1-GW-Peak-Power, Cr:ZnSe Laser

Evgeni Slobodchikov,
Peter Moulton
Motivation

Goal:

development of practical femtosecond laser source in mid-infrared (2-5 μm) with high pulse energy output (0.1-1 mJ).

Recent advances:

high-power Tm:fiber lasers,
progress with quality of Cr$^{2+}$:ZnSe crystals.

Some of the applications:

Remote sensing,
Trace gas monitoring,
Medical applications,
Semiconductor spectroscopy.
<table>
<thead>
<tr>
<th>Crystal structure</th>
<th>Cubic</th>
<th>Uniaxial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>18 W/m°C</td>
<td>28 W/m°C</td>
</tr>
<tr>
<td>Thermooptics $dn/dT$</td>
<td>$70 \cdot 10^{-6}$ 1/ °C</td>
<td>$12 \cdot 10^{-6}$ 1/ °C</td>
</tr>
<tr>
<td>Third order nonlinearity $n_2$</td>
<td>$180 \cdot 10^{-20}$ m²/W at 1.6 µm*</td>
<td>$3 \cdot 10^{-20}$ m²/W</td>
</tr>
<tr>
<td>Two-photon absorption</td>
<td>band gap 2.83 eV</td>
<td>~8 eV</td>
</tr>
<tr>
<td>Second-order nonlinearity</td>
<td>very high: 30 pm/V</td>
<td>absent</td>
</tr>
<tr>
<td>Peak emission cross-section $\sigma_{em}$ at $\lambda_0$</td>
<td>$13 \cdot 10^{-19}$ cm² 2450 nm</td>
<td>$4.5 \cdot 10^{-19}$ cm² 780 nm</td>
</tr>
<tr>
<td>Fluorescence bandwidth $\Delta\lambda$</td>
<td>1000 nm (50 THz)</td>
<td>300 nm (130 THz)</td>
</tr>
<tr>
<td>Relative bandwidth $\Delta\lambda/\lambda_0$</td>
<td>0.49</td>
<td>0.57</td>
</tr>
<tr>
<td>Peak pump cross-section $\sigma_{abs}$ at $\lambda_{max}$</td>
<td>$11 \cdot 10^{-19}$ cm² 1780 nm</td>
<td>$0.65 \cdot 10^{-19}$ cm² 500 nm</td>
</tr>
<tr>
<td>Lifetime at room temp.</td>
<td>6 µs</td>
<td>3 µs</td>
</tr>
<tr>
<td>$l_{sat} = h\nu/\sigma_{em}\tau$</td>
<td>11 kW/cm²</td>
<td>210 kW/cm²</td>
</tr>
<tr>
<td>Direct diode pumping</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

*Note: *$n_2$ is the nonlinear coefficient, measured at 1.6 µm, and $\sigma_{em}$ is the emission cross-section at the peak emission wavelength $\lambda_0$. 
Femtosecond oscillator can be pumped by either diode, Er: or Tm:doped fiber lasers.

Due to short upper state life time (6 μs) the amplifier has to be pumped by high energy source.

Ho:YLF laser can be used as an energy storage:
- can be pumped by Tm:fiber laser
- 2.05 μm output is suited for high energy pumping of Cr:ZnSe with reduced thermal stress.
<table>
<thead>
<tr>
<th>Laser characteristics</th>
<th>Output parameter</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW, output power, W</td>
<td>15</td>
<td>IPG Photonics</td>
</tr>
<tr>
<td>CW, tuning range, nm</td>
<td>2000-3100</td>
<td>Sorokina et al., 2004</td>
</tr>
<tr>
<td>CW, efficiency, %</td>
<td>70</td>
<td>Mond et al., 2001</td>
</tr>
<tr>
<td>Pulsed, output power, W</td>
<td>18.5 @ 10 kHz</td>
<td>Carrig et al., 2004</td>
</tr>
<tr>
<td>Pulsed, output energy, mJ</td>
<td>14 @ 200 μs</td>
<td>Koranda et al., 2006</td>
</tr>
<tr>
<td>Pulsed, tuning range, nm</td>
<td>1880-3100</td>
<td>Demirbas et al., 2006</td>
</tr>
<tr>
<td>SBR mode-locked</td>
<td>80 fs @ 80 mW</td>
<td>Sorokina et al., 2007</td>
</tr>
</tbody>
</table>
Mid-IR fiber laser-pumped Cr:ZnSe CPA system

- Tm:fiber 1940-nm polarized laser
  - 4.6 W

- Cr:ZnSe ~2500 nm mode-locked laser
  - 150 fs, 2.3 nJ, 100 MHz

- CVBG Pulse stretcher
  - 150 fs → 300 ps

- 2050 nm Q-switched Ho:YLF laser
  - 40 W
  - 11 mJ, 20 ns pulses
  - 1 kHz PRR

- Cr:ZnSe regenerative amplifier
  - gain 6 x 10^5
  - 0.7 mJ pulses
  - 1 kHz PRR

- Grating pulse compressor
  - 2475 nm
  - 0.35 mJ pulses
  - 346 fs

CLEO 2011
Femtosecond oscillator

Tm:fiber laser

5% O.C.

sapphire

Cr:ZnSe

ROC = 100 mm

SESAM

ROC = 150 mm
Autocorrelation trace with a FWHM pulse duration of 130 fs.

The spectrum centered at 2530 nm with a FWHM of 50 nm.
Water absorption lines between 2.5 and 2.6 μm (red) and the output spectrum of Q-switched Cr:ZnSe laser (blue) without N₂ purging.

CLEO 2011
Sealed box with remote controls
Ho:YLF MOPA

Output power 11 W
Repetition rate 1 kHz
Pulse duration 20 ns

40 W
Tm: fiber laser

Graph: relationship between pump power and output power.

CLEO 2011
Regenerative amplifier

Ho:YLF
MOPA
\( \lambda = 2050 \text{ nm} \)
11 W (1kHz)

\( \text{Cr}^{2+}:\text{ZnSe} \)
Output
0.7 mJ

Seed
~300 ps
1.2 nJ

Output
0.7 mJ
Autocorrelation trace with a FWHM pulse duration of 346 fs.

The spectrum centered at 2475 nm with a FWHM of 37 nm.
Conclusions

• We have developed a 1 GW ultrafast mid-IR high power CPA laser system based on Cr:ZnSe crystals.

• Power scaling is possible with more powerful Ho:YLF lasers.

• Shorter pulses can be achieved with conventional grating stretcher-compressor pairs.
• The work was supported by a SBIR Phase II program from AFRL

• Q-Peak’s contributors: Yelena Isyanova, Sam Wong