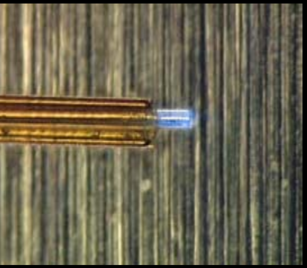
Validation of Commercial Fiber Optic Components for Aerospace Environments



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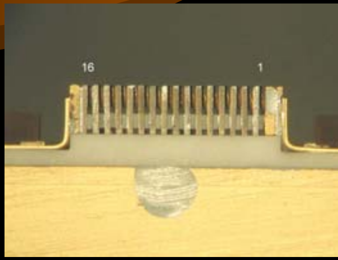
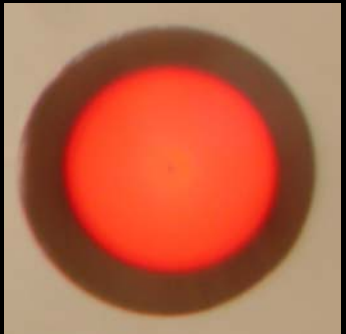
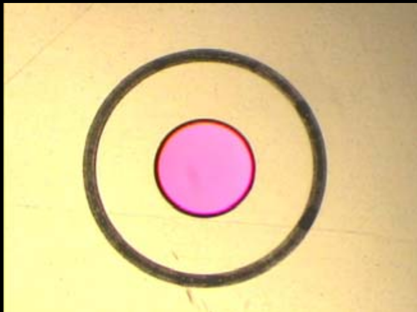






Outline

- Introduction
- NASA COTS Photonics Validation Approach
- Construction Analysis
- Vacuum Validation
- Vibration Parameters
- Thermal Parameters
- Radiation Parameters
- Examples: Shuttle Return to Flight
- Examples: Mercury Laser Altimeter
- Examples: Geoscience Laser Altimeter
- Conclusion

Introduction

Changes in Our GSFC Environment

Short term projects, low budgets

Instruments like GLAS, MLA, VCL

Changes to the Mil-Spec system, NASA relied heavily.

Telecommunications products available, state-of-the-art.

Vendors and parts rapidly changing.

Most photonics now COTS.

Qualification not only impossible but far too expensive.

Characterization of COTS for risk mitigation.

Quality by similarity where possible.

COTS Technology Assurance Approach For Space Flight

System Requirements: Define critical component parameters and the quantity by how each can deviate from optimal performance as a result and during testing.

Environmental Requirements

Contamination and materials requirements.

Box level random vibration, double for component

Thermal environment, 10 C higher at extremes

Radiation, worst case conditions.

Failure Modes Study

- Conditions and Parameters

Test Methods

- Tailored to capturing the largest amount of failure modes while testing for space environment.

Test Plan

- Contains necessary testing for mission while monitoring for failure modes.

Qualification Plan

Define critical parameters that must be stable during testing.
Define acceptable changes in performance parameters as a final result of testing and during testing (dynamic and permanent).
Define part or system to be tested.
How many samples can you afford to test (considering time, equipment, materials)

Materials Analysis,
- Outgas testing for anything unknown, take configuration into account.
- Packaging!

Vibration Survival and “Shock” Test
- Use component levels as defined by system requirements
- Define parameters to monitor during testing

Thermal Cycling/Aging Test
- Define which parameters will indicate which failure mode
- Monitor those parameters during testing.

Radiation Testing
- Accelerated dose rate, extrapolation model use if possible, worst conditions

Addition test based on specific mission requirements?

Construction/Materials Analysis

Destructive Physical Analysis

  Identify packaging issues

Gases Analysis, hermetic?

Materials identification,

  Packaging: wirebonds, die attach materials

Identify non metallic materials for vacuum exposure

  Potential contamination issues.

Construction Analysis is crucial!

  Long Term Reliability

  Will it survive harsh environments?

