Development of fiber-based laser systems for LISA
Kenji Numata, Jordan Camp

Abstract

We present efforts on fiber-based laser systems for the LISA mission at the NASA Goddard Space Flight Center. A fiber-based system has the advantage of higher robustness against external disturbances and easier implementation of redundancies. For a master oscillator, we are developing a ring fiber laser and evaluating two commercial products, a DBR linear fiber laser and a planar-waveguide external cavity diode laser. They all have comparable performance to a traditional NPRO at LISA band. We are also performing reliability tests of a 2-W Yb fiber amplifier and radiation tests of fiber laser/amplifier components. We describe our progress to date and discuss the path to a working LISA laser system design.
Development of fiber-based laser systems for LISA

Kenji Numata\textsuperscript{1,2),} Jordan Camp\textsuperscript{2)}

\textsuperscript{1)}Department of Astronomy, University of Maryland, CRESST
\textsuperscript{2)}Gravitational Astrophysics Laboratory (Code 663), NASA/GSFC
1. Introduction
   - Motivation of this activity

2. Fiber-based lasers
   - GSFC ring fiber laser
   - NP photonics DBR fiber laser
   - RIO planar-waveguide external cavity diode laser

3. Fiber amplifier

4. Other activities
   - Space qualification tests
   - Fiber-based frequency stabilization

5. Summary
1. Introduction

NPRO (Non-planar ring oscillator) has been used traditionally.
- Compact crystal cavity gives high stability.
- "Black box" in many cases
  - E.g.) TESAT NPRO for LPF

All fiber/waveguide solution
- Fiber laser/amplifier technologies matured rapidly
- Higher robustness
Fiber laser offers significant advantages over NPRO laser

<table>
<thead>
<tr>
<th>Traditional: NPRO laser</th>
<th>New: Fiber laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Material: Nd:YAG</td>
<td>Yb-doped fiber</td>
</tr>
<tr>
<td>Pump Beam (808 nm)</td>
<td>WDM</td>
</tr>
<tr>
<td>Output Beam (1064 nm)</td>
<td>Output coupler</td>
</tr>
<tr>
<td>Mirror Coating HT@808nm 99%@1064nm (typ)</td>
<td>Isolator</td>
</tr>
</tbody>
</table>

**Difficult alignment**
- No alignment needed

**Glue/solder needed**
- No glue needed

**Need to couple back into fiber**
- Laser light within fiber

**Strong magnet needed**
- No strong magnet

**Contamination sensitive (sealed package)**
- No contamination

**Distorted Gaussian beam**
- Mode & polarization cleaned by fiber
Fiber amp has..

- Higher beam quality, lower sensitivity to alignment etc., easier cooling
- Higher reliability, **higher optical/wallplug efficiency**
  - E.g. Commercial fiber amp: >10% wallplug efficiency
  - ~2% efficiency in solid state amps in flight missions

Easier addition of redundancy

- Many (~90%?) laser failures come from pump LD
- No geometrical constraints

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Core pumping by SM LDs

Clad pumping by MM LDs

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2. Fiber-based lasers

- GSFC fiber ring laser
  - Commercial highly-doped gain fiber + fiber Bragg gratings

- NP photnics/Fibertek DBR fiber laser
  - Special phosphosilicate glass fiber + fiber Bragg gratings

- RIO external cavity diode laser (ECL)
  - InP semiconductor gain chip + planar-waveguide Bragg reflector
Features

- Design & built in house
- Commercial components only
  - No special gain fiber
  - No patent issues
- Two FBGs for single-mode selection
- Fast frequency tuning by waveguide EOM
- Low power (~2mW)

Status

- Design fixed
- Iodine stabilization
- Digital system design

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Noise performance

Frequency noise

- Low frequency: comparable to (better than) NPRO
- High frequency: increased noise due to relaxation oscillation
- Stabilization experiments
  - Frequency: Planned using iodine or cavity.
  - Intensity: Done after Yb amplifier and satisfied LISA requirement at low frequency.

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Fiber-DBR laser

**Features**

- Built by NP Photonics
- Highly-doped phosphate glass fiber
  - Short cavity length
- Low reliability of splice
- Patented

**Status**

- Qualification tests by Fibertek
  - “Space version” passed thermal cycling
- Noise evaluations
Features

- Compact & simple
- Low cost
  - ~$5k
- **Lowest noise** at LISA band
- Unconditionally single-mode
- Low power (~15mW)
- Telecom C-band only

Status

- Frequency stabilization done
- Phase locking experiment
- 1064-nm version
- Lowest free-running noise levels
  - Stabilization by saturation signal of acetylene at 1542nm.
  - Controllability
- High frequency noise @ high frequency
  - Under investigations
3. Fiber amplifier

Features

- Built by Lucent Government Solutions (LGS)
  - Clad pump, LMA fiber, ~4W maximum
- Focused on reliability
  - Detailed risk analysis
  - Passed thermal cycling tests

Status

- Noise measurements at GSFC
- Stabilization experiments
4. Other activities

Space qualification tests

- To be done in collaboration with LGS
  - Proton test (@ UC Davis)
  - Gamma test (@ GSFC, 7/19~)
  - Fiber components to be radiated
    - Fiber bragg grating (FBG), circulator (isolator), Band-pass filters, gain fibers, etc.
  - Outgass, pyroshock

All-fiber frequency stabilization

- FBG Fabry-Perot cavity
  - Finesse ~300
5. Summary

Fiber approach very promising for space applications
- Higher robustness, cleaner output, no strong magnet, etc.
- Redundancy can be easily added.
- New technology introduced frequently
- No choice for solid-state amp for LISA-type CW, low-power applications

Fiber-based lasers
- At low frequency, NPRO is *not* the best anymore.
- Custom-made fiber laser possible.
- Possible issue is high frequency noise at higher frequency
  - Can be suppressed by fast frequency actuators (e.g. waveguide EOM)

Current & future activities
- Radiation tests
- Full stabilization & metrology experiments