A CW Side-Pumped Tm:YLF Laser

Alex Dergachev, Kevin Wall, and Peter F. Moulton

Q-Peak, Inc.

135 South Road, Bedford, Massachusetts 01730
Tel.: (781) 275-9535, FAX: (781) 275-9726
E-mail: dergachev@qpeak.com

Acknowledgements:
US Air Force, Contract # F08630-01-C-0037

Qpeak
APPLIED PHOTONIC SYSTEMS

Outline

1. Motivation
2. Previous Results
3. Properties of Tm:YLF Laser Crystals
   - Absorption Properties
4. Tm:YLF Development
   - Laser Element Design
   - Gain Modeling
   - Experimental Set-up
   - Laser Operation with Single-Pass Geometry
   - Laser Operation with Five-Pass Geometry
   - Tunable Operation
5. Conclusions

Qpeak
APPLIED PHOTONIC SYSTEMS

Motivation

- Feasibility of a side-pumped geometry for diode-pumped 2-μm Tm:YLF lasers
- Development of CW high-power (> 10 W), high beam quality tunable Tm-laser
- Possible applications
  - Pump source for other IR lasers
  - Industrial
  - Medical

Qpeak
APPLIED PHOTONIC SYSTEMS

Previous results – Diode-pumped Tm:YLF-lasers

- Tm:YLF
  - P. A. Budni et al., “High-power/high-brightness diode-pumped 1.9-µm Thulium and resonantly pumped 2.1-µm Holmium lasers,” IEEE J. on Selected Topics in Quantum Electron., 6, 629-635 (2000).
    - 36 W CW output at 1.907 mm (σ-line)
    - Multimode, $M^2 \sim 2$
    - Two 5x10 mm rods with diffusion-bonded caps
    - Slope efficiency ~40%
    - Longitudinal pumping, 120 W (four fiber-coupled lasers)

Qpeak APPLIED PHOTONIC SYSTEMS

Previous results – Diode-pumped Tm:YAG-lasers

Tm:YAG

- E. C. Honea et al., “115-W Tm:YAG diode-pumped solid-state laser”, IEEE J. Quantum Electron. 33, 1592-1600 (1997)
- K.S.Lai et al., “120-W CW diode-pumped Tm:YAG laser”, Optics Letters, 25, 1591-1593 (2000).

	End-pumping (Livermore)	**Side-pumping** (DSO National lab – Singapore)
CW power	115 W	120 W
Wavelength	2.01 μm	2.02 μm
Slope efficiency	~ 40%	~ 31%
Laser element	3x55 mm doped rod, diffusion-bonded caps	3x65 mm doped rod, diffusion-bonded caps
Pump power	360 W, diode array stack, lens duct	472-W, three diode arrays, compound parabolic concentrator
Mode quality	Multimode, M^2 - 14-23	Multimode, M^2 - 14-21

Qpeak APPLIED PHOTONIC SYSTEMS

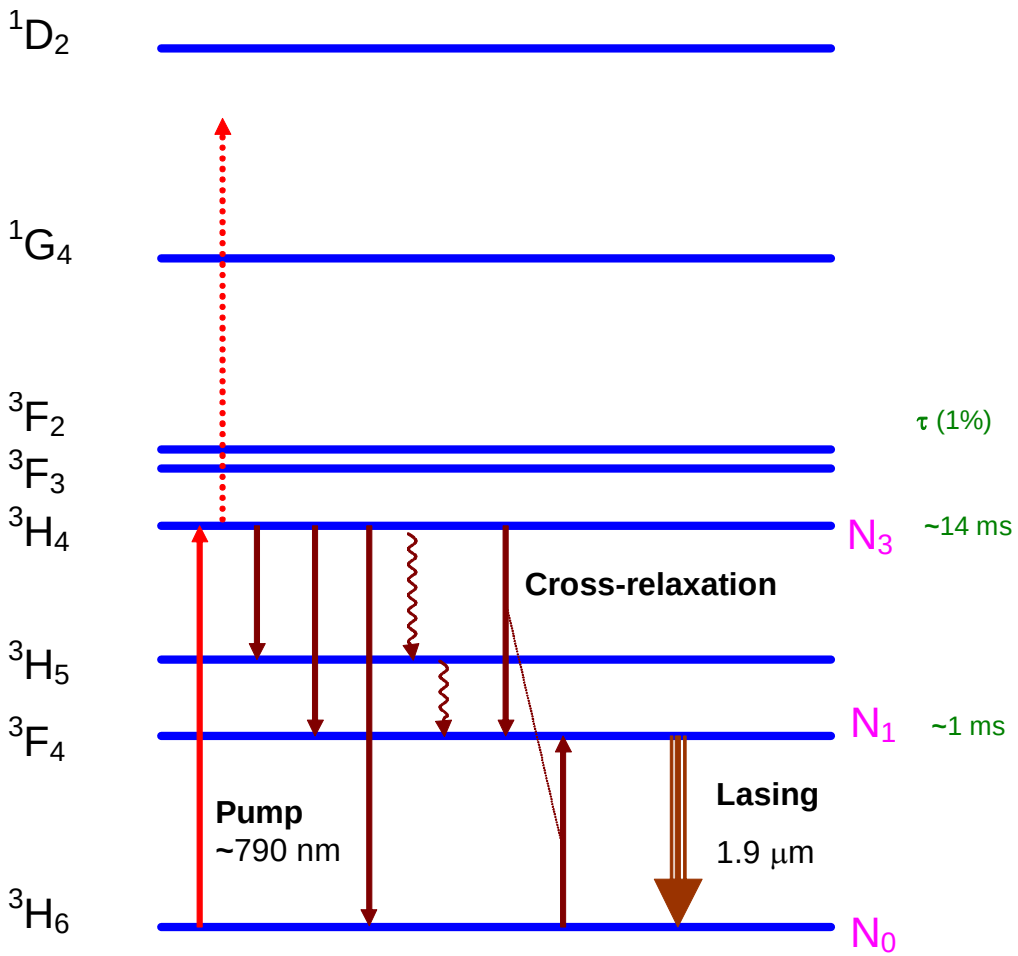
Previous results

- Drawbacks:
  - Beam quality
  - Diffusion-bonded rods
  - Complicated pump arrangements

