Short-pulse, high-repetition rate, high-power Nd:YLF MOPA system

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Outline

- Motivation
- Overview
- Approaches
- Short-Pulse Nd:YLF Oscillator
- Nd:YLF MOPA – Details
- Harmonic generation
- Conclusions
Motivation

- Develop a 0.5-µ laser source per following specifications:
  - > 30 W \textit{average power}
  - 30-100 kHz \textit{high repetition rate}
  - <15 ns at 50 kHz \textit{short pulse}
  - TEM$_{oo}$ \textit{high beam quality}

- Reliable, stable design
Q-Peak’ MPS-523 QS20H Typical Laser Parameters

MPS-523 QS20H system (2 gain modules):
MPS-1047 QS10H oscillator (TEM$_{00}$) + 1 Amp

- **Power:**
  - ~ 45 W IR
  - ~ 25 W Green
  - > 55 % Conversion efficiency

- **Repetition rate:**
  - 10-30 kHz

- **Pulsewidth:**
  - 10 kHz ~ 30 ns
  - 20 kHz ~ 50 ns
  - 30 kHz ~ 75 ns

  *too long !!!*

Osc multi-pass design and the need to establish a large cavity mode size lead to a relatively long cavity -> longer pulse
How to get there?

Power consideration:
> 30 W green \(\downarrow\) SHG \(\downarrow\) ~50% eff. \(\downarrow\) ~60 W at 1 \(\mu\)

- Power oscillator: > 60 W ???
  - Short pulses ???
- MOPA ???
- Laser material ???
### Commercial TEM$_{00}$ IR/Green systems – Some examples

<table>
<thead>
<tr>
<th></th>
<th>Max. Power, W</th>
<th>Pulsewidth, ns</th>
<th>Rep.rate, kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coherent</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vector 1064-3000-30</td>
<td>1064 nm</td>
<td>&gt; 3 W at 30 kHz</td>
<td>&lt; 15 ns (30 kHz)</td>
</tr>
<tr>
<td><strong>Coherent</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vector 1064-3000-150</td>
<td>1064 nm</td>
<td>&gt; 3 W at 150 kHz</td>
<td>~ 100 ns (150 kHz)</td>
</tr>
<tr>
<td><strong>Lightwave Electronics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q202-SM</td>
<td>532 nm</td>
<td>&gt;18W at 80 kHz</td>
<td>280 at 80 kHz</td>
</tr>
<tr>
<td><strong>SpectraPhysics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIPPO Series</td>
<td>1064 nm, 532 nm</td>
<td>17 W, 11 W</td>
<td>&lt; 13 ns at 50 kHz</td>
</tr>
</tbody>
</table>
Achieving High Power and Short Pulses at > 30 kHz

Nd:YVO$_4$ power oscillators? Nd:YVO$_4$ MOPA?

Higher gain than in Nd:YLF but:

- limited size of high-quality crystals
- strong, aberrated thermal lensing

$\Rightarrow$ challenges in scaling up to high powers
Our Preferred approach

Develop a Nd:YLF MOPA system:

- Number of MPS gain modules as amplifiers
- Low-power, end-pumped, short-cavity Q-switched laser as a master oscillator:
  - Defines the repetition rate and required pulsewidth
  - Desired average power (>500mW)

Nd:YLF material for the amplifiers:

- Low dn/dT:
  - very low thermal lens
  - easier power scaling by adding amplifiers
- Natural birefringence
  - no depolarization in amplifiers
Q-Peak’ MPS Gain Module

Typical performance in CW, TEM$_{00}$ mode either as:
- oscillator or
- amplifier (saturated)

<table>
<thead>
<tr>
<th></th>
<th>Early days</th>
<th>Nowadays (Standard)</th>
<th>Nowadays (advanced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode pump power, W</td>
<td>40</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>1-µ output, W</td>
<td>~ 12</td>
<td>~ 25</td>
<td>32</td>
</tr>
<tr>
<td>Absolute efficiency, %</td>
<td>30</td>
<td>38</td>
<td>40</td>
</tr>
</tbody>
</table>
Master Oscillator - Possible solutions

Short pulses can be generated in Nd:YLF !!!


- Buy a commercially available system

  Commercial laser: Lightwave Electronics® Model 110

  1047 nm, up to 400 mW, up to 100 kHz

<table>
<thead>
<tr>
<th></th>
<th>1 kHz</th>
<th>10 kHz</th>
<th>30 kHz</th>
<th>50 kHz</th>
<th>100 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsewidth, ns</td>
<td>&lt;5</td>
<td>8</td>
<td>26</td>
<td>39</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Pulse energy, uJ</td>
<td>&gt;100</td>
<td>40</td>
<td>11</td>
<td>6.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Power, mW</td>
<td>&gt;100</td>
<td>&lt;400</td>
<td>&lt;400</td>
<td>&lt;400</td>
<td>&lt;400</td>
</tr>
</tbody>
</table>

- Do it yourself
Short-Pulse Oscillator - Layout

- 4-W pump power at ~0.8 um
- > 1.5 W CW output at 1 um
- >20-mm long cavity
- Slab design -> good thermal management
- All elements are conductively cooled
1047-nm Short-Pulse Oscillator - Performance

