Fiber Amplifier Report for NEPP 2008

Joe Thomas
Melanie Ott
Frank LaRocca
Rick Chuska
Rob Switzer

NASA Goddard Space Flight Center
April 2008

Outline

- Fiber Laser Activities
- Qualification
- Lithium Niobate Modulator
- Passive (unpumped) Fiber Radiation Testing
- Active (pumped) Fiber Radiation Testing
- High Power Fiber Terminations
- Conclusions

Fiber Laser Activities

- Remote sensing & high-bandwidth communication
  - Physical sensing (altimetry, ranging, 3D LIDAR)
  - Chemical sensing
- Investigation of fiber laser systems and components to raise / evaluate technology readiness level (TRL)
  - Confidence for future mission
  - Part of NASA Electronic Parts and Packaging (NEPP) http://nepp.nasa.gov
- Fiber laser focus areas
  - Source / transmitter
  - Modulation

Qualification

- Desirable to use commercial-off-the-shelf (COTS) components when possible
  - Alleviate tight budget and schedule
  - Often requires custom packaging
- Optical component qualification
  - Initial gamma radiation screening
    - Transmission loss and annealing
  - Thermal vacuum testing
  - Extended radiation testing
**Lithium Niobate Modulator**

- High extinction ratio intensity modulator
- Manufacturer: Photline Technologies
- Proton exchange waveguides
- Separate DC and RF biasing
- LiNbO₃ X-cut Y-propagating
- PM input and output fibers

**Modulator Operational Theory**

Separate biasing of DC and RF portions of waveguiding region

Modulated signal's DC level will drift during normal operation

Radiation-induced effects will show up in both DC and RF signals

**Experimental Setup**

**Bench-Top Testing**

Picked DC bias voltage for quadrature operation to allow for maximum change without clipping

Drift in DC output level

No change in peak-to-peak output
Gamma Radiation Testing

CO₂ Source

Modulator

Gamma Radiation Results

7.2 rad/min 52 krad total dose

Gamma Radiation Results

111 rad/min 1 Mrad total dose

Gamma Radiation Results

Max voltage, Min voltage, and peak-to-peak voltage during radiation test

No radiation-induced change in optically modulated signal
Desirable Properties of Fiber Lasers

- High efficiency
  - Low power consumption, low waste-heat generation
  - Up to 40% electrical-to-optical conversion with a Yb-doped fiber amplifier has been demonstrated
- Diffraction limited beam quality
  - Minimum divergence, smallest spot size
  - Reduced speckle
- High reliability through monolithic structure
  - Fiber-coupled components
  - Sealed, alignment-free optical system

Desirable Properties of Yb-Doped Fibers

- Structure of Yb-atom
  - Simple energy band structure minimizes excited state absorption
  - Low quantum defect
  - No or little concentration quenching
  - Long upper-state lifetime
- High-power applications possible
  - High Yb-doping concentrations possible
  - Double-clad fibers can improve power capabilities

Desirable Properties of Er-Doped and Er/Yb Co-Doped Fibers

- Er-doped fibers
  - Amplification in the range of 1.5 μm
  - Extensively used for communication systems
- Er/Yb co-doped fibers
  - Yb acts as sensitizer and absorbs light, transferring energy to the Er atom, from where light is re-radiated at communication wavelengths.
  - This process leads to a larger overall absorption per unit length, i.e. shorter amplifiers.

Fiber Laser Testing

- Ongoing collaborative research on radiation-induced effects in Er-, Yb-, and Er/Yb-doped fibers
- Initial testing focused on unpumped (passive) fiber configurations
- Testing conducted at Sandia National Labs' Gamma Irradiation Facility (GIF)
Fiber Laser Testing
Unpumped Configuration

Test fibers located in gamma test chamber for radiation exposure, the distance from the source determining the dose rate.

Broadband optical radiation from xenon arc lamp, located outside the test chamber, is coupled into a set of standard 
coherent delivery fibers.

Delivery fibers enter test chamber through access ports and couple light into the test fibers located inside the gamma test chamber.

Transmission spectrum of each test fiber monitored at 1 min intervals throughout 7 hour gamma exposure.

Representative data show the effect of accumulated doses of gamma radiation on the normalized optical transmittance of a Yb1200-41125 fiber.

Wavelength dependence of radiation-induced optical losses visible at large total doses.

Data reported account for removal of lamp spectrum and background losses arising from fiber pigments and delivery fibers.