Qpeak
APPLIED PHOTONIC SYSTEMS

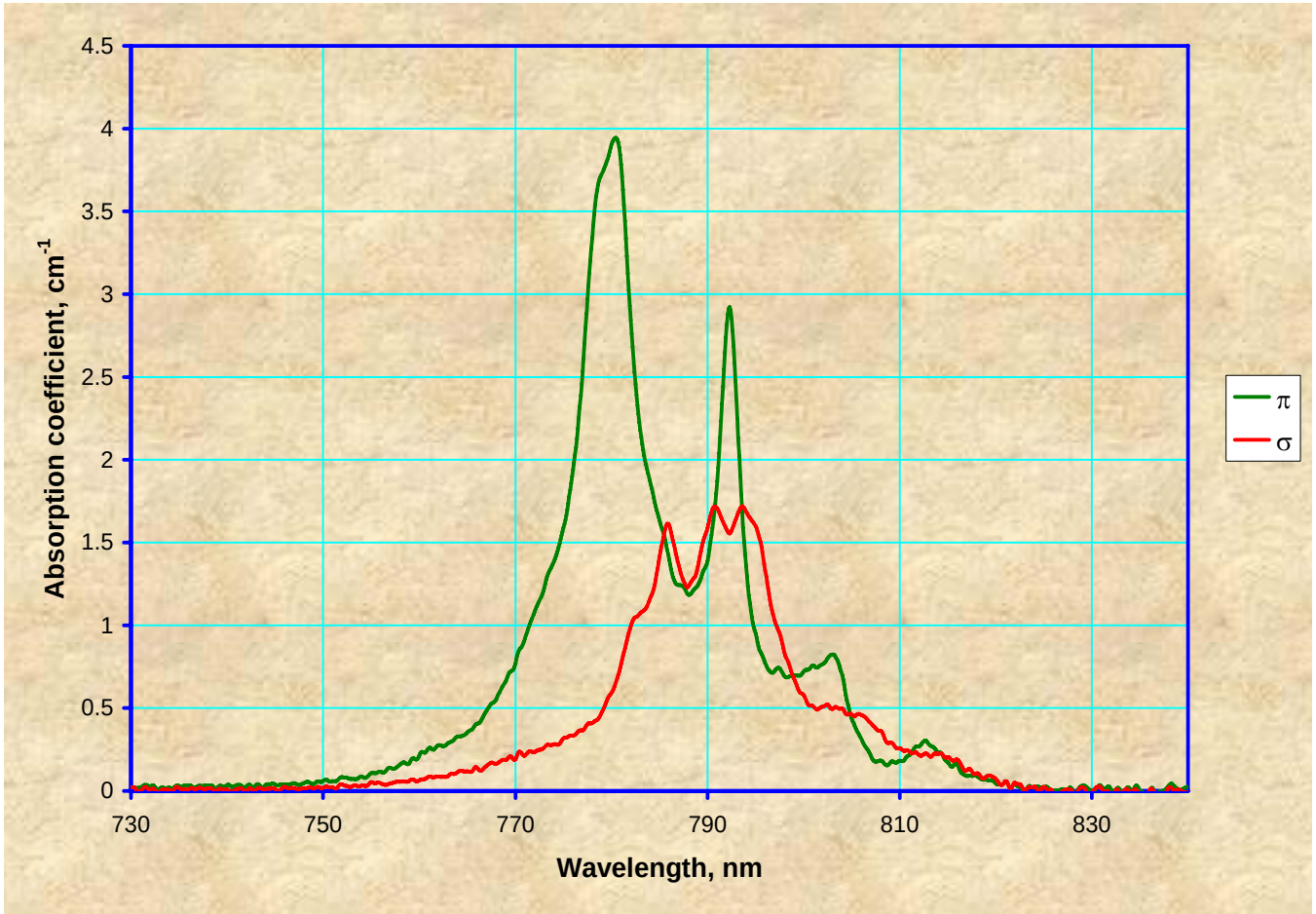
Tm^{3+} Energy Level Diagram

- $1 \rightarrow 2$ pump process due to cross-relaxation
- low up-conversion
- low heat generation (~20 %)



