Cryo- Cooled High Energy Laser Amplifiers

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Outline

- Basics of laser amplifiers
- Motivation for cryo cooling
- Common types of cryo cooled systems
- The DiPOLE architecture
- DiPOLE cryo system
(Pulsed) Laser Amplifiers

Light Amplification by Stimulated Emission of Radiation

Here: solid state
• Host, e.g. YAG, sapphire
• Active ions, e.g. Yb$^{3+}$, Ti$^{3+}$
(Pulsed) Laser Amplifiers

Pumping

Pumps source:
- Usually other laser or laser diodes
- Pulsed operation
- Pulse duration ns to ms
(Pulsed) Laser Amplifiers

After Pumping

Energy stored in excited active ions
(Pulsed) Laser Amplifiers

Amplification (Extraction)

- Pulse generated by oscillator (+ pre-amplifiers)
- Usually few ns long (naturally or stretched)
(Pulsed) Laser Amplifiers

After Extraction

- Stored energy extracted by seed pulse
- Process never 100% efficient -> heating of gain medium

Repeat…
(Pulsed) Laser Amplifiers

Heating

- The higher the average power (pulse energy x repetition rate) the more heat
- Heating (+ cooling) leads to temperature gradients
- Medium must not become too hot
- Gradients must not become too strong
Thermo-Optic Effects

Collimated Beam

Other issues
- Stress $\rightarrow$ depolarisation, fracturing
- Lower + non-uniform amplification (gain)
Why Cryo Cooling of Laser Medium

To Enable

• Higher pulse energy
• Higher repetition rate
• Higher efficiency

Through

• Mitigation of thermal effects
  • Improved thermal conductivity
  • Reduced thermo-optical effect
• Better performance
  • Higher gain coefficient
• Lower losses
  • Reduced reabsorption
Common types: Ti:sapphire

- Broad band amplification
- Very short pulses, ~30fs (after compression)
- Applications:
  - Ultrafast spectroscopy
  - Plasma physics, extreme conditions
  - Materials processing
Common types: Yb:YAG

- Fairly new material
- Quite established for cw and low pulse energies
- Needs pumping by laser diodes
- Ideally suited for high average powers + high efficiencies
- Emerging: high pulse energy systems (multi- J)

Applications:
- Laser pumping (Ti:sapphire...)
- Plasma physics / extreme conditions
- Practical: materials processing, remote sensing...

High pulse energies facilitated by cryo cooling through:
- Lower losses
- Higher gain
- Reduced thermo-optic effect
**DiPOLE Amplifier Concept**

**Diode Pumped Optical Laser Experiment**

- **He Gas in** at ~150 K
- **Window**
- **Yb:YAG Slabs**
- **Vanes**
- **He Gas out**

**Technical Details:**
- **14 cm (1 kJ)**
- **Pump + Seed**
- **Stronger Doping Towards Middle**
- **Co-sintered ceramics Absorber cladding for ASE management**

**Materials:**
- Yb:YAG Slabs
- Cr^4+:YAG
- Yb:YAG
DiPOLE Cryo- Cooling System

- **Amp Head**
- **Fan**
- **Heat Exchanger**
- **Control Valves**
- **LN₂ in**
- **N₂ out**
## DiPOLE Cryo-Cooling System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical</th>
<th>Range/ Design</th>
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</thead>
<tbody>
<tr>
<td>Working temperature</td>
<td>150 K</td>
<td>90 K – 300 K</td>
</tr>
<tr>
<td>Heat load</td>
<td>&lt;400 W</td>
<td>&gt; 1 kW</td>
</tr>
<tr>
<td>He flow rate</td>
<td>30 g/s</td>
<td>&lt; 40 g/s</td>
</tr>
<tr>
<td>He pressure</td>
<td>10 bar</td>
<td>2 bar – 20 bar</td>
</tr>
<tr>
<td>Stability</td>
<td>+/- 0.2 K</td>
<td>+/- 0.5 K</td>
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</tbody>
</table>
Current + Future systems

DiPOLE Prototype
- 100 W laser power
- 400 W heat load
- 30 g/s flow

HiLASE Contract
- 1 kW laser power
- 5 kW heat load
- 130 g/s flow

XFEL HED Project
- Similar HiLASE
- Possibly combined 0.5kW / 5kW
- OJEU tender soon..

Outlook
- More projects on the horizon, other groups active too
- Towards more compact, ruggedized systems ➔ practical applications
- Away from LN₂, towards closed-cycle cooling
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Thanks for listening!