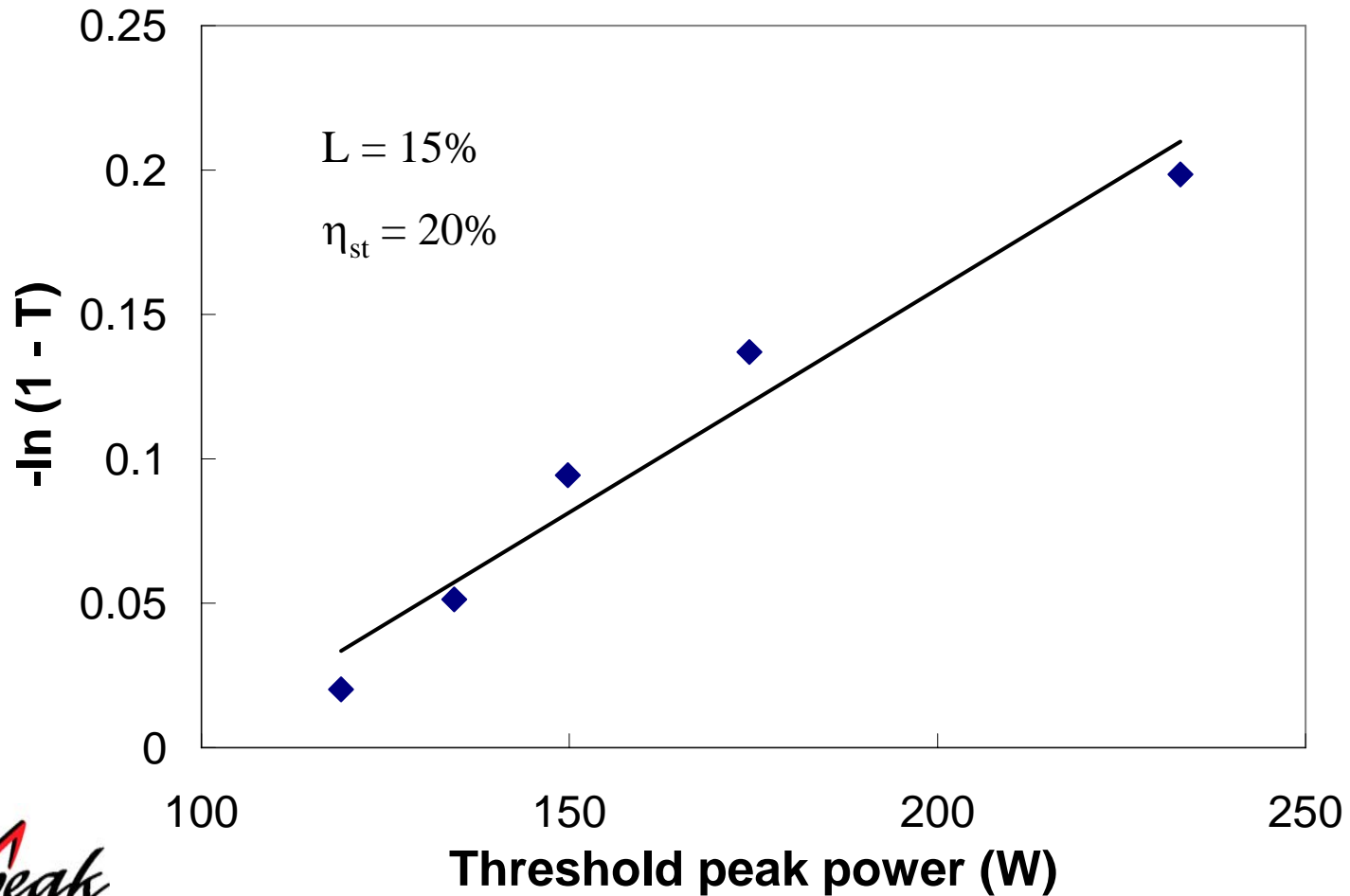
Calculation of the Slope Efficiency

$$\eta_{\text{slope}} = \eta_{\text{oc}} \eta_{\text{q}} \eta_{\text{a}} \eta_{\text{c}} \eta_{\text{qd}} = \eta_{\text{oc}} \eta_{\text{st}}$$

where η_{oc} = output coupling efficiency, η_{q} = quantum efficiency, η_{a} = absorption efficiency, η_{c} = collection efficiency, η_{qd} = quantum defect and η_{st} = storage efficiency.