Qpeak
APPLIED PHOTONIC SYSTEMS

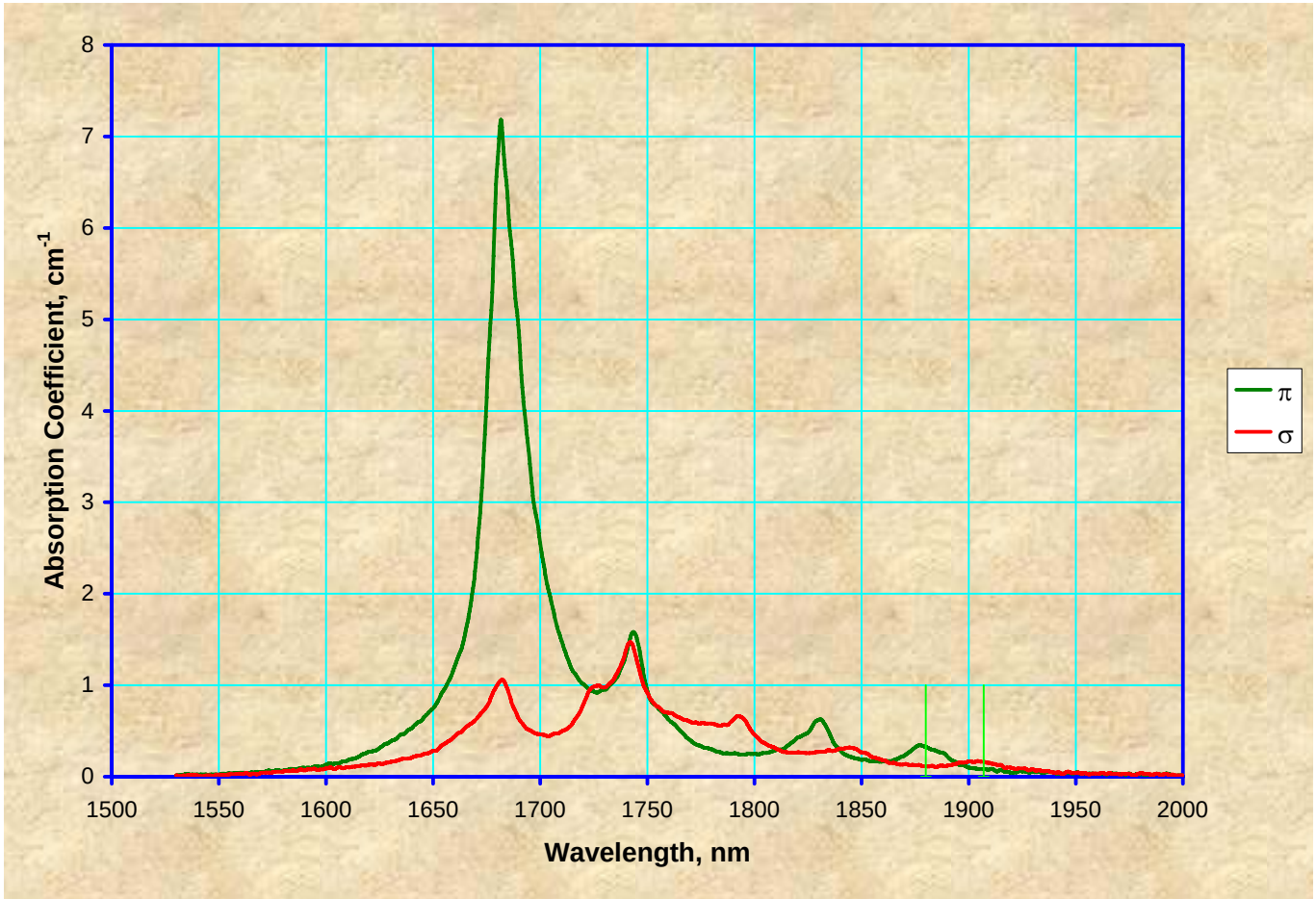
Absorption Properties of Tm:YLF Laser Crystals - Pump Region



Polarized absorption spectra $^3H_6 \rightarrow {}^3H_4$ for 3.5% Tm:YLF crystal at 300 K

Qpeak
APPLIED PHOTONIC SYSTEMS

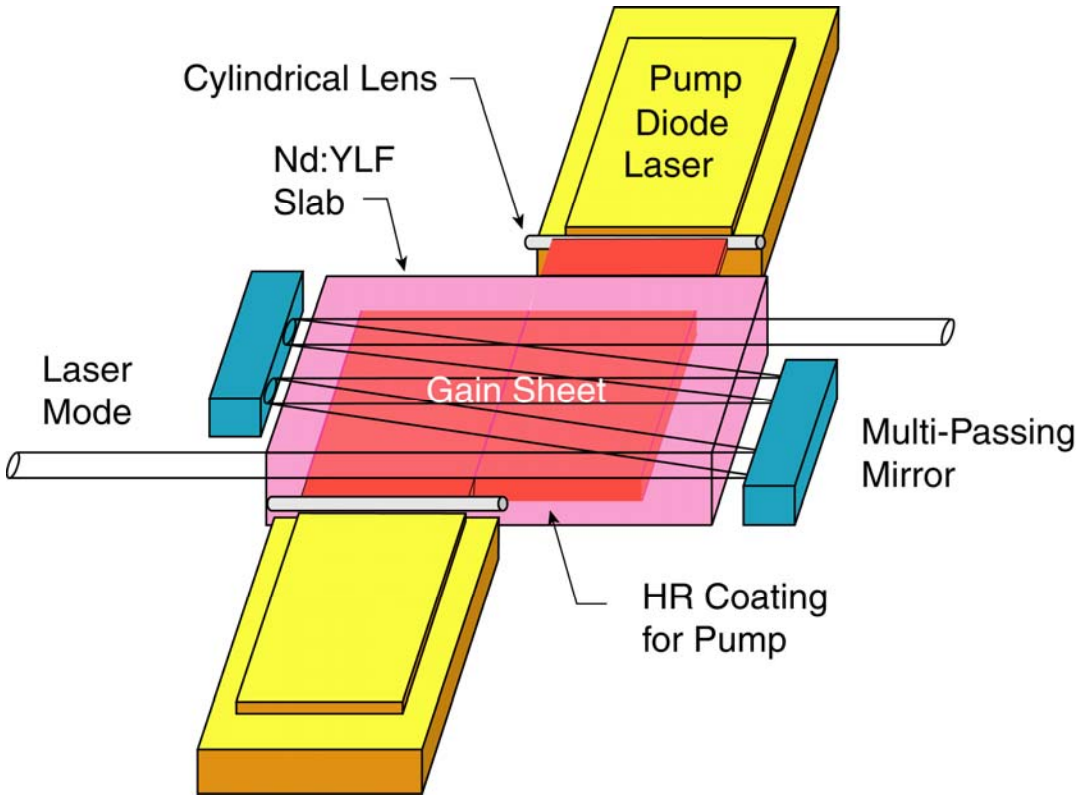
Absorption Properties of Tm:YLF Laser Crystals - Lasing Region



Polarized absorption spectra $^3H_6 \rightarrow {}^3F_4$ for 3.5% Tm:YLF crystal at 300 K

