High-energy, Yb:LuAG and Yb:YAG active mirror amplifiers

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Outline

- Motivation
- Thermal and spectroscopic properties
- Optical quality
- Amplifier Dynamic
- Near field pattern and wavefront analysis
- Conclusion
Motivation

Yb:CaF₂ direct diode-pumped front end

- diagnostics & preparation
- oscillator, stretcher & regenerative amp
- 100 mJ & 1J amplifiers
- 20J amplifier
- 2009 - 2012
- 2012

alternative Yb:YAG pumped OPOCPA front end

- diagnostics & preparation
- pump front end
- 10J pump laser
- 1J OPA stage
- 2014/2015
Motivation

- Yb:LuAG crystals are commercial available from Crytur

- Also ceramics are possible

- First comparison of Yb:YAG with Yb:LuAG in a kW-Class Thin Disk Laser
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Thermal properties

Fig. 2. (Color online) Dependency of thermal conductivity $\kappa$ of Yb:LuAG and Yb:YAG on the Yb$^{3+}$-doping concentration. Due to the nearly identical cation densities in both materials (see Tab. 1), identical percentage-values correspond to very similar Yb$^{3+}$-densities. Symbols represent the measured data while the curves represent the fits according to Eq. (3).

- Better thermal conductivity for Yb:LuAG at higher doping concentrations

Emission cross section

- Yb:LuAG has a smaller bandwidth, but a higher emission cross section
- The minimum excitation level is 5.3% for Yb:LuAG and 5.5% for Yb:YAG at 300K

Temperature dependence of $\sigma$

Fig. 6. Relative change in the peak absorption cross sections in different materials for about 940 nm (solid line) and near the zero phonon line (dashed line).

Fig. 10. Relative change in the peak emission cross sections in different materials for 1030 nm.

Spectroscopic properties

Effective absorption cross section for different laser diode parameters

- Gauss shaped laser diode spectrum
- Less absorption for Yb:LuAG but broader absorption peak
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Optical quality measurement setup

- Laser beam
- Probe Laser 1030 nm
- BS
- M2
- T1
- M1
- T2
- M3
- Screen/detector
- Laser Disk
- Light Source
- P
- A
- L
- Laser Material
- CAM
## Lasermaterials

<table>
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<th>Yb:LuAG</th>
<th>Yb:YAG</th>
<th>Yb:YAG</th>
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<td>FEE</td>
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<td>2.5mm</td>
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</table>
Optical quality

(a) Yb:LuAG 10 mol% Yb d = 1 mm
(b) Yb:YAG 10 mol% Yb d = 1 mm

Yb:YAG 3 mol% Yb d = 3 mm
Yb:YAG 2 mol% Yb d = 2.5 mm
Yb:YAG 5 mol% Yb d = 3 mm
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Experimental Setup
• Comparison of the 1mm thick Yb:YAG crystal with the Yb:LuAG ceramic
• Low threshold in the case Yb:LuAG
• Lower built-up time to saturate the gain for Yb:LuAG due to the higher $\sigma_{em}$
Single-pass gain and tuning range

- Higher small-signal gain for Yb:LuAG, but a smaller tuning range
Dynamic of the Yb:LuAG Multi-pass Amplifier

(a) Pulse energy $E_{\text{out}}$ [mJ] versus pump peak power $P_p$ [kW]

(b) Efficiency (optical-to-optical) $\eta_{\text{O-O}}$ versus pump peak power $P_p$ [kW]

Parameters:
- $t_p$ (pump duration)
- $T_c$ (cavity temperature)
- $\nu_{\text{rep}}$ (repetition rate)
- $E_{\text{seed}}$ (seed energy)

Lines indicate different conditions:
- 1.0 ms, 20°C, 1 Hz, 20 mJ, PR
- 1.0 ms, 20°C, 1 Hz, 20 mJ, no PR
- 1.0 ms, 10°C, 10 Hz, 20 mJ, PR
- 0.5 ms, 10°C, 10 Hz, 20 mJ, PR
- 0.5 ms, 10°C, 10 Hz, 50 mJ, PR

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Comparison Yb:YAG vs. Yb:LuAG

(a) Pulse energy $E_{\text{out}}$ [mJ] vs. pump peak power $P_p$ [kW]
- Seed pulse energy: 20 mJ
- Pump duration: 500 µs
- YAG: 2 mol% Yb, d = 2.5 mm
- YAG: 3 mol% Yb, d = 3 mm
- YAG: 5 mol% Yb, d = 3 mm
- LuAG: 10 mol% Yb, d = 1 mm

(b) Efficiency (optical-to-optical) $\eta_{0-0}$ vs. pump peak power $P_p$ [kW]
- Seed pulse energy: 20 mJ
- Pump duration: 500 µs
- YAG: 2 mol% Yb, d = 2.5 mm
- YAG: 3 mol% Yb, d = 3 mm
- YAG: 5 mol% Yb, d = 3 mm
- LuAG: 10 mol% Yb, d = 1 mm
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Beam profiles of the final amplifier
Wavefront analysis

Graph (a) shows the relationship between pump energy $E_p [J]$ and the Strehl ratio and focal power. The Strehl ratio decreases as the pump energy increases, while the focal power increases.

Graph (b) and (c) display intensity profiles at different pump energies.
Conclusion

- 0.5J @ 30% efficiency at room temperature
- Bending of active mirror under intense pumping vs. thermal lens + spatial gain narrowing
- LuAG vs. Yb:YAG:
  - broad pump spectrum @ 940nm
  - Lower reabsorption losses
  - 5nm instead of 10nm tuning range

High-energy, ceramic-disk Yb:LuAG laser amplifier


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Thank you