Environmental Parameters

- Vacuum requirements
- Vibration requirements
- Thermal requirements
- Radiation requirements

Environmental Parameters: Vacuum

Vacuum outgassing requirements:

- ASTM-E595,
  - 100 to 300 milligrams of material
  - 125°C at 10^{-6} Torr for 24 hours
  - Criteria: 1) Total Mass Loss < 1%
    - 2) Collected Volatile Condensable Materials < 0.1%
  - Configuration test
  - Optics or laser nearby, is ASTM-E595 enough?
    - -ask your contamination expert

1) Use approved materials
2) Preprocess materials, vacuum, thermal
3) Decontaminate units: simple oven bake out, or vacuum?

Environmental Parameters: Vibration

Launch vehicle vibration levels for small subsystem (established for EO-1)

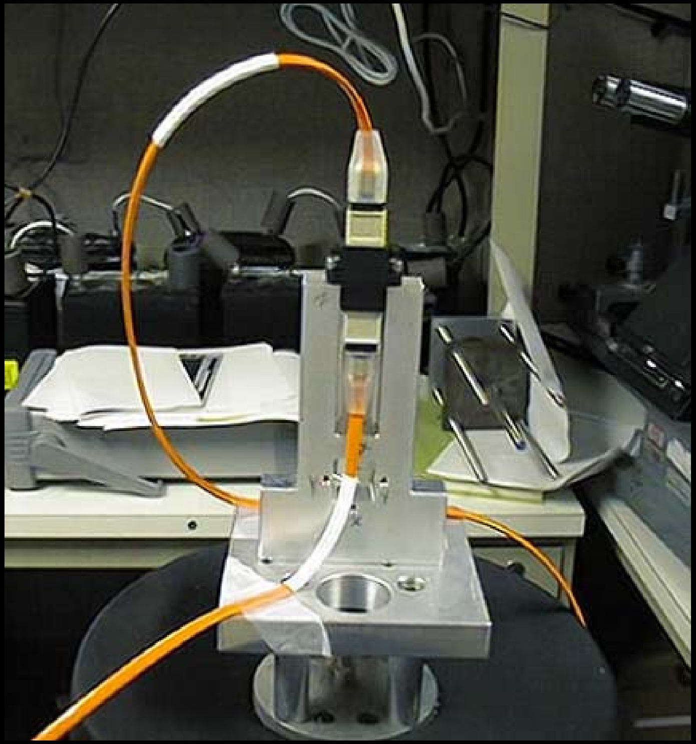
Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

However, this is at the box level, twice the protoflight vibration values establish the correct testing conditions for the small component.

Environmental Parameters: Vibration

Launch vehicle vibration levels for small component (based on box level established for EO-1) on the "high" side.

Frequency (Hz)	Protoflight Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms



3 minutes per axis, tested in x, y and z

Environmental Parameters: Thermal

There is no standard, typical and benign –25 to +85 C.
Telcordia is –45°C to +80°C.

Depending on the part for testing;