Qpeak
APPLIED PHOTONIC SYSTEMS

Q-Peak' MPS Gain Module Technology



Qpeak
APPLIED PHOTONIC SYSTEMS

Pump Diode Lasers

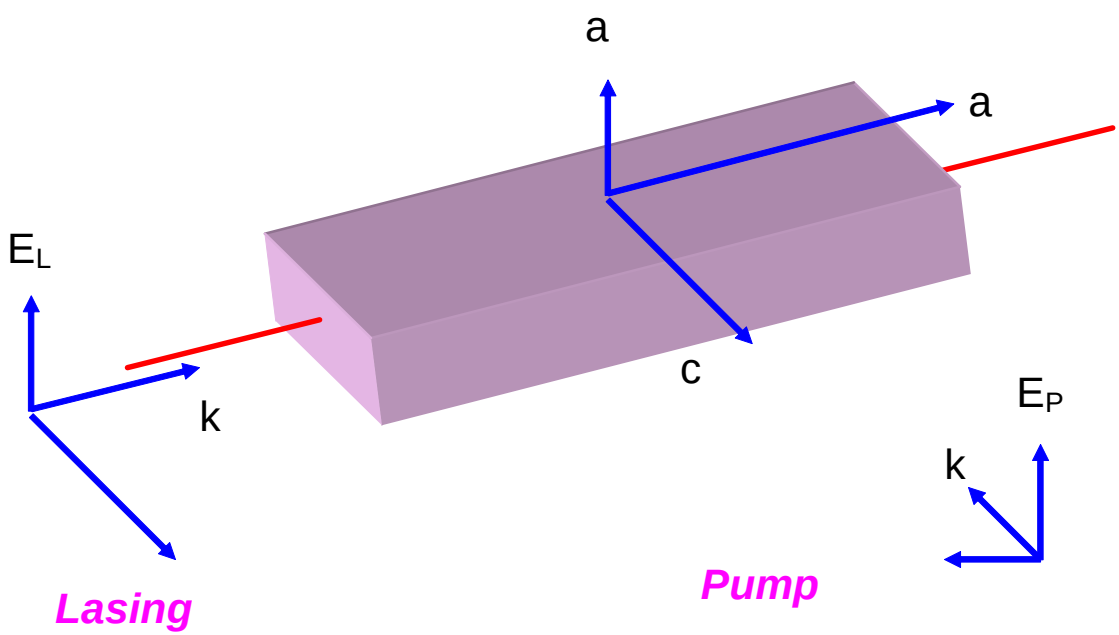
- General case:
  - Tm:YLF can be pumped by the radiation of any laser or laser diode emitting in the ~ 680 nm, ~ 790 nm, ~ 1200 nm or ~1700-nm ranges.

- This work:

Pump laser	Wavelength, nm	CW power, W
Lensed diode bar (Coherent, Inc.)	790	up to 40

Qpeak
APPLIED PHOTONIC SYSTEMS

Laser Element Design – Tm:YLF



Lasing: E_L || a – σ-polarization
Pump: E_P || a – σ-polarization

Qpeak
APPLIED PHOTONIC SYSTEMS

Theoretical Model

Cross-section determination - reciprocity method:

$$\sigma_{em(}\nu) = \sigma_{abs}(\nu)\ (\ Z_l/Z_u\ )\ exp\ [\ (E_{ZL} - h\nu) / kT\ ]$$

(Based on S.A.Payne et al. IEEE J. of QE, 28, 2619-2630 (1992)).

The net gain coefficient:

$$g(\nu) = N\ [\ p\ \sigma_{em}(\nu) - (1\text{-}p)\ \sigma_{abs}(\nu)\ ]$$

Definitions:

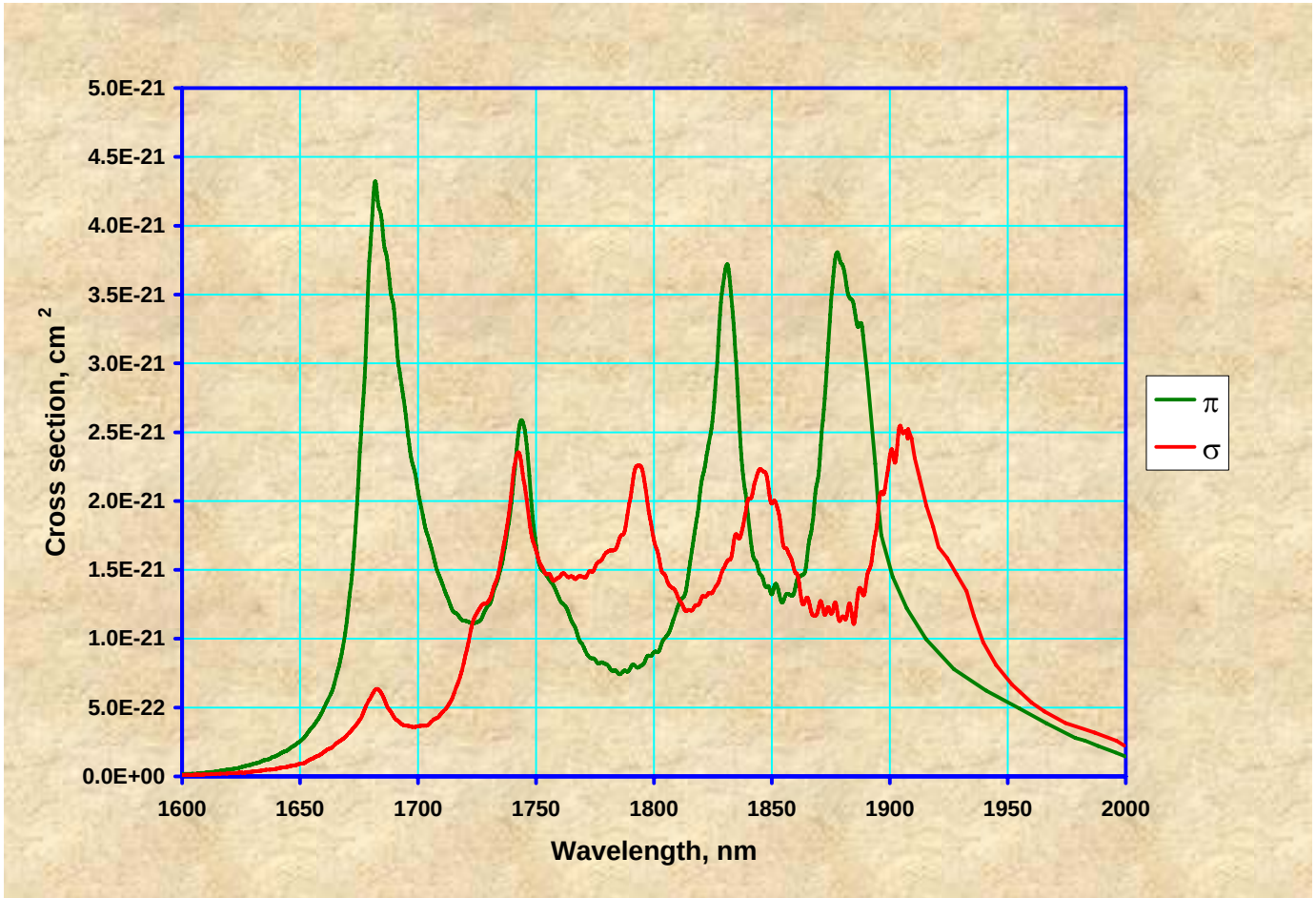
Z_l, Z_u – partition functions for upper (u) and lower (l) states,
E_{ZL} – zero-“phonon” line.
p – inversion fraction,
N – Tm^{3+} concentration

