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Fiber Amplifier Report for NEPP 2008

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Our website: photonics.gsfc.nasa.gov

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Outline

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

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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

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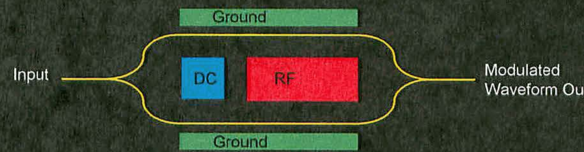
Qualification

- 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
- $LiNbO_3$ X-cut Y-propagating
- PM input and output fibers

Modulator Operational Theory

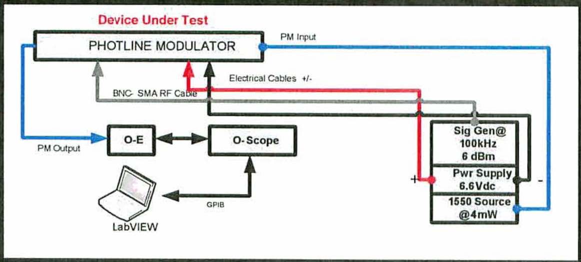


Separate biasing of DC and RF portions of waveguiding region

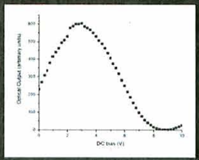
Modulated signal's DC level will drift during normal operation

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

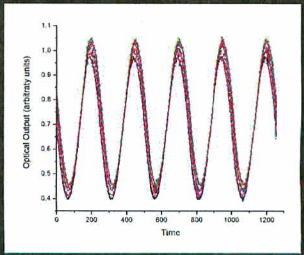
Experimental Setup



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

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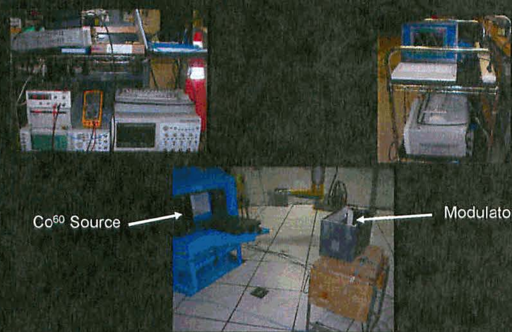
Gamma Radiation Testing



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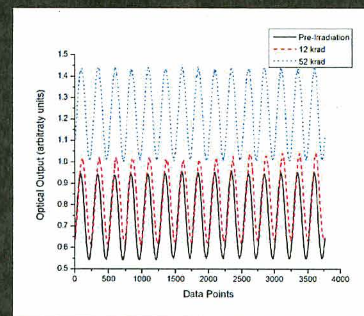
Gamma Radiation Results



7.2 rad/min 52 krad total dose

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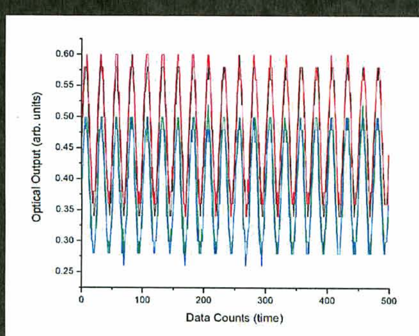
Gamma Radiation Results



111 rad/min 1 Mrad total dose

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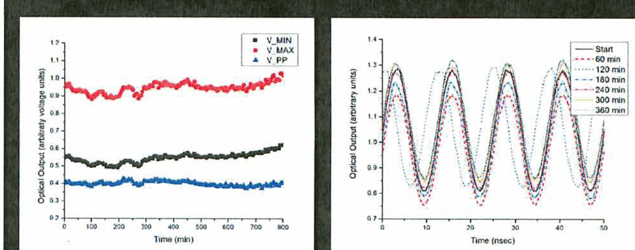
Gamma Radiation Results



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

Post-radiation testing to examine induced changes in modulator operation

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

Unpumped Configuration

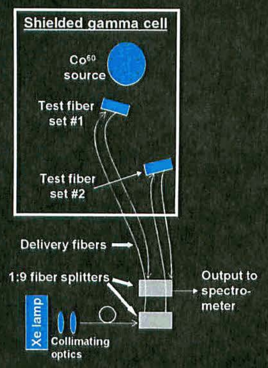
- Ongoing collaborative research on radiation-induced effects in Er-, Yb-, and Er/Yb-doped fibers
- Initial testing focused on unpumped (passive) fiber configurations
- Testing conducted at Sandia National Labs' Gamma Irradiation Facility (GIF)

The University of Arizona, Tucson Arizona

Sandia National Laboratories

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 SiO_2 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.

