Qualification and Selection of Flight Diode Lasers for the NuSTAR Space Mission

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• NuSTAR Mission
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• Laser Failure Mechanisms
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• Laser Characterization
• Laser Flight Selection
• Laser Lifetime Testing
• Summary
The Nuclear Spectroscopic Telescope Array (NuSTAR)

NASA Small Explorer (SMEX) mission

Low-Earth equatorial orbit in 2012.

Two identical high energy (6-80 KeV) X-ray telescopes

The NuSTAR mission will increase sensitivity, spatial, and spectral resolution on the order of 10 to 100 times over other missions that have operated at high X-ray energies.

The design requires a focusing length of ~10 meters

Deployable mast

A metrology system is implemented on the structure of the observatory.

The metrology system consists of two lasers mounted on the optics side of the telescopes and two position sensing detectors (PSD) mounted on the detector side of the telescopes.
Overall Laser Requirements

• Sufficient signal to generate a strong signal relative to sun reflections

• Very Reliable

• Wavelength where silicon is sensitive

• Low Budget/Schedule, so have to select something already available

• Selected 830 nm, 200 mW due to heritage at JPL

• Procured 120 lasers from 2 different vendors (60 from each)

• Vendor 1: Custom Packaged (existing laser) to JPL specification. Qualified by vendor

• Vendor 2: Standard off the shelf being qualified at JPL

• Lasers are interchangeable from an optical, electrical and mechanical point of view
## Detailed Laser Requirements

<table>
<thead>
<tr>
<th>Short Title</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>The center wavelength of the laser diode shall be 826.5 nm +/- 8.5 nm (no scanability is required)</td>
</tr>
<tr>
<td>Power</td>
<td>The optical power of the laser diode shall be &gt;= 200 mW (It will only be used at 50 mW during flight)</td>
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<tr>
<td>Mode</td>
<td>The laser diode shall be single spatial mode</td>
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<tr>
<td>Reliability</td>
<td>There shall be a probability &gt;90% that the laser diode will survive 26 months of operation when operated at 50 mW and 20 C, and on/off 4 times a second</td>
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<tr>
<td>Temperature shift</td>
<td>The laser diode emitting surface shall translate less than 8 nm/deg C relative to the case</td>
</tr>
<tr>
<td>Power Stability</td>
<td>The relative laser intensity shall not change more than 5e-5 over a period of 20 microseconds</td>
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<tr>
<td>FIT</td>
<td>The laser shall have a FIT less than 11400</td>
</tr>
<tr>
<td>Beam shape</td>
<td>The beam should be elliptical Gaussian</td>
</tr>
</tbody>
</table>
Laser Failure Mechanisms

- Random failure due to optical power
- Thermo-mechanical stress of the laser chip
- Laser diodes could be electrically destroyed
- Infant mortality failures
- Solder failure/delamination of laser
- Wire bond failures
- Workmanship problems
- Solder bond line thickness
- Contamination of laser facets
- Loose particles inside the package
- Problems encountered with the use of indium (In)
Laser Vendor A Qualification Process

Vendor Qualification

1. Visually inspect and clean
2. Inspection, Photograph
   - Capping
   - Burn in
   - Laser Mark
3. Inspection, Photograph
   - Hermetic Test
   - Temperature Cycling
   - Acceleration
   - PINR Test
   - Pre-BI characterization
   - Burn-in
   - Final characterization

12 Lasers
Flight Lasers
Visual Inspection

10 Lasers
Lifetime Testing
Laser Vendor B Qualification Process

JPL Qualification of Commercial Laser

- **DPA**
  - Look for:
    - General Architecture
    - Is junction Up or Down
    - Coating
    - Solder
    - Bond Strength
    - Die Shear
    - Leak Test

- **60 Laser Diodes**
  - Laser Characterizations
    - LIV Curves + Wavelength

- **Temperature Cycle Lasers**
  - Laser Characterizations
    - LIV Curves + Wavelength

- **Burn-in**
  - Laser Characterizations
    - LIV Curves + Wavelength

- **Flight Lasers**
  - 12 Lasers
  - **Flight Laser Selections**
    - Eliminate lasers that are in Both tails of all distributions

- **10 Lasers**
  - **Spare Lasers**

- **10 Lasers**
  - **Lifetime Testing**

- **2 Lasers**
  - 32 Lasers
    - Laser Characterizations
      - LIV Curves + Wavelength

- **Temperature Cycle Lasers**
  - Laser Characterizations
    - LIV Curves + Wavelength

- **26 Lasers**
  - **Spare Lasers**

- **SEM image of Vendor B junction**
  - Laser is junction down
  - Indium used for bonding

SEM testing shows the laser is attached with Pt/In

1. Laser Cathode (-)
2. Laser anode, MIPO cathode and case ground
3. Monitor photodiode anode (+)
Laser Characterization

All Laser characterized for

• Voltage
• Power
• Current
• Wavelength

Characterized before and after burn-in

Characterization setup

Sample LI curve
Flight Laser Selection

All characteristics were put in histograms

- Wavelength (@ 50 mW)
- Power (@ 200 mA)
- Threshold current

All laser with changes during burn-in were rejected

Fierce debate among authors on how to select flight lasers

Some Authors wanted laser with best efficiency selected

Ended up with selecting average lasers (not at any extreme in any way in histograms)
Laser Lifetime Testing

>90% probability of laser survival throughout 26 month. Equivalent to a FIT < 11400.

In flight: 50 mW, 20 C, and cycled on/off 4 times a second

An accelerated lifetime test was performed on 10 Vendor A and 10 Vendor B laser diodes.

FIT < 11,400 can be proven to a 98% confidence level if 300,000 hours of testing (assuming no laser failures)

Calculating the power acceleration factor:

\[ \text{Failure Rate (Tj,I,P)} \approx e^{-E_A/\left(K_BT_j\right)^m P^n} \]

where E is activation energy, K is Boltzmann constant, T is laser diode junction temperature, I is current, P is power, and m and n are the exponents of current and power acceleration respectively.

During lifetime testing, maximum optical output power of the laser diodes: 180 mW

Increasing output power from 50 mW to 180 mW and applying exponent power acceleration of 1.8 corresponds to a power acceleration factor of ~10.

Takes ~4 months to put 300,000 hours on 10 lasers with an acceleration factor of 10

Also applied pulse acceleration from 4Hz to 50 Hz
Laser Lifetime Testing

Fluctuation in power levels are due to temperature changes.
Extended Laser Lifetime Testing

NuSTAR Laser lifetime testing over 381 days
The changes in the intensities are due to the temperature in the room, Air-condition failure etc. No degradation observed in any lasers.
Summary

Qualified 2 different lasers for the NuSTAR Metrology system

Extended lifetime testing showed no problems

Baseline was to fly one of each type of laser on the mission

Due to unrelated issues during the optical focusing of the system, 2 lasers from vendor A ended up on the flight instrument