Passively Q-Switched Nd:YAG Laser for Spaceborne Laser Altimetry – Bepi Colombo (Mercury) Altimeter

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Overview

• BELA laser requirements & conceptual laser design

• Testbed setup for feasibility study
  – Laser performance
  – Temperature dependencies

• Optical & mechanical design of prototype models (PM)
BELA - BepiColombo Laser Altimeter

Solid-State Laser
Max Planck Institute for Solar System Research (D)

Receiver Optics/Detector
University of Bern (CH)

Transmitter Optics/Detector
DLR Berlin (D)

Electronic Unit (DPU)
DLR Berlin (D)

BELA: 11kg, 40W
BELA Diode Pumped Solid-State Laser

Oscillator Amplifier Box
Laser Zentrum Hannover e.V.

Laser Electronic Unit
Von Hoerner & Sulger GmbH

Pump Diode Unit
DILAS Diodenlaser GmbH

BELA MPS Laser Technology Preparation Program:

vH&S LZH EADS DILAS
for MPS
BELA Laser Requirements

- Pulse energy $>50\text{mJ}$
- Pulse duration $<10\text{ns}$
- Beam quality $M^2<1.6$
- Repetition rate $10\text{Hz}$
- Wavelength $1064\text{nm}$
- Radiation $100\text{krad}$
- Op. temperature $20-45^\circ\text{C}$ (laser head)
  $18-33^\circ\text{C}$ (pump diodes)
BELA Laser System Concept

Pump diode oscillator:
150W peak

Laser oscillator:
~ 2mJ

Amplifier 1st stage:
~ 22mJ

Amplifier 2nd stage:
50mJ

Pump diode amplifier:
1000W peak
BELA Laser Design Concept

- Fiber coupled pump diodes
  - Separation of pump source and laser head
- Longitudinal pumping scheme
  - Optimized overlap pump beam / laser mode
  - Higher efficiency
  - Long absorption path in laser crystal
- q-cw pumping
  - 200µs pump pulse duration as a trade off between efficiency and output energy
- Passive Q-switching with saturable absorber Cr\(^{4+}\):YAG
  - Simplicity
  - Low mass
  - Low power consumption
- 2-stage amplifier
  - Splitting of energy into 2 stages to avoid self-lasing
Master Oscillator Power Amplifier (MOPA)

120W

800 μm fiber

1000W

Dichroic coating
Nd:YAG

Cr³⁺:YAG

Output coupler

Beam expander

1000W

Dichroic coating
Nd:YAG

Amplifier 1

Amplifier 2

Master-Oscillator
Miniaturized Testbed

Mass of optical components ca. 40g
**Laser Oscillator**

- **Nd:YAG**
- **Cr<sup>4+</sup>:YAG**

- **Output coupler**

Dichroic coating

AR808nm, HR1064nm

- **120W**

  \[ \Phi_{\text{Fiber}} = 800 \mu m \]
  \[ \text{NA} = 0.22 \]

- **Pulse energy:** 2.4 mJ
- **Pulse duration:** 2.8 ns
- **Beam quality:** \( M^2 = 1.2 \)
- **Peak-pump power:** 104 W
- **Pump duration:** 200 μs
- **Opt.-opt. efficiency:** 12 %
**Amplifier: 1st Stage**

Saturated effective amplification @ > 2 mJ seed energy
Power Amplifier

- Input pulse energy: 2.4 mJ
- Pulse width: 2.8 ns
- Pump pulse duration: 200 µs

Additional losses due to ASE of the amplifiers

>50 mJ @ 2 x 550 W, $M^2 < 1.5$
Optical-to-optical Laser Efficiency

Optical-to-optical efficiency: $\approx 23\% @ 200\mu s$
Absorption > 95% between 804nm and 809nm for 25mm crystal

Pump diode shift: 0.25nm/K
-> 3.75nm for $\Delta T=15K$

$\Delta \lambda (\text{FWHM}) = 2.5$ nm
Temperature Range: Oscillator Pump Diodes

Temperature acceptance range: $\Delta T > 15K$
Temperature Range:
Amplifier Pump Diodes

Temperature acceptance range: $\Delta T > 15K$
Testbed Laser Performance

- Pulse energy 54mJ
- Pump energy 245mJ
- Pump power 2x 550W + 100W
- Pump duration 200µs
- Beam quality M² < 1.5
- Pulse duration 2.8ns

- Temperature acceptance range for pump diodes ∆T > 15K
Requirements for Flight Model

- Mass (laser system) 4kg
  - Laser head <1.3kg
- Total ionizing radiation dose 100krad
- Vibration level (Sojuz) 26g_{rms}
- Operating temperature 20-45°C
- Non-operating temperature -40-60°C

- Sealed pressurized box to avoid contamination of optics

Mass of optical components approx. 40g

Most of the mass due to housing in sealed box
2 Prototype Models

- Prototype I
  Optical functionality for integration in BELA instrument prototype

- Prototype II
  - Laser operation during thermal cycling
  - Verification of thermal model
  - Vibration tests of subcomponents

Modular concept: reversible screw joints / O-ring sealed -> easy replacement of non-adequate parts
Prototype Model Optical Materials

- Mirrors, lenses, windows  
  fused silica
- Aspheric lenses in pump optics  
  Co550
- Laser crystals  
  Nd3+:YAG
- Passive Q-switch  
  Cr4+:YAG

Materials already used for other space missions, i.e. can be made radiation hard
Planar Testbed

Planar design not suitable for pressurized box within mass budget due to pressure induced misalignment
Optical Design for Prototype

- 3D Optical Design (Zemax)
- Only reflection angles at bending mirrors have changed compared to testbed
Mechanical Mounts for Optics

1. Pump optics
2. Laser crystal
3. Q-switch
4. Output mirror
5. Beam expander
6. Bending mirrors
Optical Bench

Mounting screws

Laser output window

Pump fiber receptacles

Electrical feedthroughs for housekeeping
Mounting

- Laser output window
- Mounting by M4 screws
Stabilizing Jacket

for stability against torsional misalignment

Aluminum alloy

Thermal interface
Sealing Jacket

- Height 25cm
- Diameter 12cm (14cm)
- Mass ca. 1500g

for pressure tightness
Mechanical Design

- Good volume to surface ratio -> low mass for pressurized box 
  (Prototype Model ~1.5kg, Flight Model <1.0kg)

- Rugged optical bench due to highly symmetrical design (mainly symmetrical radial forces induced by pressure difference)

- Low thermally induced optical misalignment due to almost symmetrical thermal load

- Transport of dissipated heat via massive optical bench
Future Work

- Thermal cycling test end of 2006
- Vibration tests of critical subcomponents
- Radiation hard optical components

- Mechanical redesign after thermal cycling / vibration tests
- Replacement of screw joints by irreversible joining techniques (welding, soldering, etc.)

Qualification procedure
This work was funded by

- German Aerospace Center (DLR)
- Max Planck Institute for Solar System Research (MPS)

and performed within the framework of the BELA Laser Industrial Team

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