Fiber Laser Testing

Unpumped Configuration

Rare-Earth Doped Fiber	Manufacturer	Fiber Samples
Yb-doped fiber	Liekki	Yb1200-20/400DC, Yb1200-30/250DC,Yb1200-4/125, Yb1200-10/125DC, Yb2000-6/125DC
Er-doped fiber	Liekki	Er16-8/125, Er20-4/125, Er30-4/125, Er40-125, Er80-4/125, Er110-4/125
Er/Yb co-doped fiber	OFS	OFS Er/Yb PM DC

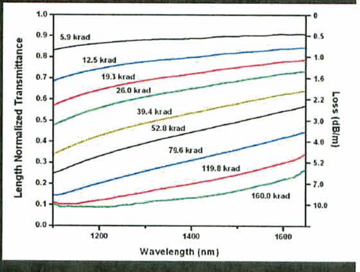
Note: First number designates the nominal peak absorption in dB/m at 976 nm for Yb (1530 nm for Er), and the second and third numbers denote the core and cladding diameters respectively in µm. The 'DC' designates the double-clad fibers.

- Pigtails (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 Yb1200-4/125 fiber.
- Wavelength dependence of radiation-induced optical losses visible at large total doses.



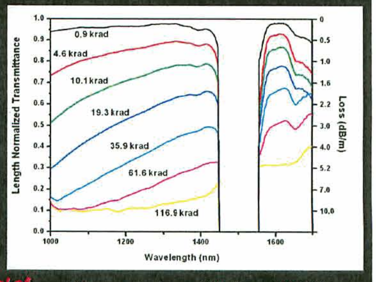
Data reported account for removal of lamp spectrum and background losses arising from fiber pigtails and delivery fibers.

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.



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

Dose rate = 40.1 rad(Si)/s

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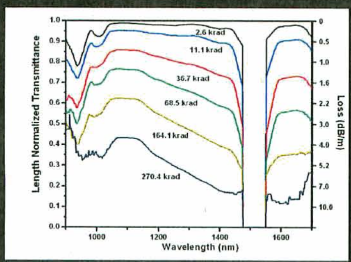
Er/Yb-Doped Fiber Radiation Results

Unpumped Configuration

- 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 1500 nm due to erbium.



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

Dose rate = 40.1 rad(Si)/s

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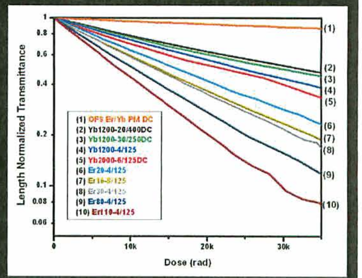
Radiation-Induced Loss With Dose

Unpumped Configuration

- Decay of optical transmittance for Er-, Yb-, and Er/Yb-doped fibers at 1100 nm.
- Radiation-induced optical transmittance reduction is roughly exponential in nature for all fibers.
- Yb-doped fibers (2-5) are more radiation resistant than Er-doped fibers (6-10).
- Co-doped fibers (1) exhibit the most radiation resistance within the suite of tested fibers.



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

Dose rate = 40.1 rad(Si)/s

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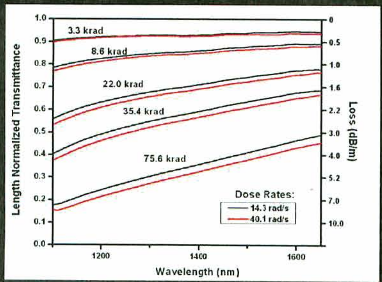
Dose Rate Effects for Yb-Doped Fiber

Unpumped Configuration



- Optical transmittance measurements for Yb1200-4/125 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 lamp spectrum and background losses arising from fiber pigtails and delivery fibers.

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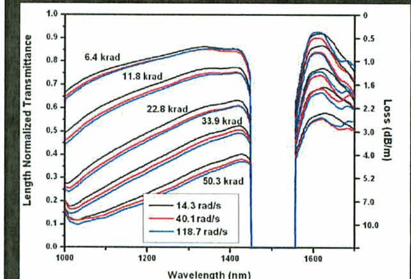
Dose Rate Effects for Er-Doped Fiber

Unpumped Configuration



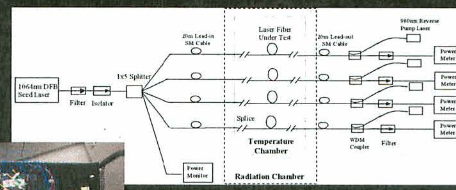
- Optical transmittance measurements for Er20-4/125 fibers exposed to three distinct dose rates.
- Dose rate dependence observed, which increases with larger total dose.
- Increase of photodarkening (relative change) due to higher dose rate is under 10%.

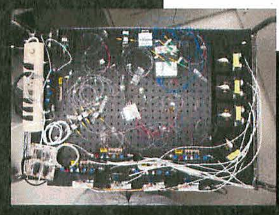
Data reported account for removal of lamp spectrum and background losses arising from fiber pigtails and delivery fibers.

