
High-power, high-energy Ho:YLF laser pumped with Tm:fiber laser

Alex Dergachev, Peter F. Moulton

Q-Peak, Inc.

135 South Road, Bedford, Massachusetts 01730

E-mail: dergachev@qpeak.com

Thomas E. Drake

Lockheed Martin Aeronautics Company

One Lockheed Blvd. MZ 6852 Bldg.4 22C, Fort Worth, TX 76108



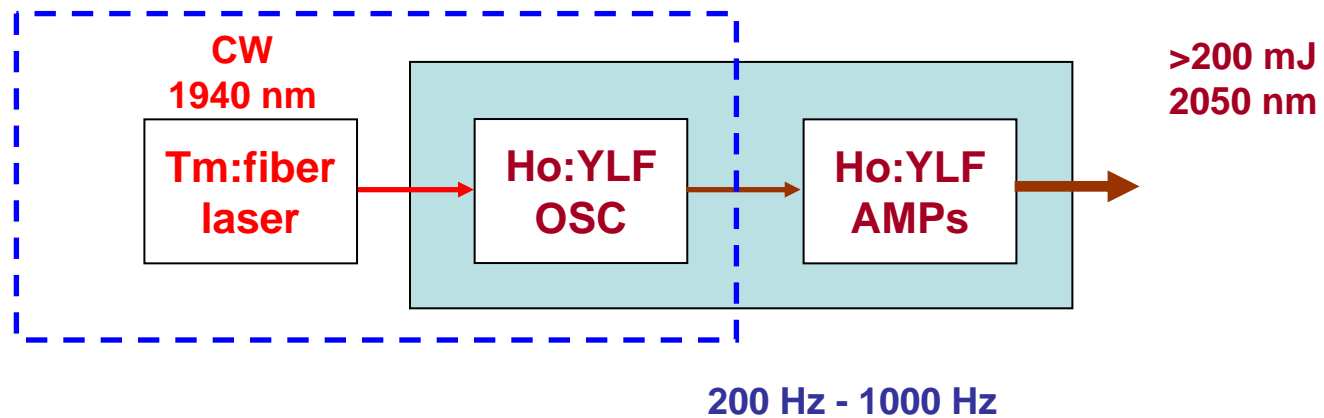
Outline

- Motivation
- Previous Results
- Tm: fiber Laser - Details
- Ho: YLF Laser – Details
- Conclusions

Motivation

□ Development of a 2-um laser source:

- High-energy (> 200 mJ)
- High repetition rate (200-1000 Hz)
- High beam quality (TEM₀₀)



□ Immediate applications:

- Pump source for OPOs
- Industrial
- Military

Advantages of Tm-pumped Ho-laser

- **Compared to diode-pumped Tm, Ho-co-doped laser:**
 - **Eliminates upconversion from Tm-Ho interaction that reduces efficiency and creates additional heating in crystal**
 - **Eliminates energy sharing between Tm and Ho that limits energy extraction in Q-switched mode**

- **Compared to direct-diode-pumped Ho-laser**
 - **Can operate at much higher power due to the availability of high-power Tm-lasers**

Previous results – Ho-lasers

□ Tm:YLF pumped Ho:YAG

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).

- Tm:YLF pump
 - 36 W CW output at 1907 nm (σ -line)
 - Multimode, $M^2 \sim 2$
- Ho:YAG
 - CW: 19 W
 - QS: 16 W at 15 kHz

