1.8-W CW Er:YLF Diode-Pumped Laser

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Motivation

- Development of a solid-state directly diode-pumped CW high-power (> 1 W) 3-μm laser
- Possible applications:
  - industrial,
  - medical.

Previous results – Er:YLF

Laser operation at 2.81 μm:

- **Maximum slope efficiency :**

  ~ 40% - Ti:Sapphire excitation (970 nm, longitudinal)

  M.Pollnau et al., *"Efficiency of Erbium 3-μm crystal and fiber lasers"* IEEE J. of Quantum Electronics, **32**, 657-663 (1996)

  ~ 35% - Diode-Pumped (970 nm, longitudinal)

  T. Jensen, A. Diening, G. Huber, and B.H.T. Chai, *"Investigation of diode-pumped 2.8-μm Er:LiYF$_4$ lasers with various doping levels,"* Opt. Lett., **21**, 585-587 (1996).

- **Maximum CW output:**

  ~ 1.1 W Diode-pumped (970 nm, longitudinal, fiber-coupled diode laser)

  T. Jensen et al. (above)

- **Drawbacks:**
  - difficult to scale to higher powers
  - fracture of the laser elements at 4-6 W pump power (0.3-0.5 mm spot)

Absorption Properties of Er:YLF Laser Crystals

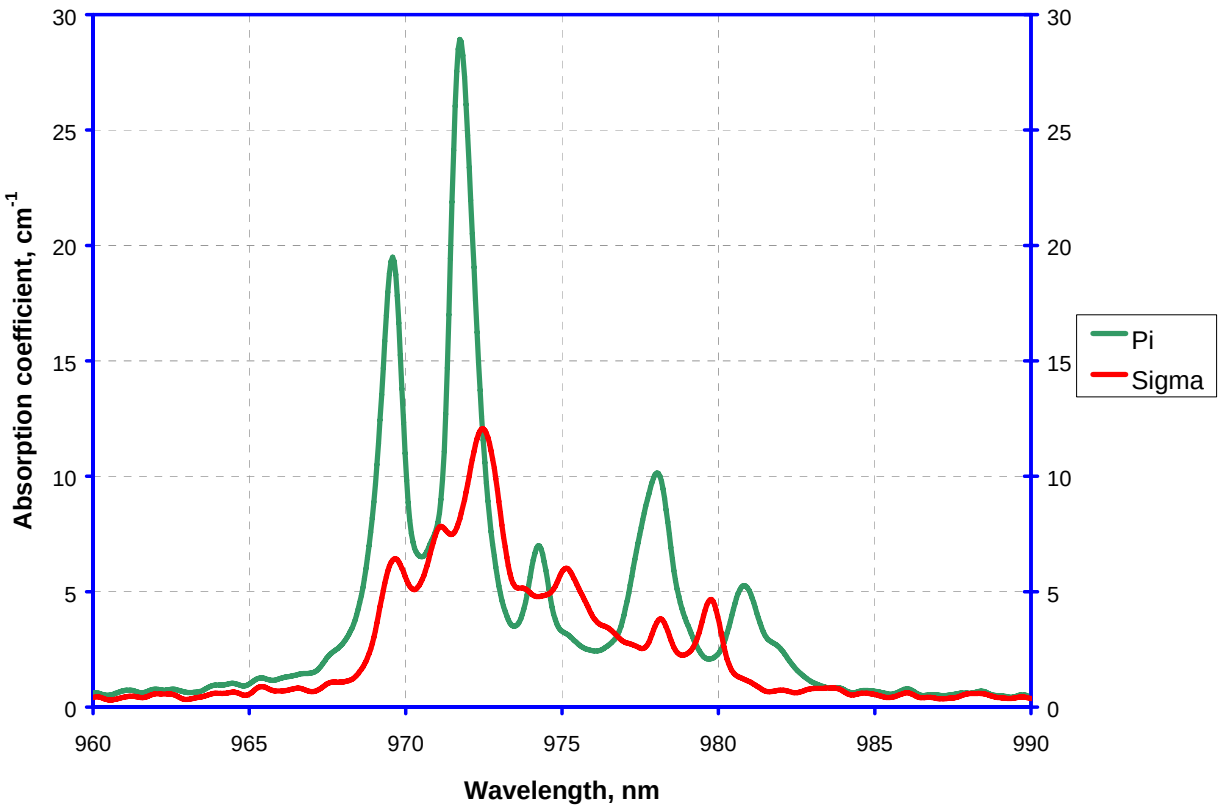
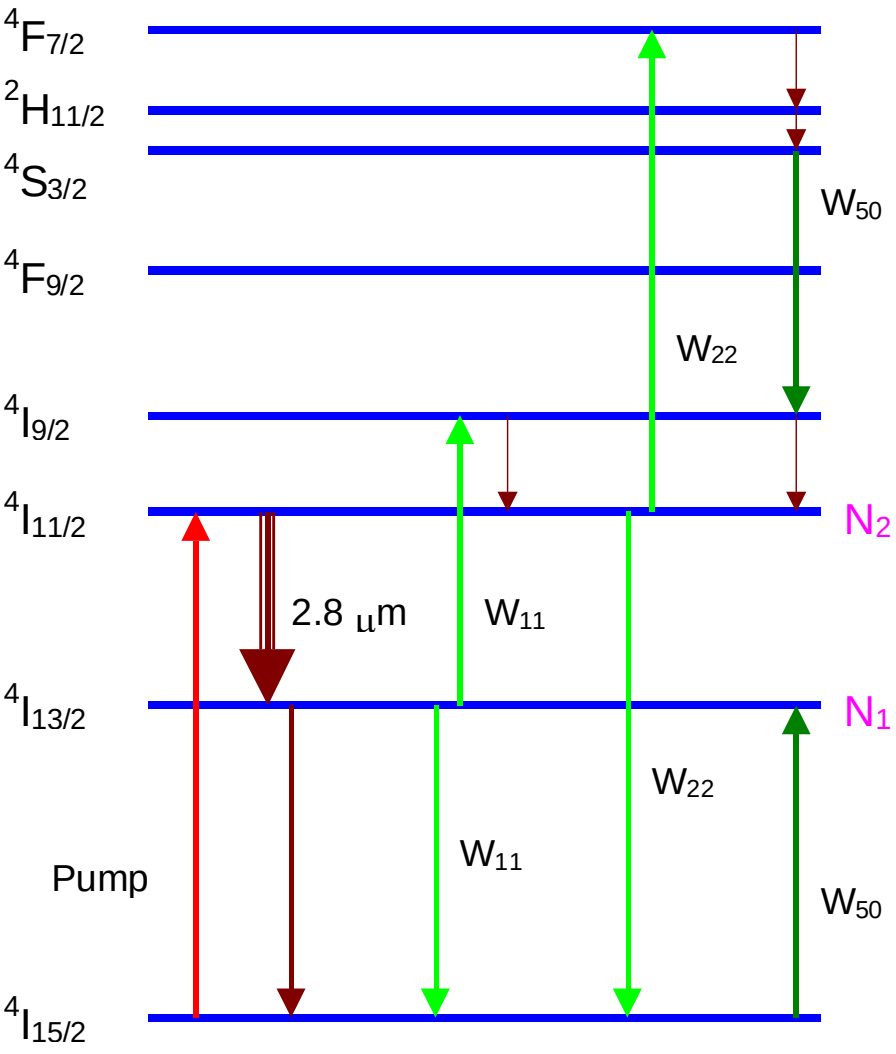