Fiber Laser Testing
Pumped Configuration

- 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

Experimental Setup
Pumped Configuration





Fiber Laser Testing
Pumped Configuration

Characteristics of Diode Lasers and Gain Fibers

Multiple Gain Fiber Radiation Test Results
Test Set-up and Experiment Completed by: Dr. Tracee L. Jamison
November 5-13, 2007

Table 1. Pump Laser Diode Characteristics

Laser Pump JDS Uniphase Serial #	Laser Diode	Temp		Diode Driver Current	Pump λ	Pump Pwr At Output of WDM (mW)	*Output Power From Gain Fiber+50m lead in/out fiber (mW)	Gain Fiber
		V	°C	(mA)	(nm)			
29-AYK394	Laser Diode #1	2.48	75	400	980	250	.2	LMA
29-AYK384	Laser Diode #2	2.46	75	400	980	250	28	LEIKKI
29-AYK402	Laser Diode #3	2.48	75	400	980	260	2.163	SMA

*WDM is connected to input of 25m lead-in fiber. This measurement is the amount of power measured from the output of 25m lead-out fiber.

Table 2. Seed Laser Characteristics

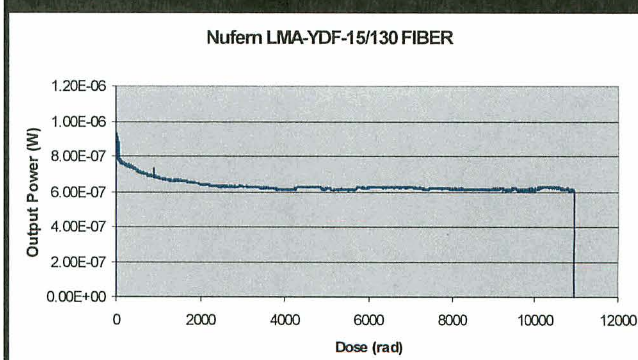
Laser Pump JDS Uniphase Serial #	Seed Laser Diode	Temp		Pump λ	Power at Input To Gain Fiber	Output Power From Gain Fiber+50m lead in/out fiber (μW)		
Lumics		V	°C	(nm)	(mW)	LEIKKI	LMA	SMA
SN0077223	Seed Laser Diode	2.48	75	1064	5	.0040	.5713	.0416

*WDM is connected to input of 25m lead-in fiber. This measurement is the amount of power measured from the output of 25m lead-out fiber.

Table 3. Gain Fiber Under Radiation Testing Summary

Gain Fiber	Length (m)	Gain Characteristics
Nufern LMA-YDF-15/130	2	6.0dB/m @975nm
Nufern SM-YDF-5/130	6	1.7dB/m @975nm
LEIKKI Yb1200-4/125	1	12dB/m @976nm

Fiber Laser Testing
Pumped Configuration



Data provided by Tracee Jamison-Hooks

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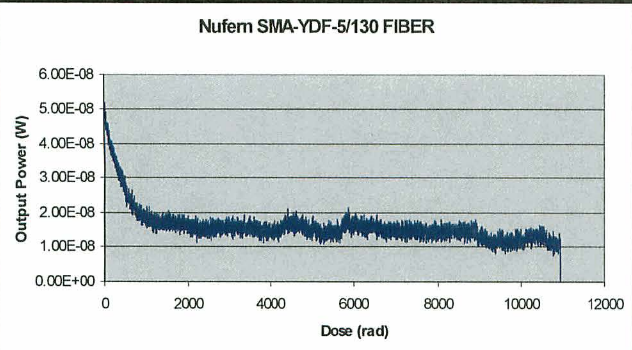
Fiber Laser Testing

Pumped Configuration



Data provided by Tracee Jamison-Hooks

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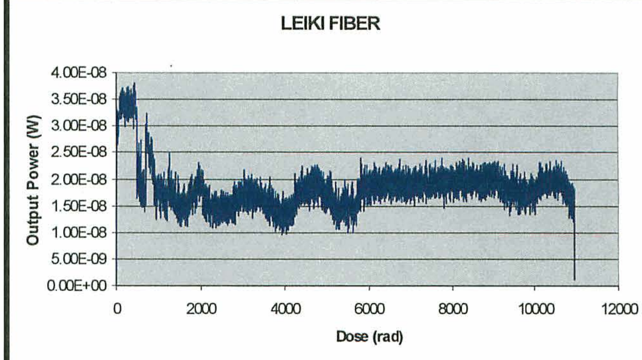
Fiber Laser Testing

Pumped Configuration



Data provided by Tracee Jamison-Hooks

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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

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Conclusions

- Ongoing qualification activities of $LiNbO_3$ 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

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Acknowledgements

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

Special thanks to NASA Radiation Effects Group

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For more information, please see the websites

http://photonics.gsfc.nasa.gov

http://nepp.nasa.gov