□ Tm:YLF pumped Ho:YLF

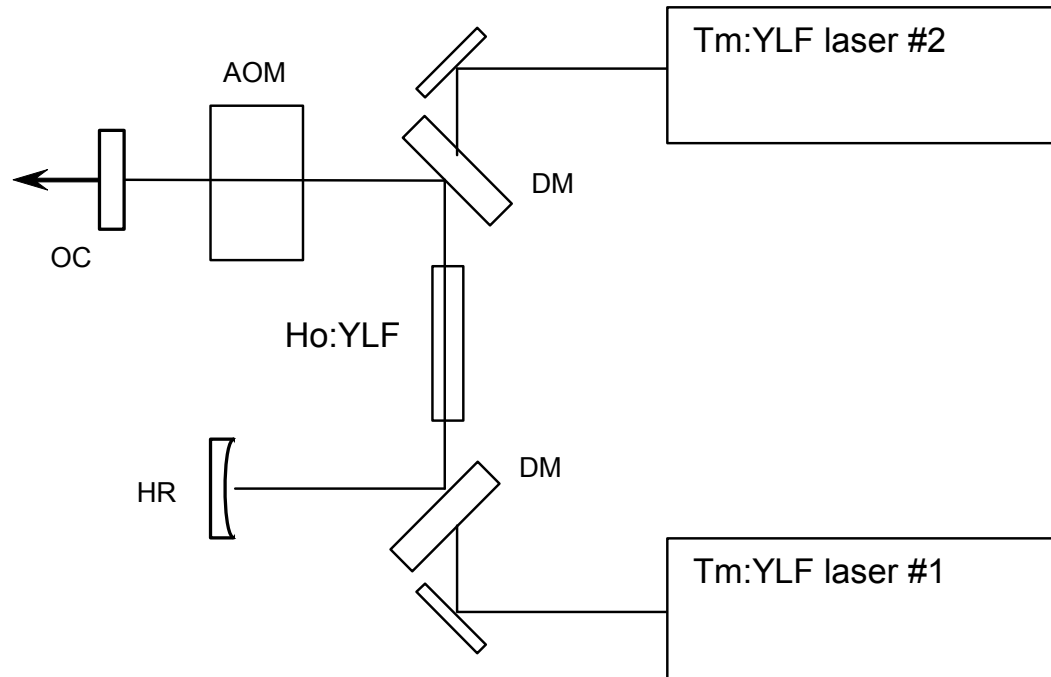
A. Dergachev, P.F.Moulton, "High-power, high-energy diode-pumped Tm:YLF-Ho:YLF-ZGP laser system", OSA TOPS Vol. 83, ASSP, (OSA, 2003), pp. 137-141

- Tm:YLF pump
 - 2 x ~25 W CW output at 1940 nm (σ -line)
 - $M^2 \sim 1.05 \times 7$
- Ho:YLF
 - CW: 21 W
 - QS: 16 W at 1 kHz

□ Ho-lasers pumped with Tm: fiber lasers:

- NASA (Ho:YLF)
- BAE Systems (Ho:YAG)
- ORC, Univ. of Southampton (Ho:YAG)