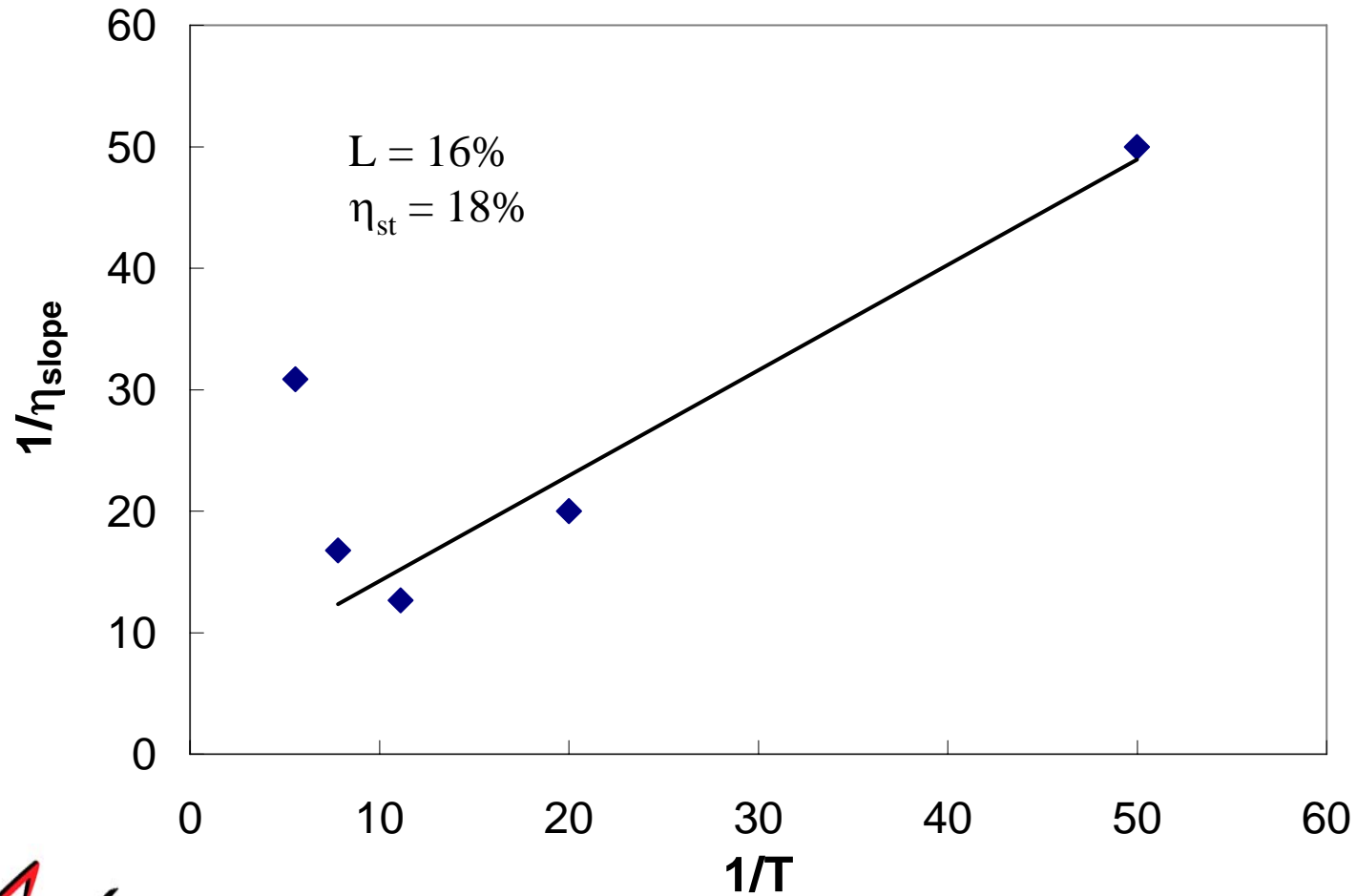
Findlay_Clay Analysis

$$-\ln(1-T) = \left(\frac{2\eta_{st}}{A I_{sat}} \right) P_{th} - L$$



Caird Analysis

$$\frac{1}{\eta_{\text{slope}}} = \frac{1}{\eta_{\text{st}}} \left(1 + \frac{L}{T} \right)$$



Rate Equation Governing the Absorption of Pump Photon

$$\frac{\partial N_1}{\partial t} = 0 = \sigma_a [f_a N_0(z) - f_b N_1(z)] \frac{I(z)}{h\nu} \frac{N_1}{\tau} \quad (1)$$

$$\frac{\partial I(z)}{\partial z} = -[f_a N_0(z) - f_b N_1(z)] \sigma_a I(z) \quad (2)$$

where N_1 and N_0 are the population density of ions in the excited and ground state, respectively, f_a and f_b are the Boltzmann occupation factors for the lower level and upper level, respectively, z is the spatial coordinate, t is the time, σ_a is the absorption cross-section, I is the pump intensity, h is Planck's constant, ν is the laser frequency, and τ is the excited state lifetime.

Assumptions:

- Quasi three level laser under CW pumping.
- There is rapid thermalization among the levels within a manifold and that the pumping is from one direction only.