Figure Polarized absorption spectra for 15% Er:YLF crystal at 300 K.

Thermo-Mechanical Properties of YLF Crystals

Material	YLF	YAG
Knoop hardness, kg/mm^2	300	1215
Modulus of elasticity, GPa	85	310
Thermal expansion coefficient, $1/^0C$	$8x10^{-6}$ ||c $13x10^{-6}$ ||a	~$8x10^{-6}$
Coeff. of thermal conductivity, W/m·K	6.3	13

Er^{3+} Energy Level Diagram



Theoretical Model

Rate equations:

$$dN_2/dt = W + W_{11}(N_1)^2 - W_{22}(N_2)^2 - N_2/\tau_2 ,$$

$$dN_1/dt = \beta_{21}\, N_2/\tau_2 + W_{22}(N_2)^2 - 2\, W_{11}(N_1)^2 - N_1/\tau_1,$$

The net gain coefficient:

$$g = \sigma_{21}\,(b_2N_2 - b_1N_1),$$

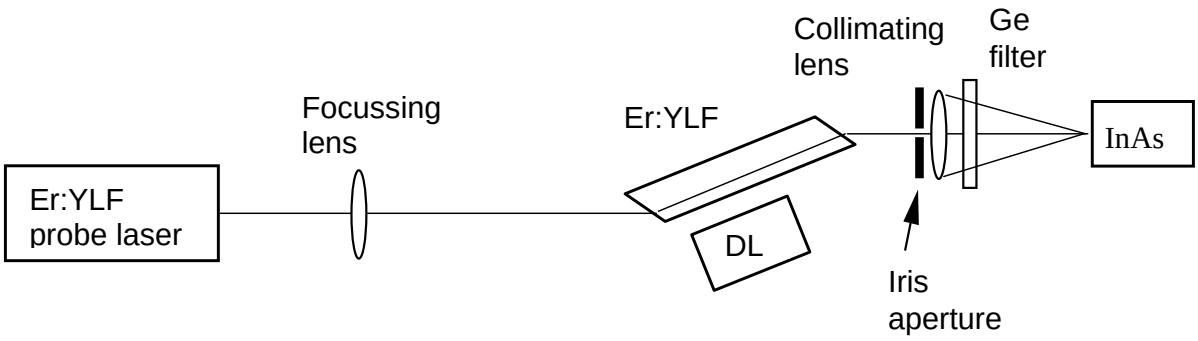
Table. *Values for 15%Er:YLF used in the calculations*
(Based on the data from: M.Pollnau et al. IEEE J. QE, 321, 657-663 (1996)).

τ_1	10 msec
τ_2	4.0 msec
W_{11}	3×10^{-17} cm^3/sec
W_{22}	1.8×10^{-17} cm^3/sec
β_{21}	0.39
σ_{21}	3×10^{-20} cm^2
b_1	0.113
b_2	0.2

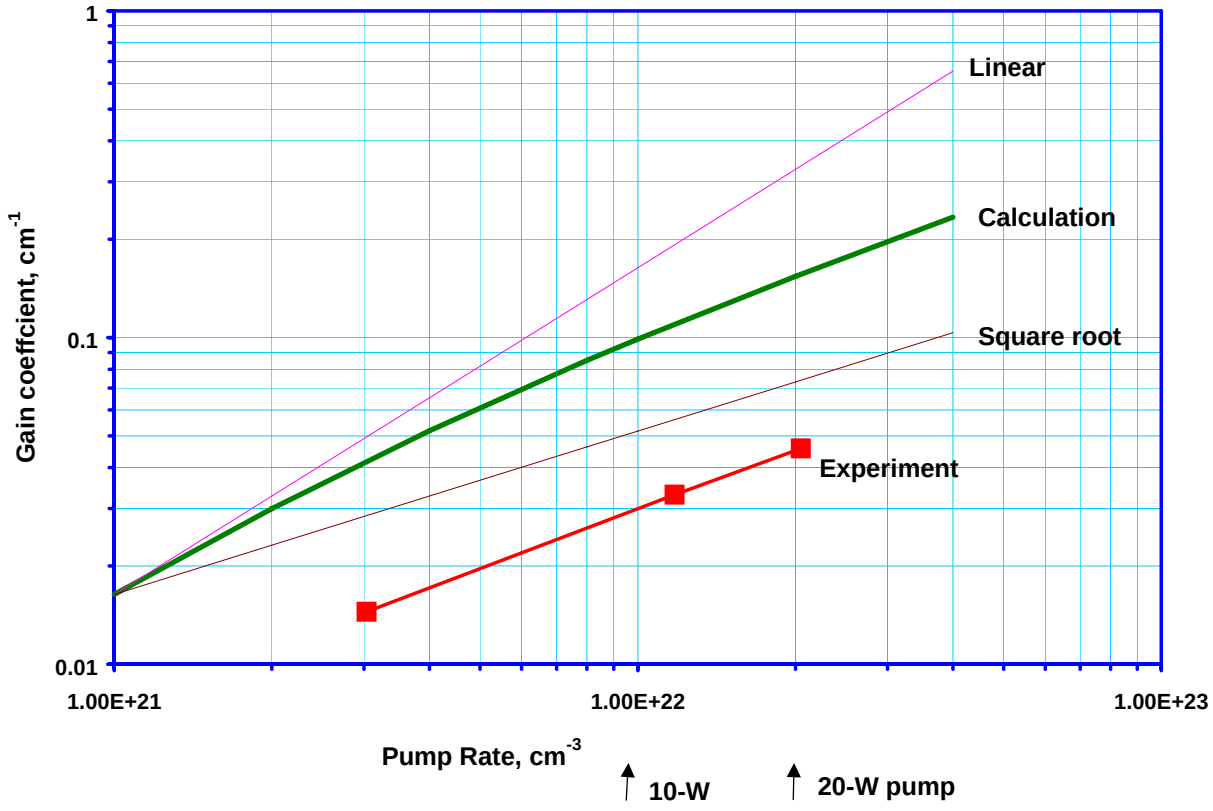
Definitions:

W_{11}, W_{22} - upconversion rate parameters
τ_1 and τ_2 - lifetimes for spontaneous decay
β_{21} - the branching ratio
σ_{21} - spectroscopic cross section for the transition
b_1 , b_2 - Boltzmann factors for the lower and upper manifolds

Gain Measurements - Experiment



Gain Calculation



Gain – Temporal Behavior

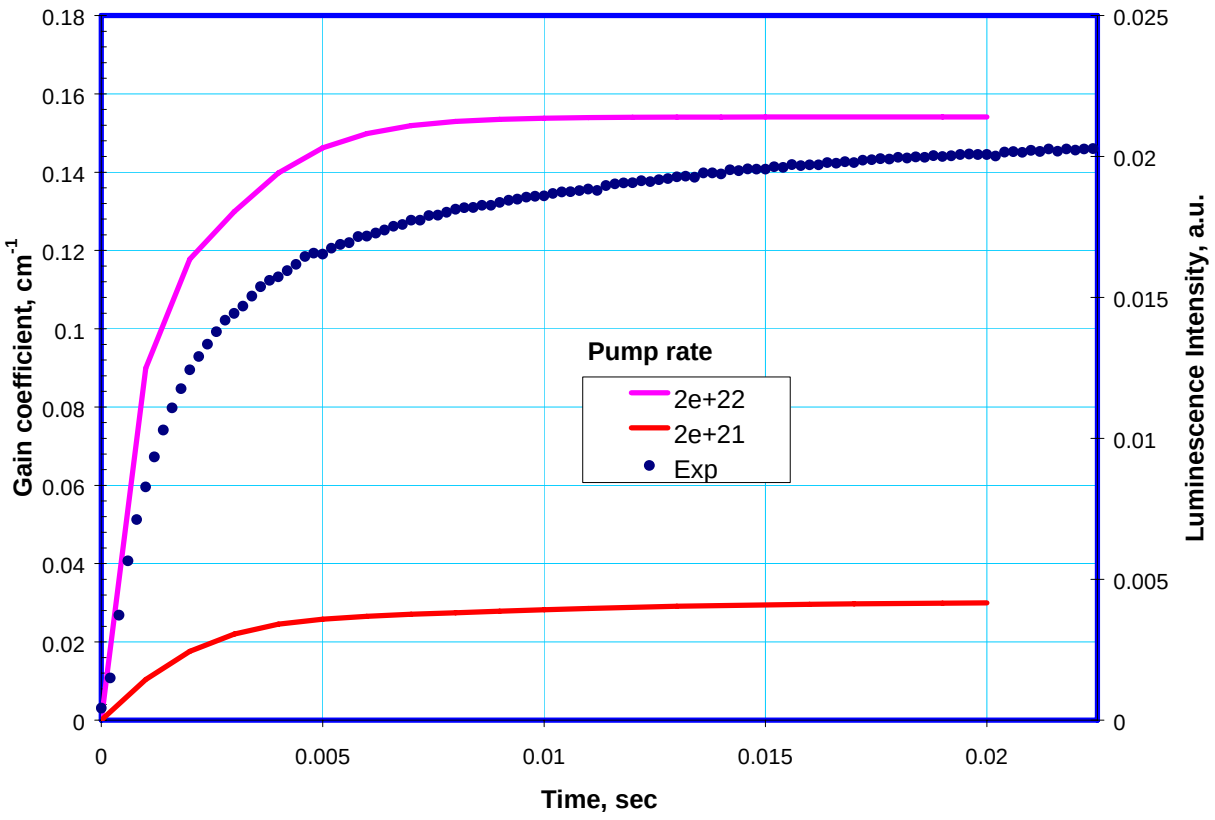
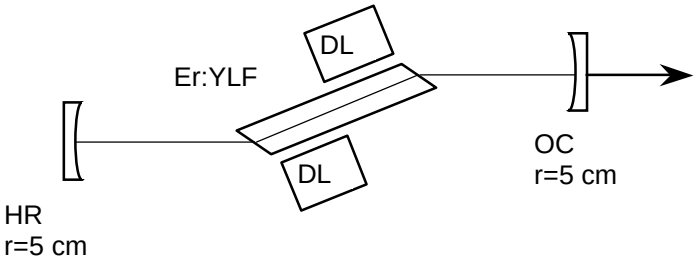
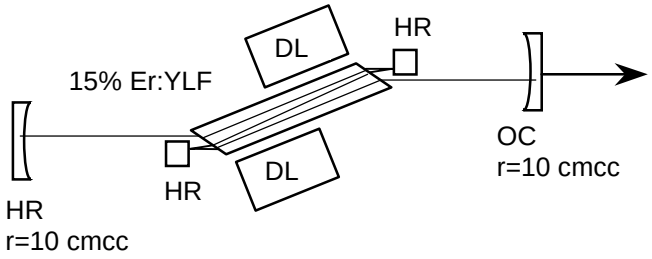