End-pumped Ho:YLF laser – Q-Peak' Prior Results



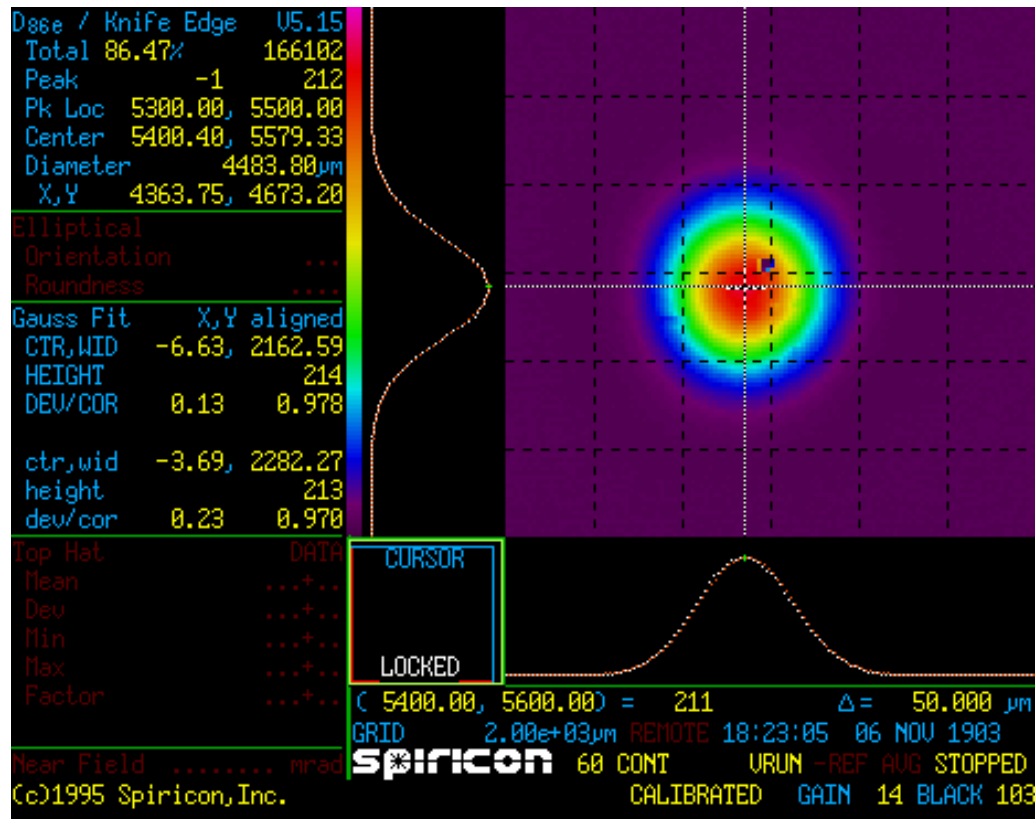
DM – Dichroic Mirror,
AOM – Acousto-Optic Modulator,
OC – Output Coupler,
HR – High Reflector

Ho:YLF Laser Operation (TEM₀₀) – Prior results

CW output: 21 W
(max)

Pulse energy (max):
 100 Hz 35 mJ
 400 Hz 27 mJ

Pulsewidth:
 100 Hz 12 ns
 400 Hz 15 ns



Ho-laser Power Scaling

- Cw Tm: fiber lasers with output >100 W emerge as alternative to bulk Tm-laser:
 - Turn key operation
 - Cost-effective
 - Maintenance-free
 - Fiber delivery (no surprise!)

Ho:YLF vs Ho:YAG

□ Why Ho:YLF?

- Long upper laser level lifetime ~ 15 ms
- Higher emission cross-section
- Naturally birefringent material
- Low dn/dT → weak thermal lensing
- ~5% quantum defect

□ Ho:YAG

- Isotropic
- Lifetime (5I_7) 7 ms
- Strong thermal lensing
- Excellent thermo-mechanical properties
- ~10% quantum defect

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:

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

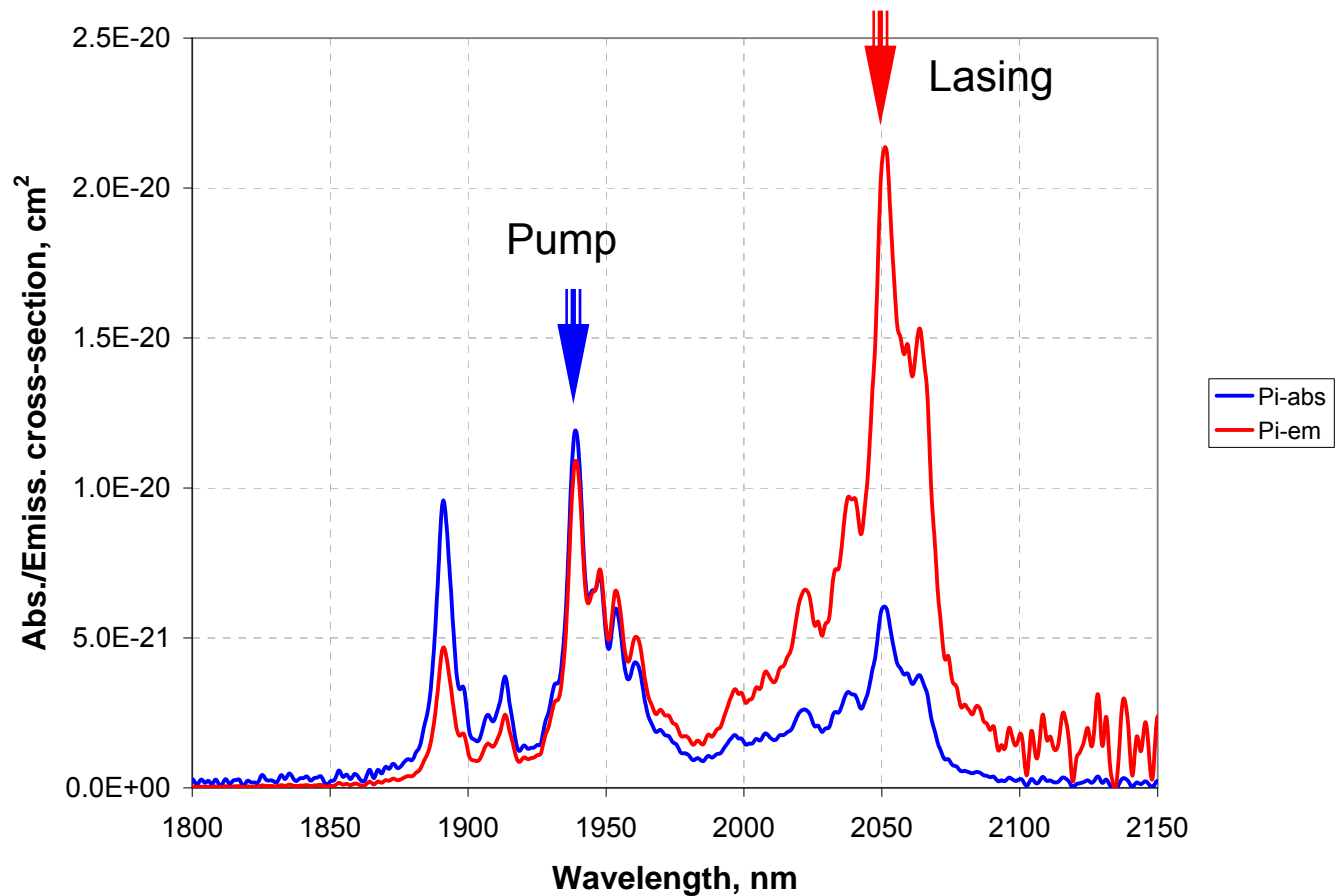
Definitions:

- Z_l, Z_u – partition functions for upper (u) and lower (l) states,
- E_{ZL} – zero-“phonon” line.
- ρ – inversion fraction,
- N – Ho³⁺ concentration