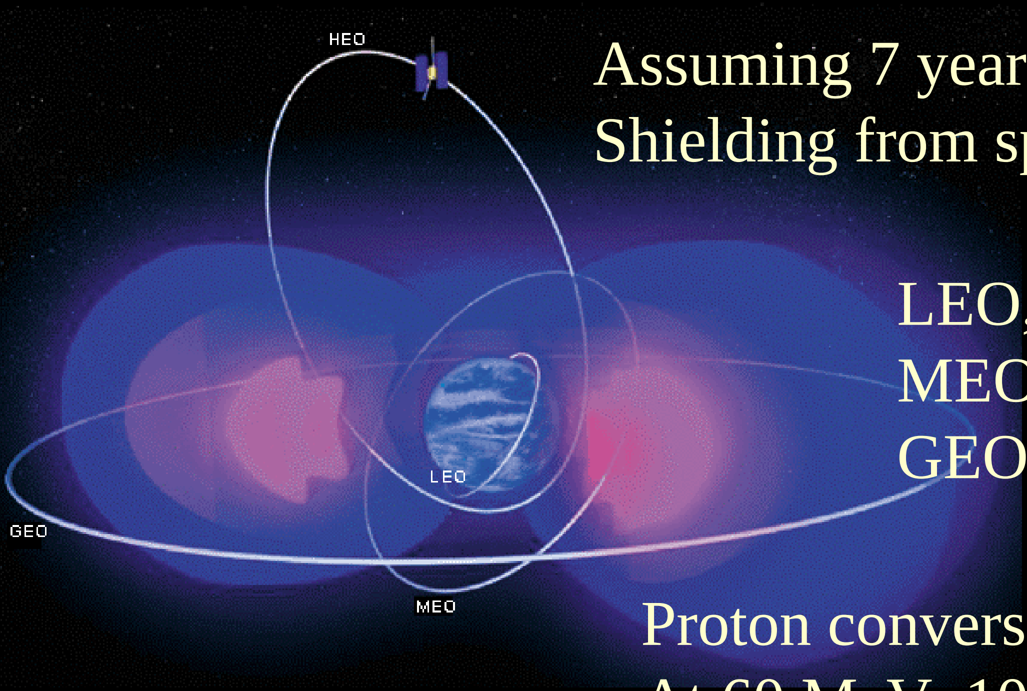
- Insitu testing where possible
- Add 10°C to each extreme for box level survival

Thermal cycles determined by part type

- 60 cycles for assemblies for high reliability
- 30 cycles minimum for assemblies, high risk
- 100 or more, optoelectronics.
- More for high power systems

Knowledge of packaging and failure modes really helps with cycles determination.

Environmental Parameters: Radiation



Assuming 7 year mission,
Shielding from space craft

LEO, 5 – 10 Krads, SAA
MEO, 10 –100 Krads, Van Allen belts
GEO, 50 Krads, Cosmic Rays

Proton conversion to Total Ionizing Dose (TID)
At 60 MeV, 10^{10} protons/Krad
For systems susceptible to displacement damage

Environmental Parameters: Radiation

Typical space flight background radiation total dose
30 Krads – 100 Krads over 5 to 10 year mission.

Dose rates for fiber components:

- GLAS, 100 Krads, 5 yr, .04 rads/min
- MLA, 30 Krads, 8 yr, .011 rads/min (five year ave)
- EO-1, 15Krads, 10 yr, .04 rads/min

Any other environmental parameters that need to be considered? For example, radiation exposure at very cold temp, or prolonged extreme temperature exposure based on mission demands.

Shuttle Return to Flight: Construction Analysis

Optical Fiber Pigtailed Collimator Assemblies

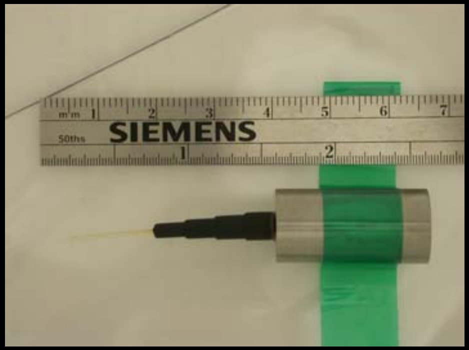
Lightpath: pigtailed fiber to collimator lens and shell

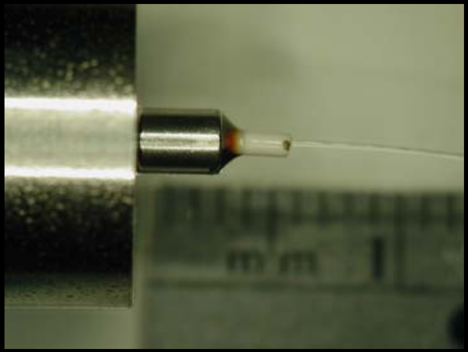
GSFC: upjacket (cable), strain relief and termination, AVIMS, PC, SM