Figure. Gain coefficient as a function of time (for two pump rates) and temporal behavior of 3-μm luminescence.

Experimental Set-Up



Layout of side-pumped Er:YLF laser resonator with 1-pass geometry



Layout of side-pumped Er:YLF laser resonator with 3-pass geometry

- **Er:YLF Active Element:**
  - parallel Brewster-cut faces,
  - 28 mm long
  - clear aperture 2.5x5 mm.

Pump Diode Lasers

- **General case:**

  Er:YLF can be pumped by the radiation of any laser or laser diode emitting in the 980 nm, 790 nm, or 1500-nm ranges.

- **This work:**

Pumping laser	Wavelength, nm	CW power, W
Lensed diode bar (Coherent, Inc.)	980	up to 30

Er:YLF CW Laser Operation

Single Pass Geometry

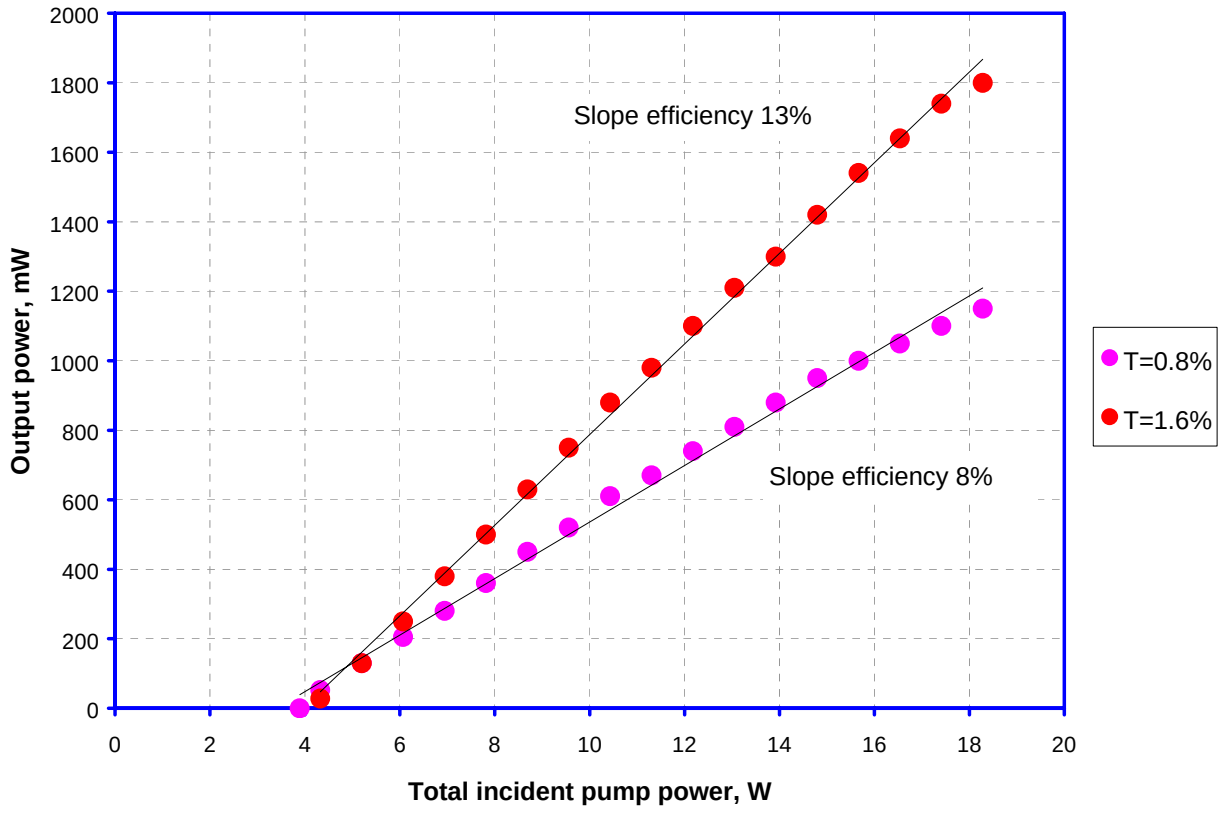


Figure Input/Output dependencies for single pass geometry

- **Nearly-confocal resonator:**

HR mirror:	R>99.9% at ~ 2700-2850 nm
	Concave r = 5 cm
Output coupling:	R ~ 0.8% and 1.6% at 2810 nm
	Concave r = 5 cm
Length:	6.5 cm

