Diode-pumped, High-Power Nd:YLF and Nd:YVO$_4$ Lasers

D. Lee, K.J. Snell, J.G. Manni, K.F. Wall, Y. Isyanova and P.F. Moulton

8 June, 2000
Albuquerque, NM
Outline

- Laser materials choices
- Basic Nd:YLF laser design and performance
- Basic Nd:YVO₄ laser design and performance
- MOPA systems
- Applications
# Three Nd Laser Hosts As Choices

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Wavelength (nm)</th>
<th>Gain cross section (10-19 cm²)</th>
<th>Lifetime (µs)</th>
<th>Peak absorption (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG</td>
<td>1065</td>
<td>3.3</td>
<td>240</td>
<td>10</td>
</tr>
<tr>
<td>YLF (π)</td>
<td>1047</td>
<td>1.9-2.3</td>
<td>480-520</td>
<td>11</td>
</tr>
<tr>
<td>YLF (σ)</td>
<td>1053</td>
<td>π / 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YVO4 (π)</td>
<td>1064</td>
<td>9.8-15.6</td>
<td>97</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Thermal conductivity (W/m K)</th>
<th>Expansion coeff. (10-6)</th>
<th>Thermal shock (W/m)</th>
<th>dn/dT (10-6)</th>
<th>Lensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG</td>
<td>13</td>
<td>6.7</td>
<td>1450</td>
<td>+7.3</td>
<td>moderate</td>
</tr>
<tr>
<td>YLF</td>
<td>5.8 (c)</td>
<td>8 (c)</td>
<td>240</td>
<td>-4.3 (e)</td>
<td>weak</td>
</tr>
<tr>
<td></td>
<td>7.2 (a)</td>
<td>13(a)</td>
<td></td>
<td>-2.0 (o)</td>
<td></td>
</tr>
<tr>
<td>YVO4</td>
<td>5.2</td>
<td>7.3 (a)</td>
<td>?</td>
<td>+2.9 (e)</td>
<td>strong</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?? (c)</td>
<td></td>
<td>+8.5 (o)</td>
<td></td>
</tr>
</tbody>
</table>
MPS Pumping Design

- Diode laser
- Cylinder lens
- Laser beam
- Pump beam
- Nd:YLF Laser crystal
- Diode laser
MPS gain module with resonator (MPS-1047)
Production data on MPS gain module

Average: 12.1 W  
Median: 12.1 W  
Standard deviation: 0.9 W
MPS Q-switching produces high powers

- MPS-E
- MPS

- Peak Power
  - 1 MW
  - 100 kW
  - 10 kW
  - 1 kW

- Pulse rate (Hz)
  - 100
  - 1000
  - 10000
  - 100000
CW oscillator performance scales upward
TEM preperties are power-independent.
Q-switched average power is nearly doubled with 50% more pump power.

![Graph showing the relationship between Pulse rate (kHz) and Average power (W)].

- **63 W**
- **40 W**

Legend:
- ▲ 63 W
- □ 40 W
Higher gain yields shorter pulses

- **Pulsewidth (ns)** vs. **Pulse rate (kHz)**

- **40 W** (purple squares)
- **63 W** (red triangles)

- **Pump power**

Peak power is increased at high PRR.
High-power, MPV (Nd:YVO₄) gain module
• 1064 nm, >15 W multimode, >13 W TEM\textsubscript{00}, 46.3% slope, 35.0% optical and 13% electrical efficiency.
• 1342 nm, >6 W TEM\textsubscript{00}, 26% slope, 15% optical and 6% electrical efficiency.
- Gain of 17 with 27 mW input at a pump power of 38.7 W. 3-pass small signal gain >30 based on later single-pass measurements.
MPS and MPV pulsewidth vs. rate

- MPS
- MPV
MPS MOPA system #2 generates 50 W cw

Two-module Nd:YLF Oscillator

EO Q-switch

50 W CW
40 W Q-Sw @ 5 kHz
14-ns pulsewidth

2nd Stage Amplifier

Cylinder lens

1st Stage Amplifier

Cylinder lens
MOPA design allows scaling to 60 W cw

(20-W pump lasers)

Q-Switched, Nd:YLF, Master Oscillator

Gain Module

AO Q Switch

Relay Optics

Mirrors

50 W QS @ 5 kHz

60 W cw
MOPA generates 54 W cw with one amplifier

(40-W pump lasers)

54 W cw with 128 W total pump
$M^2 \approx 1.1$
• 5 Gain Modules; 1 Oscillator, 4 Power Amplifiers. Same design for both 1064 nm and 1342 nm.
• Relay-imaged between master oscillator and amplifiers to preserve optimum beam size throughout the MOPA chain.
1064 nm
• Outputs CW/Q-Switched @ 50 kHz
  Oscillator:  11.4 W /10.5 W, 10 ns FWHM
  Output:  53.5 W / 50.7 W, 10 ns FWHM, 1.01 mJ/pulse
  101.4 kW Peak
• 200 W pump power → >25% optical, >10% electrical efficiency.