Materials & Construction Analysis

- Non compliant UV curable adhesive for mounting lenses to case
  - Solution 1: replace with epoxy, caused cracking during thermal cycling
  - Solution 2: replace with Arathane, low glass transition temp. adhesive

  Lesson: coordinate with adhesives expert, care with adhesive changes.
- Hytrel, non compliant as an off the shelf product (outgassing, thermal shrinkage)
  - Thermal vacuum preconditioning (145°C, <1 Torr, 24 hours)
  - ASTM-E595 outgas test to verify post preconditioning.
  - Thermal cycling preconditioning (30 cycles, -20 to +85°C, 60 min at +85°C)



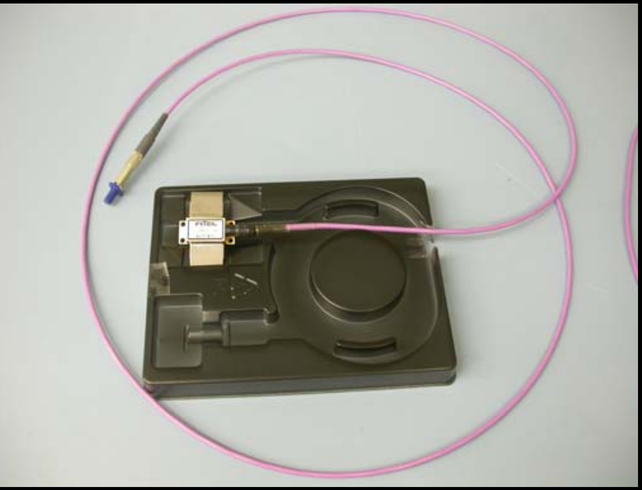


Shuttle Return to Flight

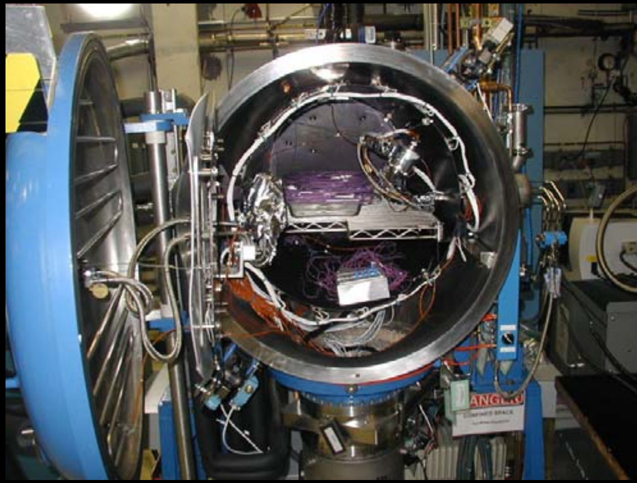
Laser Diode Assemblies

Fitel: laser diode pigtails
GSFC: Upjacket (cable), strain relief, termination, AVIMS APC SM
Fitel uses silicone boot, non-compliant!
Too late in fabrication process, schedule considerations to preprocess.

Cable: Thermal preconditioning, 30 cycles
Hytrel boots: Vacuum preconditioning, 24 hours
Kynar heat shrink tubing, epoxy: approved for space use.



Post manufacturing decontamination of entire assembly required
Laser diode rated for 85°C processing performed at 70°C



Mercury Laser Altimeter (MLA): Construction Analysis

Optical Fiber Assemblies

Diamond AVIMS connector / W.L. Gore Flexlite
Polymicro Technologies FIA 200/220
Performance: <.04 dB loss