Table. *Values for 3.5% Tm:YLF used in the calculations*

Z_l / Z_u	1.51
E_{ZL}	5600 cm^{-1}
N	4.89×10^{20} cm^{-3}

Qpeak APPLIED PHOTONIC SYSTEMS

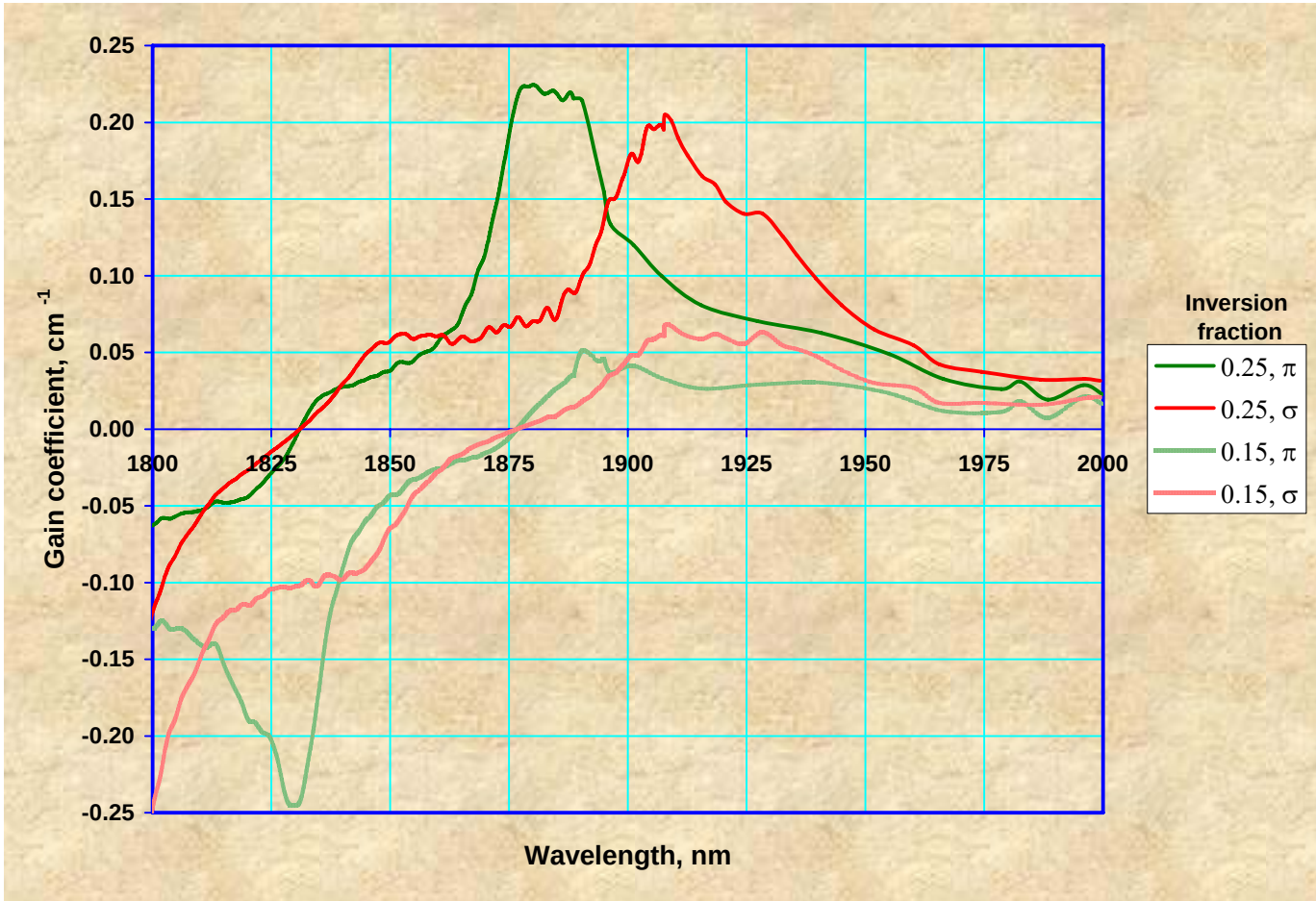
Emission Cross-Section – 3.5% Tm:YLF



Polarized emission cross-section $^3F_4 \rightarrow {}^3H_6$ for Tm:YLF (calculated from absorption spectra).