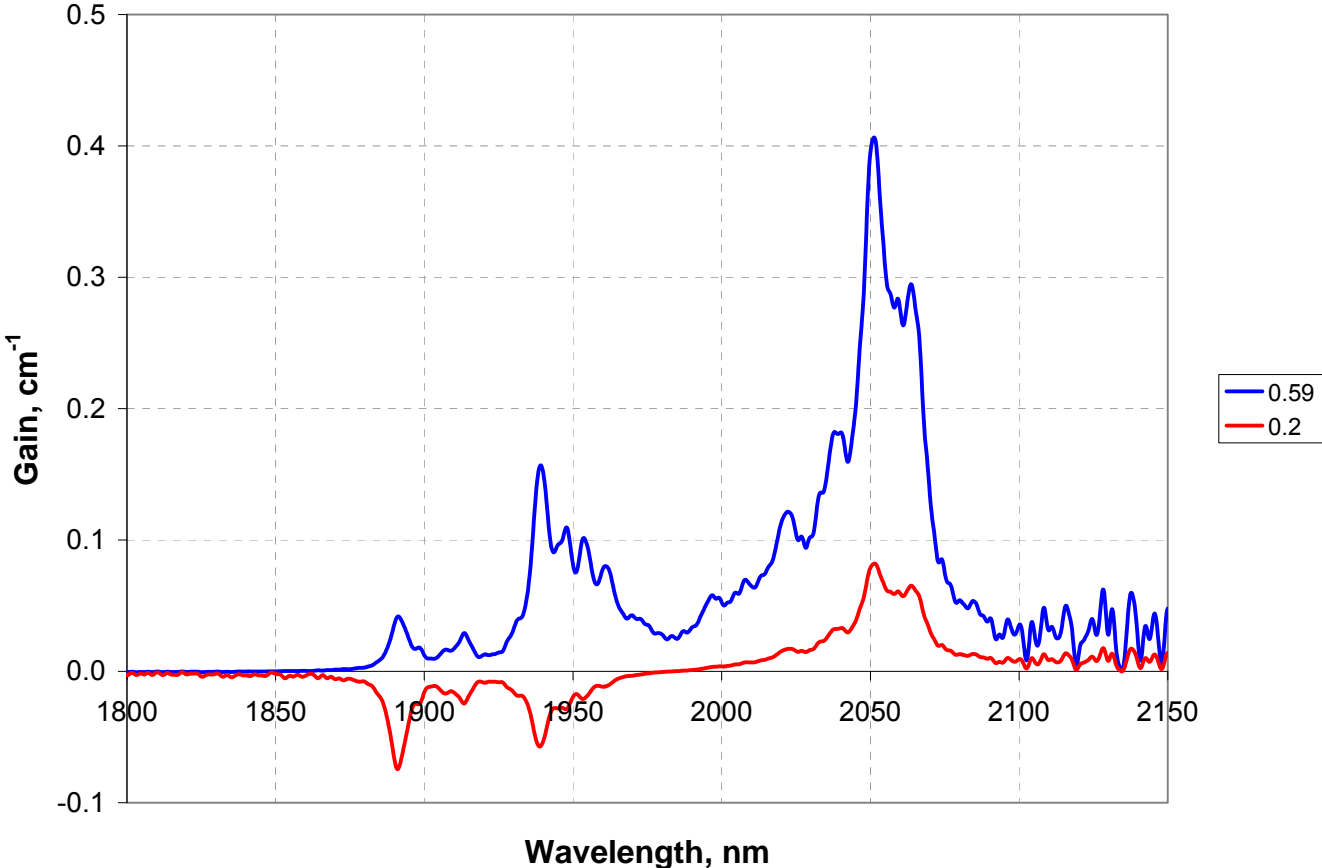
Table. Values for 0.5% Ho:YLF used in the calculations