1342 nm
• Outputs CW/Q-switched @ 50 kHz
  Oscillator:  11 W /9.6 W, 22 ns FWHM (Double crystal)
  Output:  26.5 W / 25.0 W, 22 ns FWHM, 0.5 mJ/pulse
  23 kW Peak
• 240 W pump power → 10.4% optical, 4% electrical efficiency.
Nd:YLF harmonic conversion generates high visible, UV powers (with Ushio)

SHG (523.5 nm):
30 W at 67 kHz
and 60-68% conversion in LBO

3HG (349 nm):
6 W at 10 kHz (30%)
15 W at 5 kHz in LBO

4HG (262 nm):
10 W at 5 kHz with CLBO
2.5 W at 10 kHz in BBO

5HG (207 nm):
2 W (internal)
at 5 kHz with CLBO
MPS-based 349-nm commercial product

Nd:YLF Oscillator

A/O QS

1047 nm 10 Watt

Amplifier Gain Module

1047 nm 20 Watt

SHG LBO

1047 nm 10 Watt

THG LBO

1047 nm 523 nm 10 Watt

349 nm 6 Watt

1047 nm

and

523 nm
Schematic of RGB OPO

Singly Resonant OPO

Pump 524 nm

Type-I OPO LBO

Signal 898 nm + Green 524 nm

Red 628 nm

f = 29 mm

Type-II SHG LBO

Idler 1256 nm

Intracavity SHG

SWP: HR@ 1256 nm; HT@ 524, 628, and 898 nm

Blue 449 nm

Walk-Off compensated Type-I SHG LBO

Signal 898 nm

LWP

Green 524 nm

SWP

Watt-level doubled OPO outputs at 10 kHz

Graph showing the relationship between Power (W) and Green power (W) for different wavelengths:
- **Signal** (squares)
- **Red** (diamonds)
- **Blue** (triangles)

The graph indicates a linear increase in Power with increasing Green power, with different slopes for each wavelength.
IR parametric oscillator systems

Intracavity OPO

- 1 W output at 1507 nm
- 12.5 kHz PRR
- 6 ns pulsewidth

Gain module
- AO Q-switch
- Nd:YLF slab
- Diode Laser bar
- KTA 25 mm

External OPO

- 43% conversion to 1507 nm
- 5 kHz PRR

Pump power (W)
Signal power (W)

KTA 75 mm
Tuning curve for MPS-driven KTA OPO

Power (W) vs. Wavelength (um)
Tandem OPO design gives full IR coverage

Results to date:
(At 4 kHz pulse rate, 30-W pump power)

- KTA signal at 1514 nm: 6.5 W
- KTA idler at 3450 nm: 5 W
- CdSe signal at 5120 nm: threshold
- CdSe idler at 10570 nm: threshold
MPS modules amplify a mode-locked laser

0.7 W, 4.5 ps @100 MHz

TBW Oscillator

Amplifier Gain Module

(Modules pumped by 20-W bars)
Amplified ML laser converts efficiently

Amplified ML laser → NCPM LBO → CPM CLBO

Second Harmonic Crystal

15.0 W at 1047 nm
M² < 1.1

Fourth Harmonic Crystal

8.4 W at 523.5 nm
M² < 1.1

2.9 W at 262 nm
MPV amplifies a micro-chip laser

3 mW at 2 kHz, 400 ps pulsewidth

Nd:YAG / Cr:YAG microchip laser at 1064 nm

Faraday rotator

HR mirror

650 mW

MPV gain module

NCPM LBO SHG

390 mW, 2 kHz PRR at 532 nm
Side-pumped Nd:YLF MPS and Nd:YVO₄ MPV designs combine simplicity, scalability of side pumping with the high-efficiency, TEM₀₀-mode performance of fiber-coupled, end-pumping designs.

Recent availability of 40-W bars has more than doubled the output of MPS Nd:YLF “gain module” to > 25 W and increased peak power at high pulse rates. Nd:YVO₄ performance may improve as well, but strong thermal lensing will be a challenge.

CW-pumped, Q-switched systems can efficiently drive nonlinear optics to generate tunable, vis-UV and IR wavelengths.

Systems designers should consider cw-diode-pumped systems instead of pulsed-pumped systems for cost and reliability reasons.