Qualification of space laser optics for ESA LIDAR missions

Wolfgang Riede, Helmut Schröder, Paul Allenspacher
Institute of Technical Physics, DLR Stuttgart

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German Aerospace Center (DLR)

Approx. 8000 employees across 33 institutes and facilities at 20 sites.

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Institute of Technical Physics

Director: Prof. Dr. Thomas Dekorsy

Topics:
Laser systems for applications in:
Aeronautics / Space / Security / Defense

Staff:
3 departments
70 employees
Our motivation: Upcoming ESA LIDAR space missions

**Atmospheric Dynamics Mission (ADM) Aeolus**

Global measurement of wind profiles
- Sun-synchronous orbit with 7 days repeat cycle
- Launch period: 11/2017 – 01/2018 soon!
- Projected lifetime: 3 years
- Laser: ALADIN (Atmospheric Laser Doppler Instrument)
- Specs: 50 Hz, $\sim < 120 \text{ mJ} @ 355 \text{ nm}$, 20 ns
- Partial pressure oxygen: $\sim 40 \text{ Pa}$

**EarthCARE**

Global profiling of aerosols
- Expected launch in Q4/2018
- Design lifetime: 3 years
- Laser: ATLID (Atmospheric LIDAR)
- Specs: 51 Hz, $>35 \text{ mJ} @ 355 \text{ nm}$
- Pressurized (artificial air)
Challenges for laser components / sub-modules in space

Specific mission requirements (ESA ADM Aeolus)

- 3 years of operation in orbit -> ~ 4.7 billion laser pulses -> long term stability of laser components
- High pulse energy (up to 120 mJ, 20 ns) in the UV (355 nm) -> high damage threshold of components

Space environmental effects (impacting the performance of space optics)
Challenges for laser components / sub-modules in space

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Space environmental effects (impacting the performance of space optics)

Need for on-ground test setups and test procedures for simulation of space environment

No service visit possible ;-}
Test bench for LIDT evaluation under high vacuum

- 1-on-1 / S-on-1 tests according to ISO 21254
- Testing under high vacuum (10^{-6} mbar) or artificial atmosphere
- Fundamental mode laser (Gaussian beam profile on sample) $M^2 \sim 1.5$
- Nd:YAG wavelength and harmonics: 1064, 532, 355, 266 nm
- Damage detection by scatter probing and pressure sensing (threshold $\sim \mu$m size)
LIDT setup (IR beam line)

Sample environment

High vacuum 10^{-6} mbar
Artificial atmosphere (<=5 bar)

High vacuum stainless steel chamber
LIDT setup (UV beam line)

Sample environment

High vacuum 10⁻⁶ mbar
Artificial atmosphere (<5 bar)

High vacuum stainless steel chamber
### Large database of space laser optics: Vendor / batch screening

![Characteristic damage curve 9570327_13Air](image)

<table>
<thead>
<tr>
<th>Optic</th>
<th>Coating</th>
<th>Wavelength [nm]</th>
<th>Fluence* $F_{10000}$ [J/cm²]</th>
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</thead>
<tbody>
<tr>
<td>waveplate</td>
<td>AR</td>
<td>1064</td>
<td>12.4</td>
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<tr>
<td>reflector</td>
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Best LIDT values of optical components exposed to 1064 / 355 nm pulses

- 350 space laser optics tested
- 10 years of test campaign
- 20 different types
- 355, 532 and 1064 nm

40% IR, 10% VIS, 50% UV
10 European / 6 US vendors
### Large database of space laser optics: Vendor / batch screening

**All critical laser optics for ESA ALADIN were tested in our facilities!**

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Best LIDT values of optical components exposed to 1064 / 355 nm pulses
Raster scans – supplemental test for flight modules

Interrogation of large test areas (up to 100 mm$^2$ )

Optical micrographs of AR 355 coating (with activated damage sites)
Setup for laser-induced contamination tests

- Stainless-steel UHV chamber
- 4 parallel beam lines allow for simultaneous sample testing (identical conditions)
- Non-depletable contamination source
- Long distance microscope
- Online fluorescence / transmission monitoring
LIC scheme: Deposit formation on the surface of optics

Hydrocarbons used for lab tests (purity, handling)

Space qualified glues, adhesives...