Z_l/Z_u	0.81
E_{ZL}	5153 cm ⁻¹
N	7x10 ¹⁹ cm ⁻³

Ho:YLF – Absorption/ Emission



Ho:YLF – Calculated Gain



Tm-Laser Requirements and Characteristics

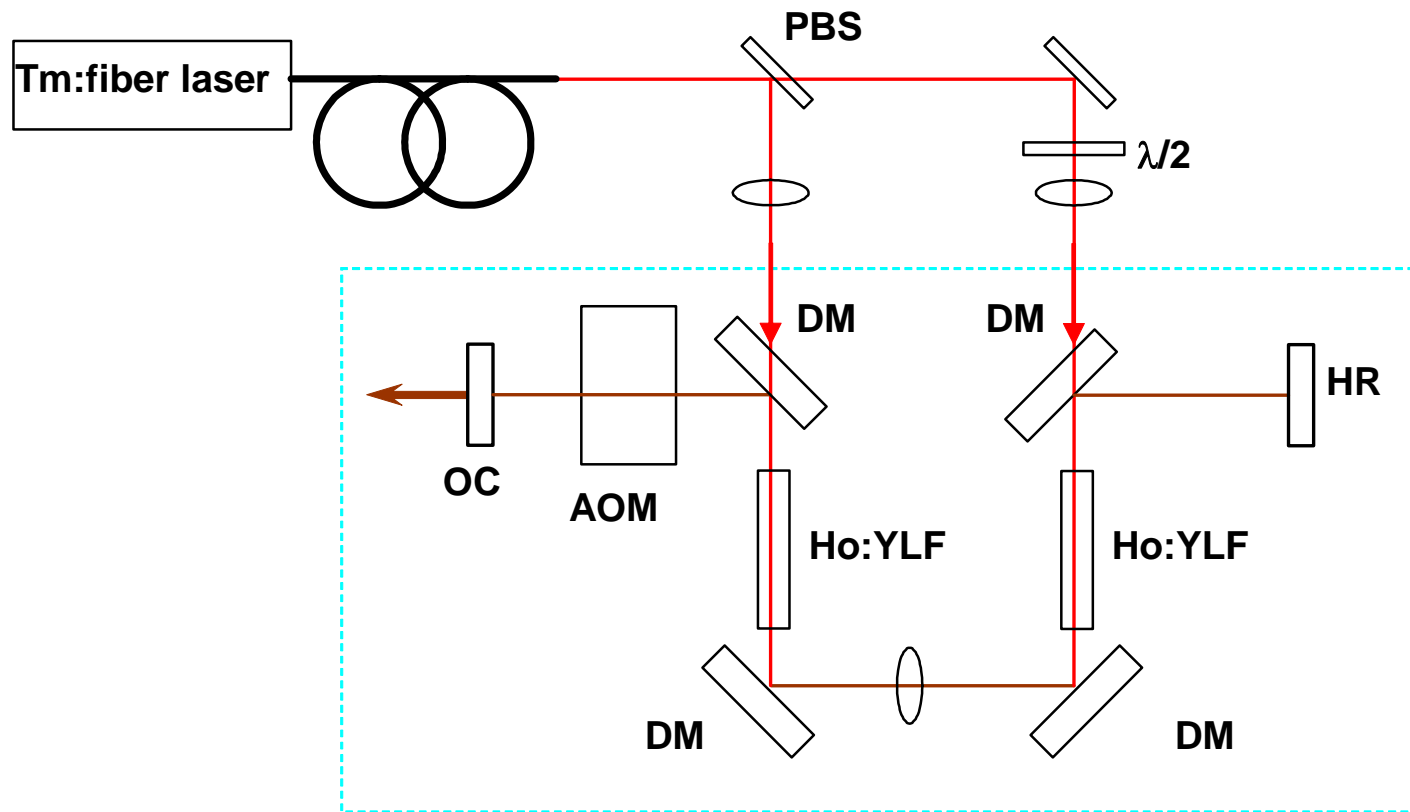
Specific requirements for Tm-laser as a pump source for Ho:YLF:

- Linear polarization (preferably)
- Lasing wavelength at ~ 1940 nm
- Linewidth < 6 nm

Tm-fiber laser TLR-100-1940
(IPG Photonics, www.ipgphotonics.com)