Qpeak APPLIED PHOTONIC SYSTEMS

Gain Calculation – 3.5% Tm:YLF

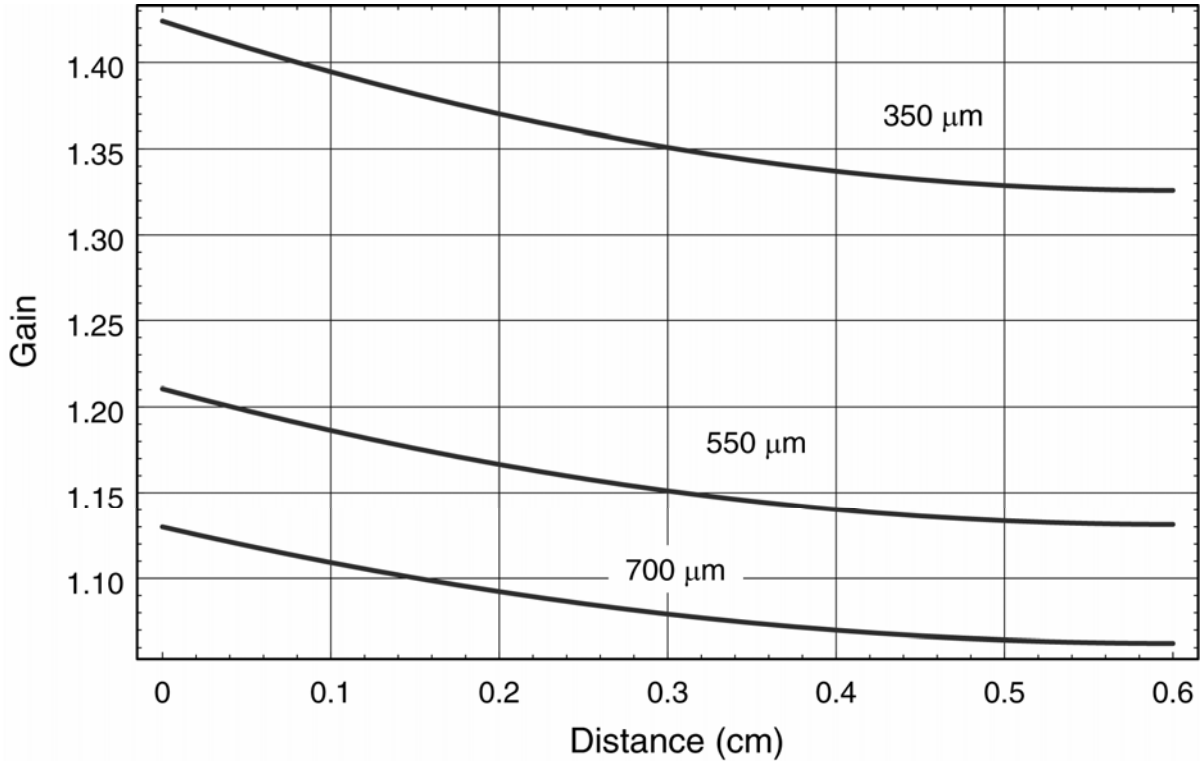


Polarized gain in Tm:YLF at two values of inversion fraction

$$g(\lambda) = N\,[\,p\cdot\sigma_{em}(\lambda) - (1-p)\cdot\sigma_{abs}(\lambda)\,],$$

where p – inversion fraction, N - Tm-concentration

Gain Calculation – 3.5% Tm:YLF Slab
Spatial Distribution



Calculations include:

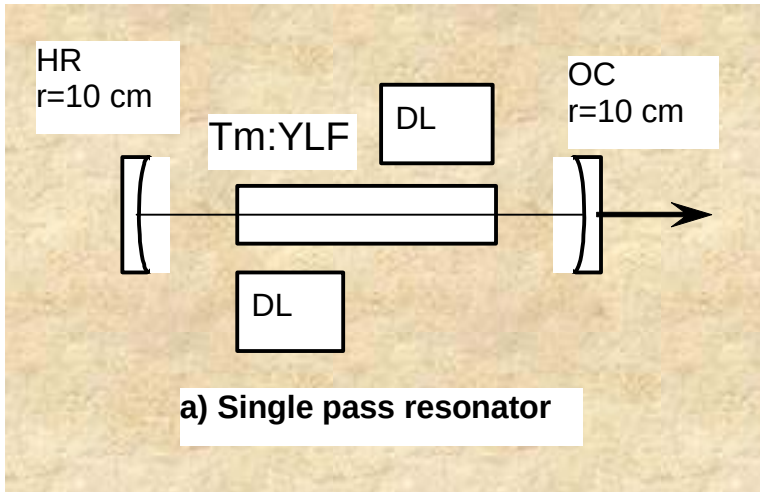
- Pump double passing
- Cross-relaxation
- One pump diode laser operated at 40 W at ~ 790 nm

Result:

All parts of the slab show gain

Qpeak
APPLIED PHOTONIC SYSTEMS

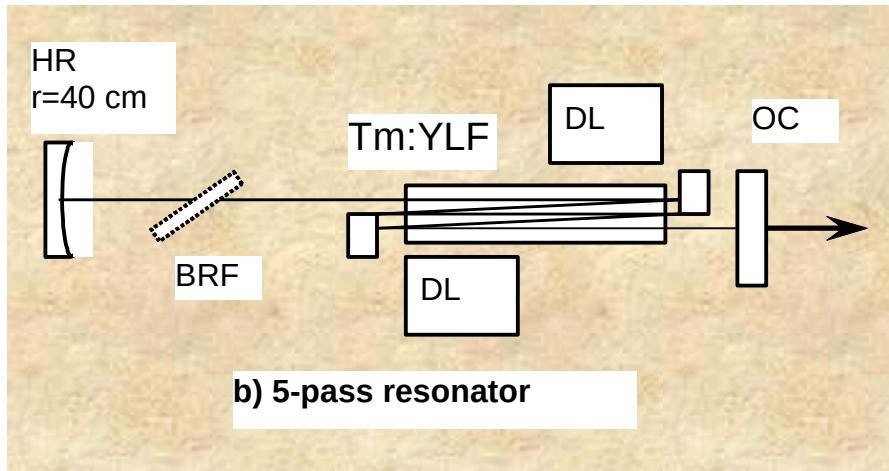
Experimental Set-Up



a) Single pass resonator

- **Tm:YLF Active Element:**

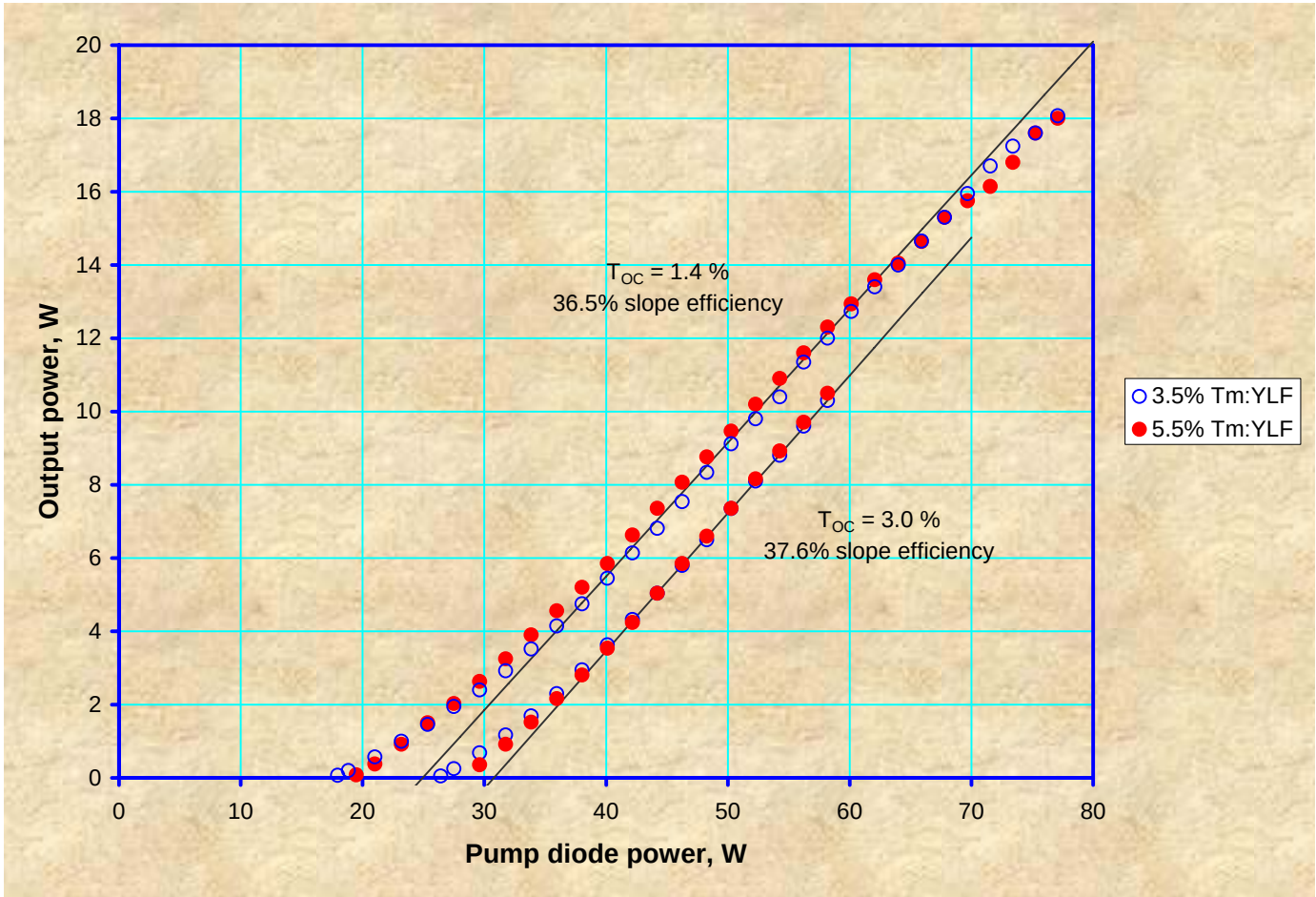
Rectangular slab:
22-mm long
Clear aperture 2.5x6 mm.