Er:YLF CW Laser Operation

Three Pass Geometry

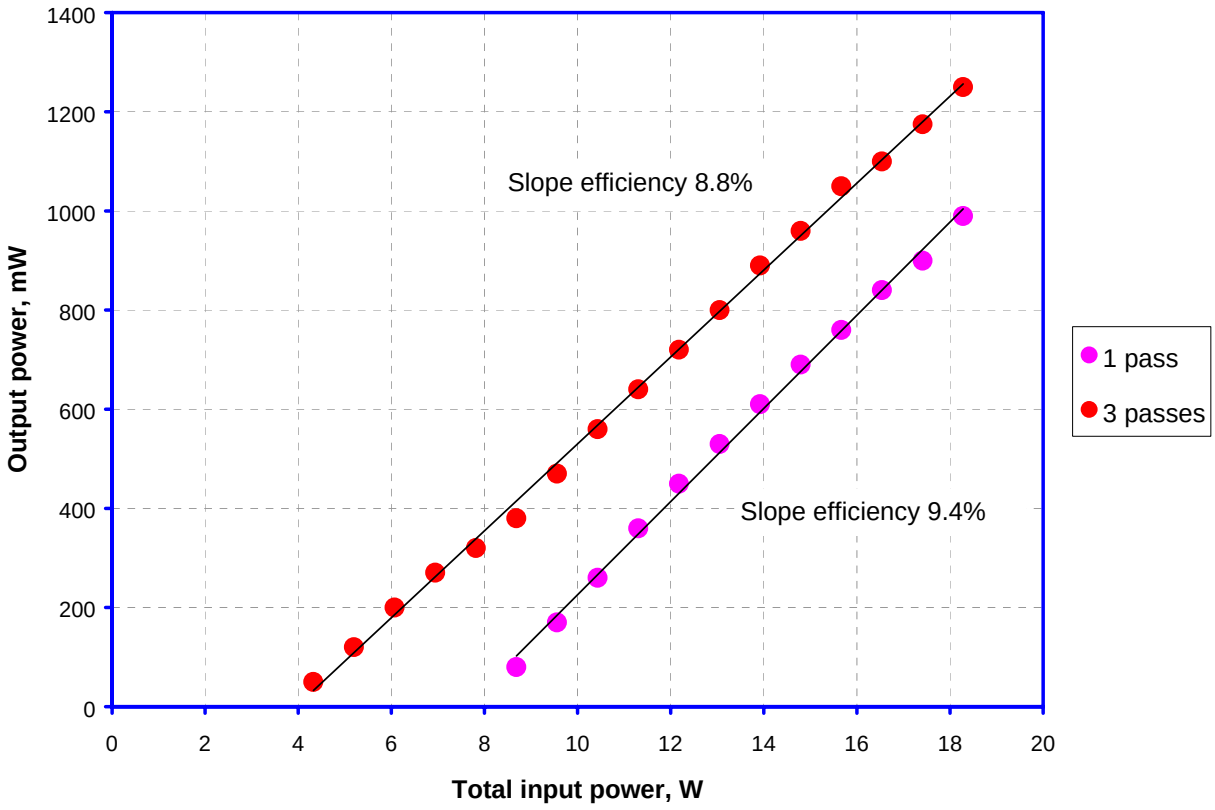


Figure Input/Output dependencies for single pass and 3-pass geometry

- **Nearly-confocal resonator:**

HR mirror: R>99.9% at ~ 2700-2850 nm
Concave r = 10 cm

Output coupling: R ~ 5% at 2810 nm
Concave r = 10 cm

Resonator length: 1 pass: 11 cm
3 pass 17 cm

Conclusions

Development of an efficient CW Er:YLF laser:

- First demonstration (to the best of our knowledge) of a side-pumped 3-μm Er:YLF laser
- Record output CW power ~ 2 W