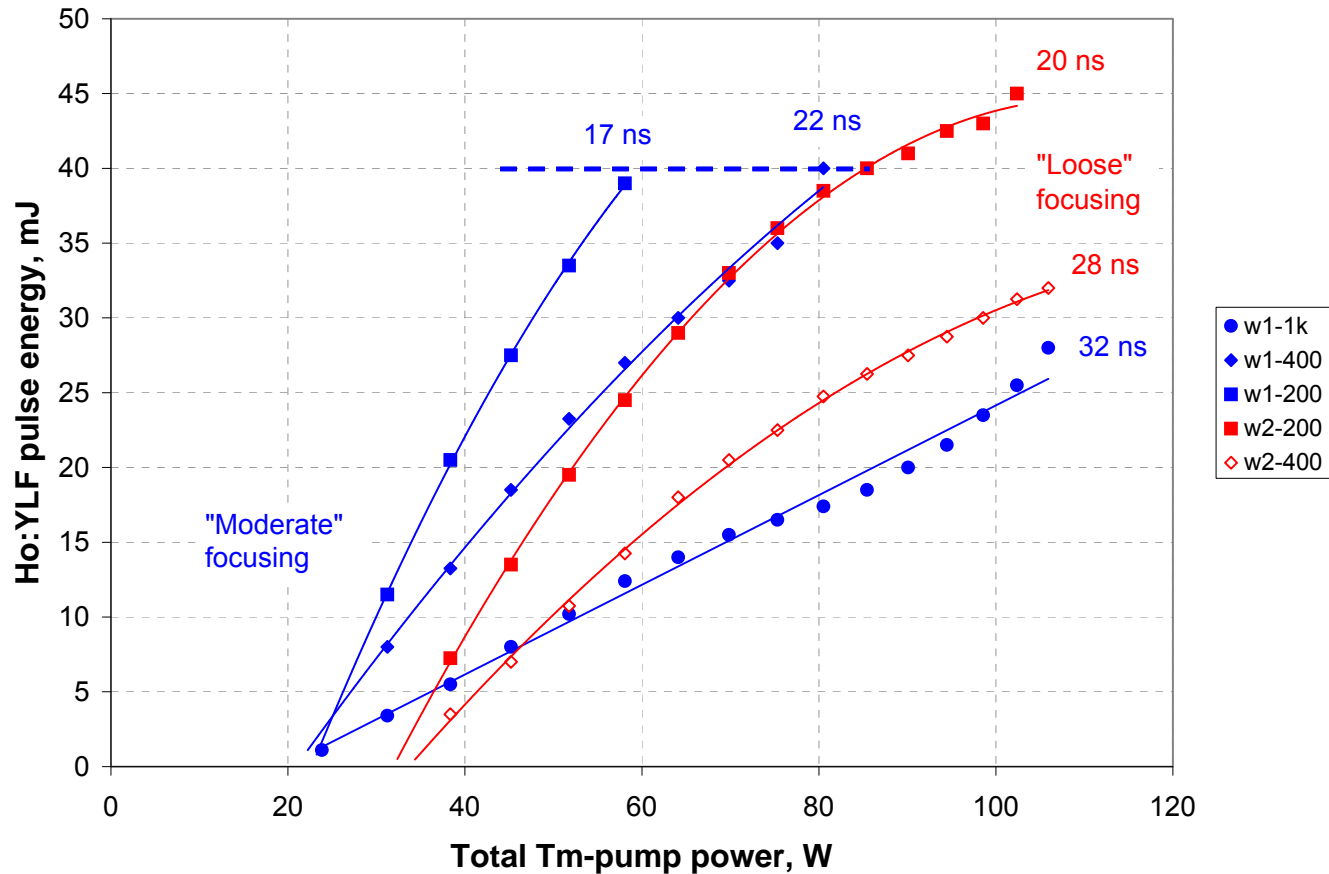
Operation regime	CW
Operational temperature	RT
Output power	≥ 100 W
Lasing wavelength range:	1750-2200 nm
Polarization:	Random
Linewidth	≤ 2 nm

Schematic layout of the end-pumped Ho:YLF laser



DM – Dichroic Mirror,
AOM – Acousto-Optic Modulator,
OC – Output Coupler,
HR – High Reflector

Ho:YLF Laser – Pulse Energy



Conclusions

Development of an efficient cw-pumped 2-um Ho:YLF laser:

- ❑ Highest (to the best of our knowledge) CW output of 43 W
- ❑ Efficient Q-switched operation (up to 45 mJ per pulse)
- ❑ Repetition rates in wide range (Hz to kHz), particularly, in 100-1000 Hz
- ❑ High beam quality (TEM₀₀ beam)