- 1047 nm
- 1.3 W QS output
- 30-100 kHz
- TEM$_{00}$ ($M^2 < 1.1$)
Short-Pulse Nd:YLF MOPA

- Amp 1 (GM2): ~15 W
- Amp 2 (GM3): ~60 W
- Amp 3 (GM4): ~34 W
- Pre-amp (GM1): ~1 W
- Short-Pulse Osc: 30-100 kHz, 6.5-20 ns
- HR: ~80 W 1047 nm

Qpeak
APPLIED PHOTONIC SYSTEMS
SHG IN LBO

- IR Power
  - Up to 80 W
- LBO
  - 20-mm long
  - NCPM
  - 170 C
SHG in LBO

- ≤50 W at 523 nm
- ≤ 68% eff.
- 30-100 kHz
- TEM$_{00}$

Typical performance at 30 kHz
SHG Stability Measurement

42.1 (± 0.3) W
FHG IN CLBO - LAYOUT

- CLBO
  - 15-mm long
  - unmounted
  - 160°C
  - 2.5 years old

- Focusing:
  - Collimated beam - 18 MW/cm² max
  - Focused beam - 100 MW/cm² max
FHG in CLBO

- \( \leq 10 \) W at 262 nm
- \( \leq 33\% \) eff.
- 30 kHz
- TEM\(_{00}\)
THG IN LBO

- LBO
  - 20-mm long
  - Type II ($\theta=46^\circ$, $\phi=90^\circ$)
  - RT

Diagram:

```
IR MOPA → SHG → THG
```
Second and Third Harmonics Generation

Focusing in SHG and THG crystals optimized at 33 kHz

![Graph showing output power vs repetition rate for SHG and THG](image-url)
## TEM$_{00}$ UV systems

<table>
<thead>
<tr>
<th></th>
<th>Max. Power</th>
<th>Pulsewidth</th>
<th>Rep.rate, kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3$\omega$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>355 nm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coherent</strong></td>
<td>&gt; 10 W (50 kHz)</td>
<td>&lt; 30 ns (60 kHz)</td>
<td>0-100</td>
</tr>
<tr>
<td>Avia-X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coherent</strong></td>
<td>&gt; 0.5 W at 30 kHz</td>
<td>&lt; 10 ns (40 kHz)</td>
<td>0-100</td>
</tr>
<tr>
<td>Avia Ultra 355-500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lightwave</strong></td>
<td>&gt;10 at 10 kHz</td>
<td>34 at 10 kHz</td>
<td>10-30</td>
</tr>
<tr>
<td><strong>Electronics</strong></td>
<td>&gt; 8 at 30 kHz</td>
<td>80 at 30 kHz</td>
<td>30-70</td>
</tr>
<tr>
<td>Q30_-SM Series</td>
<td>&gt;6.5 at 70 kHz</td>
<td>135 at 70 kHz</td>
<td>70-130</td>
</tr>
<tr>
<td><strong>SpectraPhysics</strong></td>
<td>6 W</td>
<td>&lt; 13 ns at 50 kHz</td>
<td>15-100 kHz</td>
</tr>
<tr>
<td>HIPPO Series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4$\omega$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>266 nm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coherent</strong></td>
<td>&gt; 3 W (30 kHz)</td>
<td>&lt; 25 ns (30 kHz)</td>
<td>0-100</td>
</tr>
<tr>
<td>Avia 266-3000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SpectraPhysics</strong></td>
<td>2.5 W</td>
<td>&lt; 13 ns at 50 kHz</td>
<td>15-100 kHz</td>
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<td>HIPPO Series</td>
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# MOPA Parameters

<table>
<thead>
<tr>
<th></th>
<th>IR (1047 nm)</th>
<th>SHG (523 nm)</th>
<th>THG (355 nm)</th>
<th>FHG (262 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max average power</strong>, W</td>
<td><strong>80</strong></td>
<td><strong>50</strong></td>
<td><strong>25</strong></td>
<td><strong>10</strong></td>
</tr>
<tr>
<td><strong>Rep.rate, kHz</strong></td>
<td><strong>30-100</strong></td>
<td><strong>30-100</strong></td>
<td><strong>30-100</strong></td>
<td><strong>30-100</strong></td>
</tr>
<tr>
<td><strong>Pulsewidth, ns</strong></td>
<td><strong>8-20</strong></td>
<td>&lt; <strong>8-20</strong></td>
<td>&lt; <strong>8-20</strong></td>
<td>&lt; <strong>8-20</strong></td>
</tr>
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Conclusions

High power short-pulse Nd:YLF MOPA system:

- Diffraction limited beam
- Pulsewidth:
  - < 10 ns below 50 kHz
  - 10-20 ns at 50-100 kHz
- Up to 50 W of green power
- Up to 25 W of UV power at 349 nm
- Up to 10 W of UV power at 262 nm

Possible applications:

- High average/peak power green driver for nonlinear frequency conversion:
  - Harmonics, OPOs, Raman etc.
  - Pump for RGB systems
- High gain, modular, scalable 1047-nm (1053-nm) amplifier system:
  - CW or Q-switched
  - Single frequency