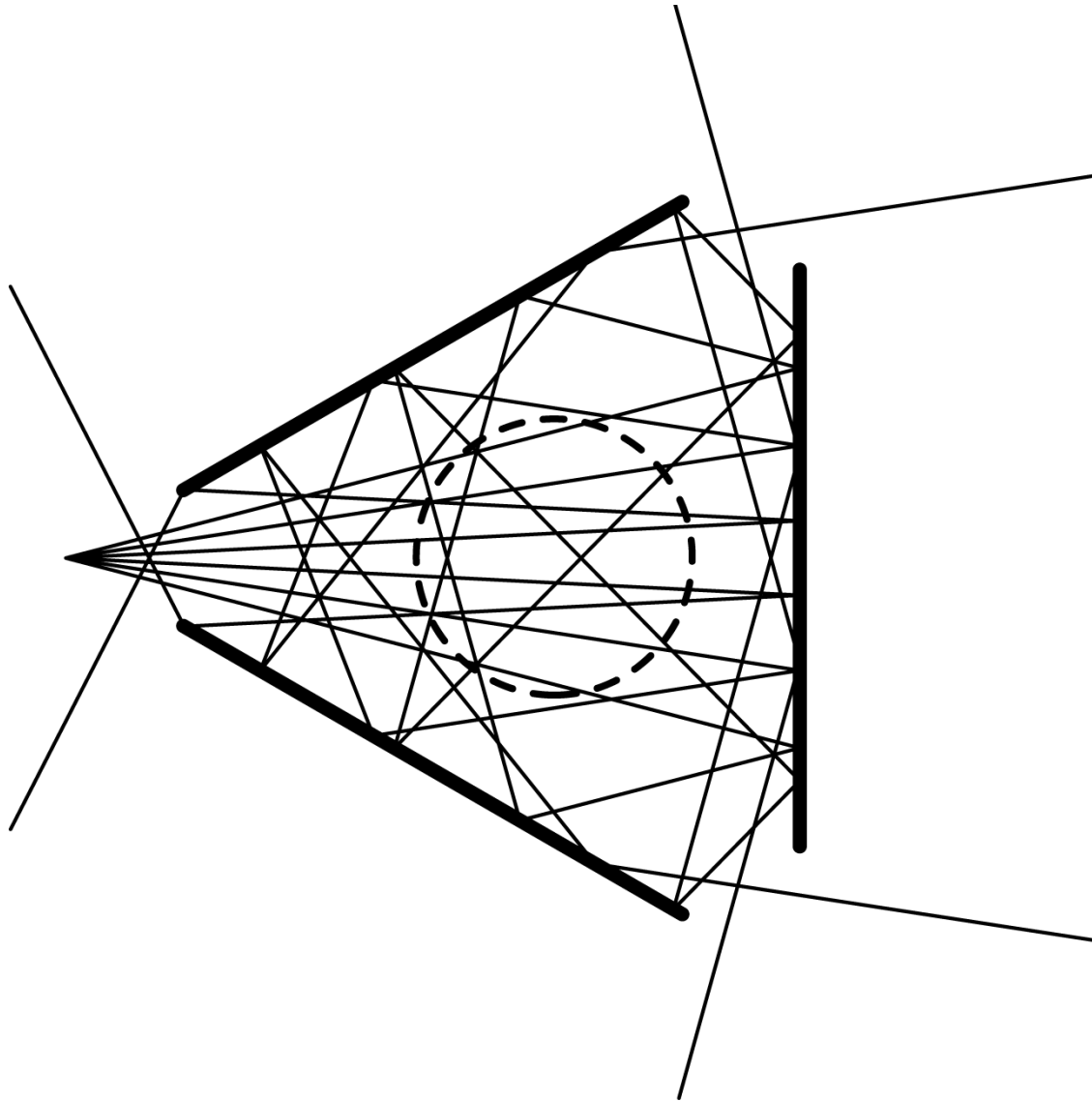
Close Form Solution to the Rate Equations

$$I'(z) = \frac{1}{f} P \text{Log} \left\{ f I'_0 \text{Exp} [f I'_0 - f_a \sigma N_t z] \right\}$$

$$I'(z) \equiv \frac{I(z)}{I_s} \quad f \equiv \frac{f_a + f_b}{f_a}$$

Estimated input intensity is 250 W/cm². The saturation intensity (for the σ polarization) is 4.3 kW/cm², $f_a = 0.820$, $f_b = 0.141$, $\sigma_a = 0.4 \times 10^{-19}$ cm², and $N_t = 1.1 \times 10^{19}$ cm⁻³. Under these conditions and assumptions, the intensity (as a function of z) decreased linearly. On the first pass through the rod, 13 % of the pump power is absorbed.

Simplified Ray Tracing in the Prism -Pump Cavity



Calculation of Absorption Efficiency

$$\eta_a = 1 - (1 - 0.13)^2 = 0.24$$

In an average the pump ray passes only two times through the laser rod before escaping out of the prism.

Improvements

- ❑ Rotating the polarization of the diode lasers will improve the absorption efficiency two times.
- ❑ Reducing the pump window of MgF_2 prism would trap the pump light better.
- ❑ Increase the pump power by stacking the diode bars.
- ❑ Change the side-pump geometry.

Summary

- We have reviewed the known Yb-based laser media
- Our initial choice of materials is Yb:S-FAP
- We have demonstrated a side-pumped Yb:S-FAP laser in a prismatic pump cavity
- We obtained 8% optical to optical slope efficiency and 4% electrical to optical slope efficiency
- M^2 of the laser was measured to be 22