Development of a US Gravitational Wave Laser System for LISA

Jordan Camp
Kenji Numata*

NASA Goddard Space Flight Center
* University of Maryland, College Park

APS April Meeting 2015
Apr. 13, 2015
eLISA laser program at GSFC

• Provide TRL 5 laser system by 2016
  – Modern, fiber-based design
  – Technical details to be made available to all LISA members

• Funding
  – SBIR (Small Business Innovative Research)
  – Internal GSFC R&D
  – LISA project funds
  – Strategic Astrophysics Technology award
  – ~ $3.5M over 6 years
GSFC LISA laser design

MOPA design
External Cavity Laser, fiber preamp, fiber amplifier
1064 nm wavelength
2 Watt output
Oscillator: External Cavity Laser

- **Gain Chip**, **PLC**, **Waveguide**, **AR**, **Bragg Reflector**, **Lens**

- **1550 nm**

- Simple, compact, low mass, highly reliable laser (butterfly package)

Numata, Camp, Krainak, Stolpner, OE 18, 22781

NPRO: $25K  
ECL: $5K
Packaging of ECL and Preamp

2 ECLs
2 Preamp Diodes
10 cm x 5 cm x 1 cm
50 mW output

Redundant ECL and Preamplifier package
1550 nm ECL is space qualified

Other tests:
- Hermiticity
- Gamma-ray exposure
- Accelerated aging

→ Robust design suitable for space operation

Fig. 5 Reliability testing of ECL a) thermal cycling b) proton irradiation
Conversion of ECL wavelength to 1064 nm

<table>
<thead>
<tr>
<th></th>
<th>RWG (1064nm)</th>
<th>BH (1550nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Complex epi design</td>
<td>epi design is decoupled from mode size converter</td>
<td></td>
</tr>
<tr>
<td>a Use special design to expand beam size</td>
<td>Beam defined by BH and mode size converter</td>
<td></td>
</tr>
<tr>
<td>2 Waveguide defined by RWG</td>
<td>Waveguide defined by BH</td>
<td></td>
</tr>
<tr>
<td>a Weak index guiding</td>
<td>Strong index guiding</td>
<td></td>
</tr>
<tr>
<td>b Thermal and carrier lensing affect beam profile</td>
<td>No thermal and carrier lensing</td>
<td></td>
</tr>
<tr>
<td>c Beam profile depends on operating current</td>
<td>Beam profile does not depend on operating current</td>
<td></td>
</tr>
<tr>
<td>d Excitation of TEM$_{01}$ could degrade noise</td>
<td>Only TEM$_{00}$</td>
<td></td>
</tr>
<tr>
<td>f High ellipticity</td>
<td>Almost circular</td>
<td></td>
</tr>
<tr>
<td>g High GC-PLC coupling loss</td>
<td>Low GC-PLC coupling loss</td>
<td></td>
</tr>
<tr>
<td>h Requires facet passivation</td>
<td>Does not require facet passivation</td>
<td></td>
</tr>
<tr>
<td>i One-step growth</td>
<td>Two-step growth</td>
<td></td>
</tr>
</tbody>
</table>

- PLC = Planar linear cavity
- GC = gain chip
- BFM = back facet monitor

Numata, Alalusi, Stolpner, Camp, Krainak, OL 39, 2101 (2014)
Frequency noise of world’s 1st 1064 nm ECL (in Butterfly package)

Lowering phase noise: 1) optimize optical cavity reflectivity slope \(\rightarrow\) strong feedback \(\rightarrow\) low noise 2) optimize gain chip for low loss \(\rightarrow\) low noise 3) select gain chip for lowest 1/f noise
Frequency stabilization with iodine

- 1064nm PW-ECL + Yb fiber amp + Waveguide doubler

Satisfies the freq. noise requirement for eLISA at low frequency

Numata et al., Opt. Lett 39, 2101
Frequency stabilizing the ECL

External AOM as frequency actuator to suppress frequency noise at high frequency
Frequency Modulation of ECL on laser chip (to be implemented)

- Modulation of the effective refractive index inside the cavity, results in frequency modulation of the external wavelength up to 100 MHz
- FM section on the gain chip, separated from gain section by etching

\[ I_a = \text{bias current of section-a} \]
\[ I_m = \text{modulation current} \]
Power Amplifier

- **Design**
  - All fiber coupled
  - Large mode area, double-clad Yb fiber
  - Forward pump to avoid risk and noise sources

- **Noise performance**
  - No additional frequency noise
  - eLISA requirement level
    - Differential phase noise (@2GHz)
    - Stabilized low frequency RIN with feedback to pump diode

![Diagram of Power Amplifier](image)

**Graphs:**
- Differential phase noise
- RIN and its stabilization (low/high frequency ends)
1064 nm ECL oscillator, rebuilt power amplifier
Temperature stabilized environment
Tests: noise, accelerated aging, etc.
Laser Development Schedule

- **FY 2014 - 2015**
  - Iterate design of 1064 nm ECL gain chip, planar cavity

- **FY 2015**
  - Laser system testing with 1064 nm ECL
  - Achieve final frequency noise performance

- **FY 2016**
  - Reliability testing of 1064 nm ECL
    - Low risk since same packaging as 1550 nm, also Eagleyard data indicates reliable 1064 nm gain chips
    - Implement on-chip frequency modulation