Progress in ultrafast Cr:ZnSe Lasers

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Diode-pumped Cr:ZnSe femtosecond oscillator

CPA Cr:ZnSe laser system with 1 GW output

This work was supported by SBIR Phase II programs from AFRL and DoE
Motivation

Goals:

Development of a low-noise, mode-locked femtosecond laser source at 2.5 $\mu$m

Development of high-energy, high-peak-power femtosecond laser source at 2.5 $\mu$m

Some applications:

High-power amplifier seeding (for oscillator)
Mid-IR super-continuum generation
High-harmonic generation
### Ti:Sapphire of infrared, courtesy Sorokin(a)

<table>
<thead>
<tr>
<th></th>
<th><strong>Cr:ZnSe</strong></th>
<th><strong>Ti:Sapphire</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crystal structure</strong></td>
<td>Cubic</td>
<td>Uniaxial</td>
</tr>
<tr>
<td><strong>Thermal conductivity</strong></td>
<td>18 W/m°C</td>
<td>28 W/m°C</td>
</tr>
<tr>
<td><strong>Thermooptics $dn/dT$</strong></td>
<td>$70 \cdot 10^{-6}$ 1/ °C</td>
<td>$12 \cdot 10^{-6}$ 1/ °C</td>
</tr>
<tr>
<td><strong>Third order nonlinearity</strong></td>
<td>$180 \cdot 10^{-20}$ m²/W at 1.6 µm*)</td>
<td>$3 \cdot 10^{-20}$ m²/W</td>
</tr>
<tr>
<td><strong>Two-photon absorption</strong></td>
<td>band gap ~2.83 eV</td>
<td>~8 eV</td>
</tr>
<tr>
<td><strong>Second-order nonlinearity</strong></td>
<td>very high: 30 pm/V</td>
<td>absent</td>
</tr>
<tr>
<td><strong>Peak emission cross-section</strong></td>
<td>$\sigma_{em}$ at $\lambda_0$</td>
<td>$\sigma_{em}$ at $\lambda_0$</td>
</tr>
<tr>
<td></td>
<td>13 $\cdot 10^{-19}$ cm²</td>
<td>4.5 $\cdot 10^{-19}$ cm²</td>
</tr>
<tr>
<td></td>
<td>2450 nm</td>
<td>780 nm</td>
</tr>
<tr>
<td><strong>Fluorescence bandwidth</strong></td>
<td>1000 nm (50 THz)</td>
<td>300 nm (130 THz)</td>
</tr>
<tr>
<td><strong>Relative bandwidth</strong></td>
<td>0.49</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Lifetime at room temp.</strong></td>
<td>6 µs</td>
<td>3 µs</td>
</tr>
<tr>
<td>$E_{sat} = h\nu/\sigma_{em}$</td>
<td>0.06 J/cm²</td>
<td>0.6 J/cm²</td>
</tr>
<tr>
<td>$I_{sat} = h\nu/\sigma_{em}\tau$</td>
<td>11 kW/cm²</td>
<td>210 kW/cm²</td>
</tr>
<tr>
<td><strong>Direct diode pumping</strong></td>
<td>Yes (cw)</td>
<td>Emerging (cw)</td>
</tr>
</tbody>
</table>
Pumping options for Cr\textsuperscript{2+}-doped lasers

- Cr:ZnS
- Cr:ZnSe
- GaSb diodes
- InGaAs diodes
- Er:YAG
- Ho:YLF
- Tm:YAG
- Co:MgF\textsubscript{2}
- Tm:fiber
Diode-pumped Cr:ZnSe femtosecond oscillator

Wavelength 1550 nm
3.5 W, diode laser

Cr\textsuperscript{2+}:ZnSe

M1 - 2\% T output coupler;
M2 – ROC=100 mm;
M3 – ROC=150 mm;
M4 – flat HR;
M5 – ROC=100 mm;
L1-4 – collimating-focusing telescope.

M5 - SESAM

4 mm xtal
50 um spot
60\% abs.

M1 - sapphire

output
Photograph of oscillator in enclosure
Characterization of the laser output

Autocorrelation trace of 180 fs pulse

Spectrum of the laser output centered at 2520 nm with 30 nm bandwidth

Pave = 50 mW
RF spectra of Cr:ZnSe femtosecond lasers

Output of laser pumped by cw Er:fiber-pumped Tm:fiber laser

Output of laser pumped by 1550-nm diode laser

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Topics

Diode-pumped Cr:ZnSe femtosecond oscillator

CPA Cr:ZnSe laser system with 1 GW output

This work was supported by SBIR Phase II programs from AFRL and DoE
Setup of typical CPA Ti:Sapphire system

- SHG CW Nd:doped pump laser, 5 W at 532 nm
- Femtosecond KLM mode-locked Ti:S laser, 10-50 fs, 10 nJ, 800 nm, 100 MHz
- Pulse stretcher
- Ti:S regenerative amplifier, 1 mJ, 800 nm
- Pulse compressor
- Ti:S amplifier, 800 nm
- SHG Nd:doped Q-switched pump laser, 5 mJ, 532 nm
- Output 800 nm, 30-100 fs, mJ-J
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
  - 2475 nm
  - 0.35 mJ pulses
  - 346 fs

- **Grating pulse compressor**

- **Tm:fiber 1940-nm laser**
  - 40 W

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

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

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Ho:YLF MOPA

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

40 W Tm: fiber laser

Graph showing output power vs. pump power:
- Output power: 0 to 12 W
- Pump power: 10 to 40 W
- The graph shows a linear relationship between output power and pump power.
Stretcher-compressor pair

Stretcher CVBG
150 fs -> 300 ps

Compressor (ruled diffraction gratings)
300 ps -> 350 fs
CPA system photograph
CPA output characterization

**Autocorrelation trace of 346 fs pulse**

**Spectrum of the CPA output centered at 2475 nm with 30 nm bandwidth**
> 1 kW of Tm:fiber power output at 2045 nm

![Graph showing MOPA output power vs. pump power with different efficiencies and fiber configurations.](image)

- One stage Fiber #1
- One stage Fiber #2
- Two stage
- 61.6% slope efficiency
- 53.2% slope efficiency

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2.05-\(\mu\)m Ho:YLF MOPA scaling (Dergachev)

<table>
<thead>
<tr>
<th>Operation regime</th>
<th>CW</th>
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<tbody>
<tr>
<td>Beam Profile</td>
<td>TEMoo</td>
</tr>
<tr>
<td>Output power</td>
<td>(\geq 120) W</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1940 nm</td>
</tr>
<tr>
<td>Polarization</td>
<td>Random</td>
</tr>
<tr>
<td>Linewidth</td>
<td>(\leq 2) nm</td>
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</tbody>
</table>

Tm-fiber laser TLR-100-1940
IPG Photonics
www.ipg Photonics.com

ASSP 2012
Summary

• We have developed a directly diode-pumped femtosecond Cr:ZnSe oscillator
  – 180 fs pulsewidth

• We have built and operated the first Cr:ZnSe-based CPA system
  – 1 GW peak power (350 fs, 0.35 mJ) at a 1-kHz rate
  – 2475 nm center wavelength

• Future:
  – Improved SESAMs with broader spectral coverage
  – Further CPA scaling with Q-switched Ho:YLF pumps