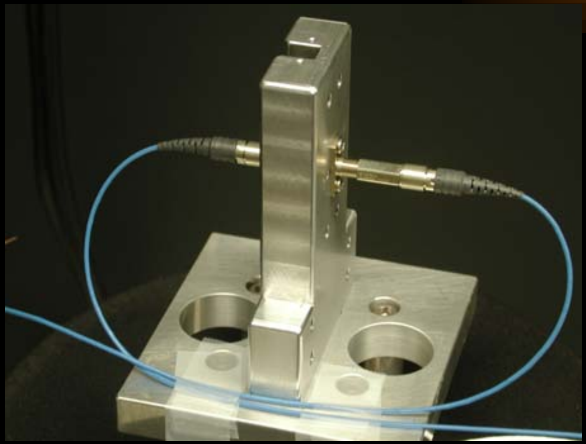
Preconditioning of non metallic materials and failure modes knowledge of construction

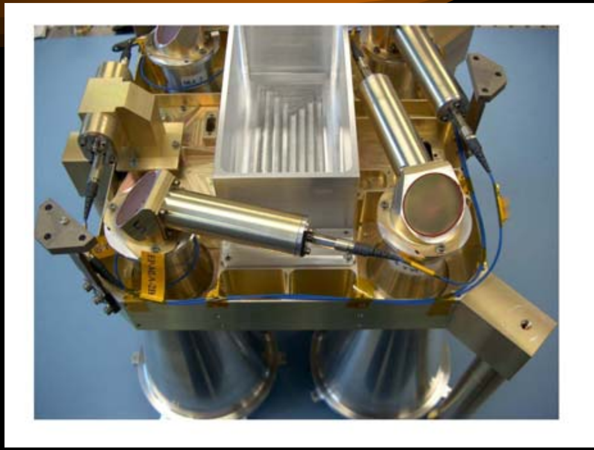
Hytrel boots: Thermal vacuum precondition: 140°C, 24 hrs, 1 Torr
Flexlite cable: Thermal preconditioning, 8 cycles, -20 to +60°C, 60 min at 60°C
Epotek 353ND: approved for space.

Post processing decontamination of assemblies @ 50°C (To bake out but not to age)

- Cure schedule on outgassing database is very high temp.
- Best to use close to usage temp cure, with a post cure bake out

MLA Assembly Environmental Validation





Requirements/Testing: Performance < .4 dB for all, 850 nm

Vibration 14.1 grms, 3 min/axis

Because box level @ 10 grms

Thermal: -30°C to +50 °C, 90 cycles, last 42 monitored

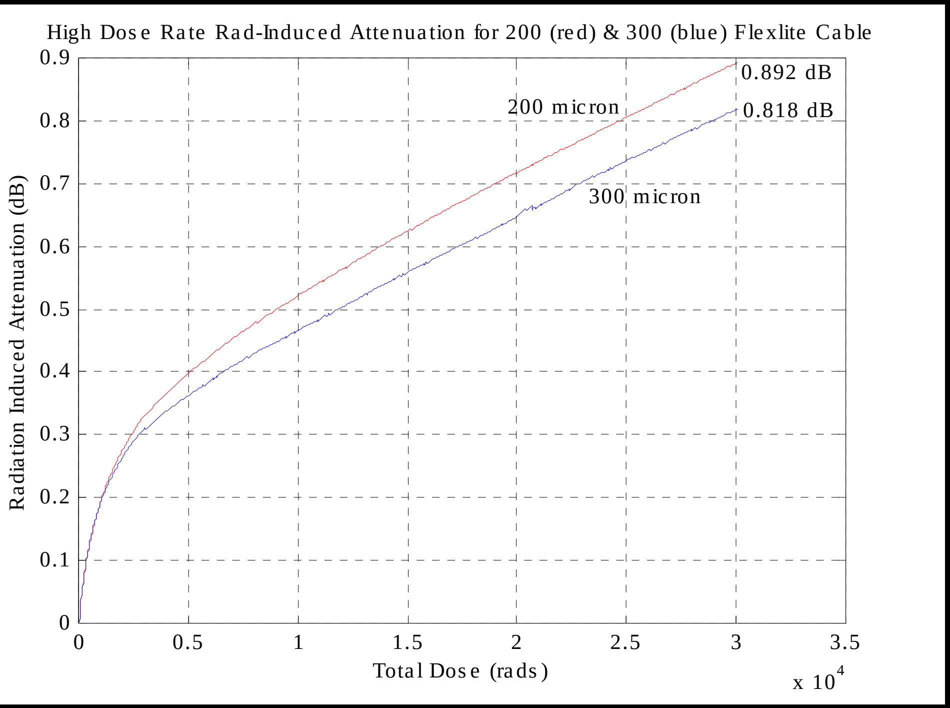
25 minute soak, 2 °C/min ramp rates.