Toluene \hspace{1cm} Naphthalene \hspace{1cm} Anthracene

and CV 2566, Solithane, A12 Epoxy ………
Laser-induced fluorescence detection of deposits

Correlation between deposit thickness and fluorescence intensity

**Test parameters***:
- Temperature: 100°C
- Contaminant: A12 epoxy
- Pressure: HV
- Wavelength: 355 nm

**Fluorescence detection limit**: few nanometers
Contamination induced damage: in-situ microscopy

High reflector 45°@ 355 nm
Naphthalene molecular contamination
3x10^{-5} mbar

Peak fluence: 0.4 J/cm²
Repetition rate: 1000 Hz

10h, R=98%
16h, R=88%
20h, R=56%
29h, R=15%

36 x 10^6 pulses
Contamination induced damage: in-situ microscopy

High reflector 45°@ 355 nm
Naphthalene molecular contamination
3x10^{-5} mbar

Peak fluence: 0.4 J/cm²
Repetition rate: 1000 Hz

Very small threshold fluence for damage under presence of molecular contamination
Contamination induced damage: Mitigation by oxygen

- Threshold behavior of oxygen pressure ratio
- Cleaning of contaminated surface by UV irradiation in O₂ atmosphere

**Test conditions:**

- Wavelength: 355 nm
- Fluence: 1.0 J/cm²
- Pulse number: 3.6 Mio shots
- Pulse repetition rate: 1 kHz
- Optical samples: fused silica, AR @355nm
- Naphthalene partial pressure fixed: 10⁻⁵ mbar
- O₂ pressure variable: 10⁻⁶ – 4 10⁻² mbar
Contamination induced damage: mitigation by oxygen

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Small partial pressures of oxygen suppresses contamination effects
Proton radiation tests of nonlinear crystals

Proton irradiation facility PIF @ PSI, CH

Test philosophy:
3 year equivalent orbital dose of $p^+$
(applied in 1 hour)
Dose: $< 10^{12} \text{ p}^+/\text{cm}^2$
Flux: $< 5 \times 10^8 \text{ p}^+/(\text{cm}^2 \text{ s})$
Irradiation in air
$p^+$ radiation tests at 10 MeV

Proscan high energy facility @ PSI, CH

Test philosophy:
3 year equivalent orbital dose of $p^+$
(applied in 1 hour)
Dose: $< 10^{12} \text{ p}^+/\text{cm}^2$
Flux: $< 2 \times 10^8 \text{ p}^+/(\text{cm}^2 \text{ s})$
Irradiation in air
$p^+$ radiation tests at 100 & 230 MeV
Low energy (10 MeV) proton radiation test

KTA, after $6.5 \times 10^{11} \text{p}^+/\text{cm}^2$

darkening

LBO, after $6.5 \times 10^{11} \text{p}^+/\text{cm}^2$

no darkening
Test philosophy:
3 year equivalent orbital dose
Gamma energy: 1.17 / 1.33 MeV
Typical radiation flux: 36 rad/min
ESA test specs:
100 krad overall dose

Strong degradation for Titanyls (KTP, RTP, KTA)
No degradation for Borates (BBO, LBO, BIBO)
Summary

• Operation of qualification test benches for high-power space laser optics (LIDT, LIC, raster scanning)

• Damage testing of all critical laser optics of ALADIN instrument (ADM mission)

• Sensitive in-situ monitoring technologies (eg fluorescence imaging)

• Identification of risks for laser optics in space (contamination effects may reduce the LIDT)

• Investigation of LIC mitigation effects ($O_2$ pressurizing)

• Exposure of nonlinear optical crystals to energetic radiation (borates show only minor effects)
Thank you for your attention

The support by ESA/ESTEC is kindly acknowledged!