b) 5-pass resonator

Qpeak
APPLIED PHOTONIC SYSTEMS

Tm:YLF CW Laser Operation
Single Pass Geometry

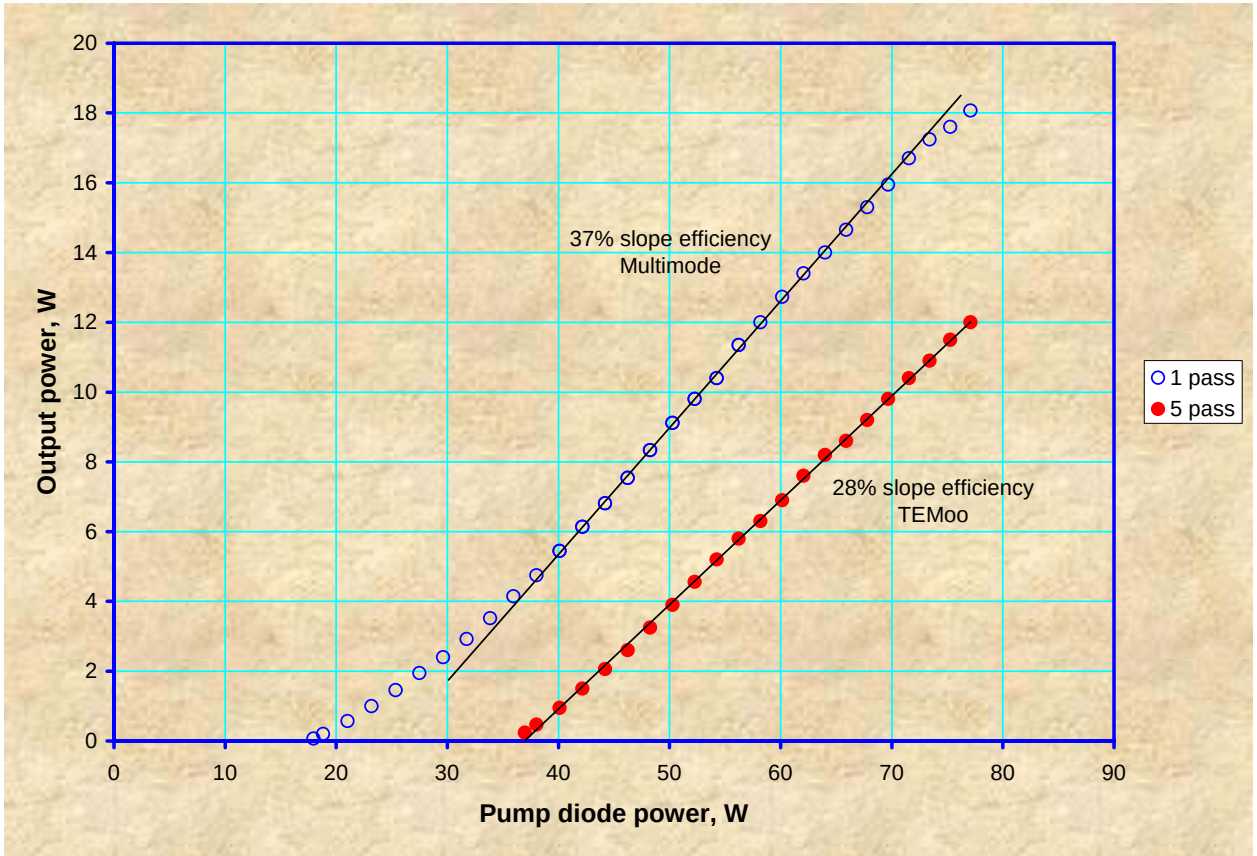


Nearly-confocal resonator:

HR mirror:	~ 1800-2000 nm
Output coupling:	R ~ 1.4% and 3.0% at ~2000 nm
Length:	13 cm

Qpeak APPLIED PHOTONIC SYSTEMS

Tm:YLF CW Laser Operation
Five-Pass Geometry

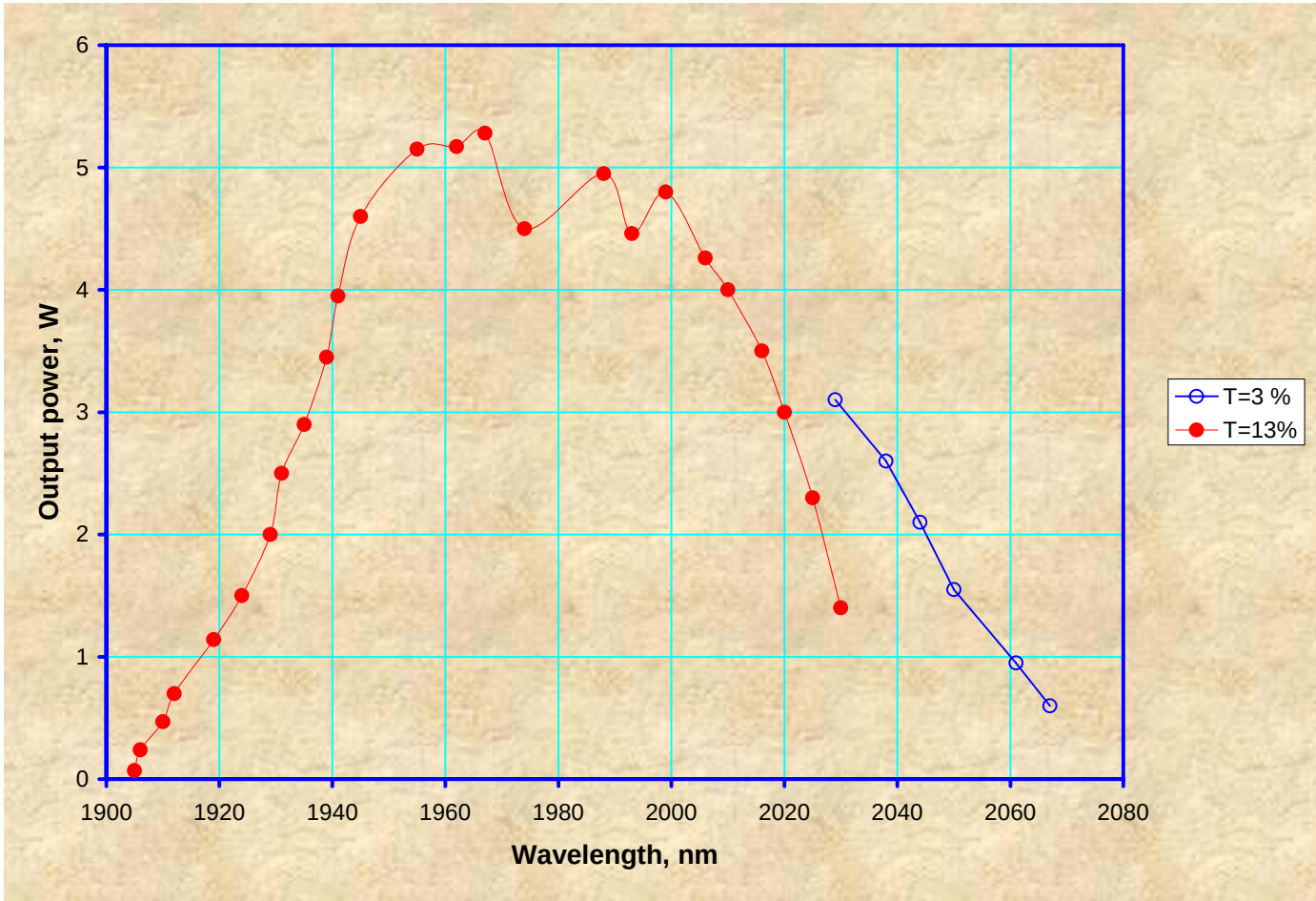


	1 pass	5 pass
HR mirror	1800-2000 nm	
Output coupling	R ~ 1.4% at ~ 2000 nm	R ~ 13-14% at 1850-2020 nm
Resonator length	13 cm	35 cm

Resonator properties

Qpeak APPLIED PHOTONIC SYSTEMS

Tm:YLF CW Laser Operation
Wavelength tuning



Qpeak APPLIED PHOTONIC SYSTEMS

Wavelength tuning of Tm:YLF laser with a 2-plate birefringent filter (TEM_{oo} operation) for two values of output coupler transmission.

Conclusions

Development of an efficient side-pumped CW Tm:YLF laser:

- First demonstration (to the best of our knowledge) of a CW side- pumped 2-μm Tm:YLF laser
- Wide tuning range: 1905-2067 nm (up to10 W)
- Record output CW power for a side-pumped laser ~ 18 W multimode and 12 W TEM_{00}

Qpeak APPLIED PHOTONIC SYSTEMS