Dose rate = 40.1 rad(SI)/s

Fiber Laser Testing
Unpumped Configuration

Table: Rare-Earth Doped Fiber Samples

<table>
<thead>
<tr>
<th>Rare-Earth Doped Fiber</th>
<th>Manufacturer</th>
<th>Fiber Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yb-doped fiber</td>
<td>Uniphi</td>
<td>Yb1200-20/400C, Yb1200-30/500C, Yb1200-41/125, Yb1200-41/250, Yb1200-50/125, Yb1200-60/125, Yb1200-80/125</td>
</tr>
<tr>
<td>Er-doped fiber</td>
<td>Uniphi</td>
<td>Er16-4/125, Er20-4/125, Er30-4/125, Er40-125, Er50-125, Er60-4/125, Er100-4/125</td>
</tr>
<tr>
<td>Er/Yb co-doped fiber</td>
<td>OFS</td>
<td>OFS Er/Yb PM DC</td>
</tr>
</tbody>
</table>

Note: First number designates the nominal peak absorption in dB/m at 476 nm for Yb (1532 nm for Er), and the second and third numbers denote the core and cladding diameters respectively in µm. The ‘DC’ designates the double-clad fibers.

Pigtailed (SMF-28, Hi-1060) were utilized to couple reference xenon light into the core of double-clad Yb-doped fibers.

Yb-Doped Fiber Radiation Results
Unpumped Configuration

Representative data show the effect of accumulated doses of gamma radiation on the normalized optical transmittance of a Yb1200-41125 fiber.

Wavelength dependence of radiation-induced optical losses visible at large total doses.

Absorption feature at 1500 nm.

Dose rate = 40.1 rad(SI)/s

Er-Doped Fiber Radiation Results
Unpumped Configuration

Representative data show the effect of accumulated doses of gamma radiation on the normalized optical transmittance of an Er20-4/125 fiber.

Wavelength dependence of radiation-induced optical losses visible at large total doses.

Absorption feature at 1500 nm.

Dose rate = 40.1 rad(SI)/s
Representative data show the effect of accumulated doses of gamma radiation on the normalized optical transmittance of an OFS Er/Yb PM DC fiber. Wavelength dependence of radiation-induced optical losses visible at large total doses. Photodarkening proceeds slowly. Absorption feature at 1550 nm due to erbium.

Data reported account for removal of laser spectrum and background losses arising from fiber pigments and delivery fibers.

**Dose rate effects for Yb-doped fiber**

Optical transmittance measurements for Yb1200-41125 fibers exposed to two distinct dose rates. Up to a 10% increase (relative change) observed in measured optical transmittance loss at higher dose rate.

Data reported account for removal of laser spectrum and background losses arising from fiber pigments and delivery fibers.

**Dose rate effects for Er-doped fiber**

Optical transmittance measurements for Er20-41125 fibers exposed to three distinct dose rates. Dose rate dependence observed, which increases with larger total dose. Increase of photodarkening (relative change) due to higher dose rate is under 10%.

Data reported account for removal of laser spectrum and background losses arising from fiber pigments and delivery fibers.
Passive tests showed that Yb-doped fibers exhibited higher radiation resistance than Er-doped fibers.

- Initial active testing will focus on Yb-doped fibers.

Initial active (pumped) configuration tests were conducted at NASA GSFC.

- Study self-annealing effects due to pumping during radiation exposure.
- Testing and results provided by Tracee Jamison-Hooks.
**High Power Fiber Terminations**

- Mechanical polishing techniques developed for handling high power without endface damage
  - Limited by silica / air interface breakdown
  - Being used in high power fiber laser applications

- New ferrule designs for high power injection
  - Allow slight mechanical misalignment without catastrophic damage

  All designs use space-qualified materials

**Conclusions**

- Ongoing qualification activities of LiNbO₃ modulators
- Passive (unpumped) radiation testing of Er-, Yb-, and Er/Yb-doped fibers
  - Yb-doped fibers exhibit higher radiation resistance than Er-doped fibers
  - Er/Yb co-doped fibers exhibit largest radiation resistance

- Active (pumped) radiation testing of Yb-doped fibers conducted at NASA GSFC
  - Typical decay behavior observed
  - No comparison could be made to other fibers due to problems with test setup

- Development of new high power fiber terminations
Acknowledgements

Collaborators at University of Arizona and Sandia National Labs for passive testing of fibers

Special thanks to NASA Radiation Effects Group

The GSFC Testing was performed at NASA GSFC Radiation Facility Located in Code 201, Greenbelt, MD and Funded by the NASA Electronic Parts and Packaging Program

For more information please see the websites

http://photonics.gsfc.nasa.gov
http://nspc.nasa.gov