Radiation: two dose rate model, -20°C,

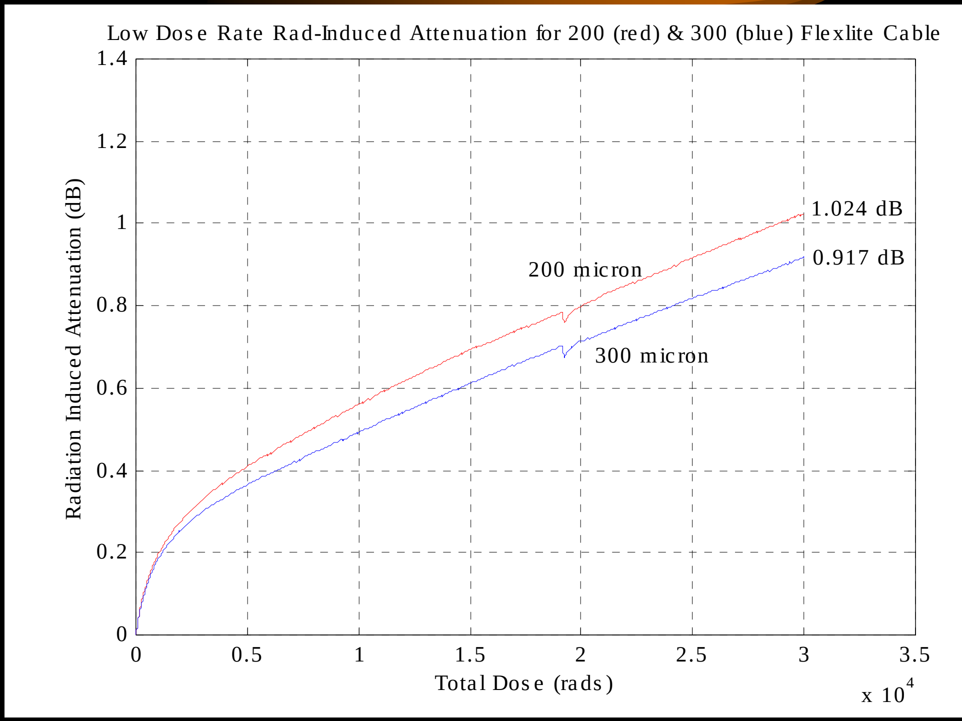
11.2 and 22.7 rads/min to 30 Krads

(Actual dose rate .011 rads/min)

MLA Assembly Environmental Validation



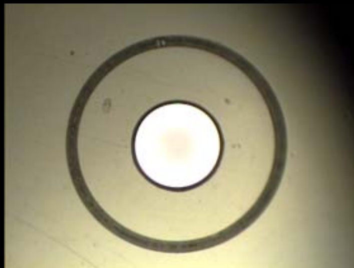
Flexlite Radiation Test, 22.7 rads/min at –18.3°C



Flexlite Radiation Test, 11.2 rads/min at –24.1°C

Radiation Conclusion: < .07 dB, using 11.2 rads/min, -24.1°C, 26.1 in, “dark”
Results for 10 m, at 30 Krads, -20°C, 850 nm, 23 rads/min ~ 1 dB or 0.10 dB/m

Random Vibration and Thermal Cycling: no registered losses
</= .04 dB power increase

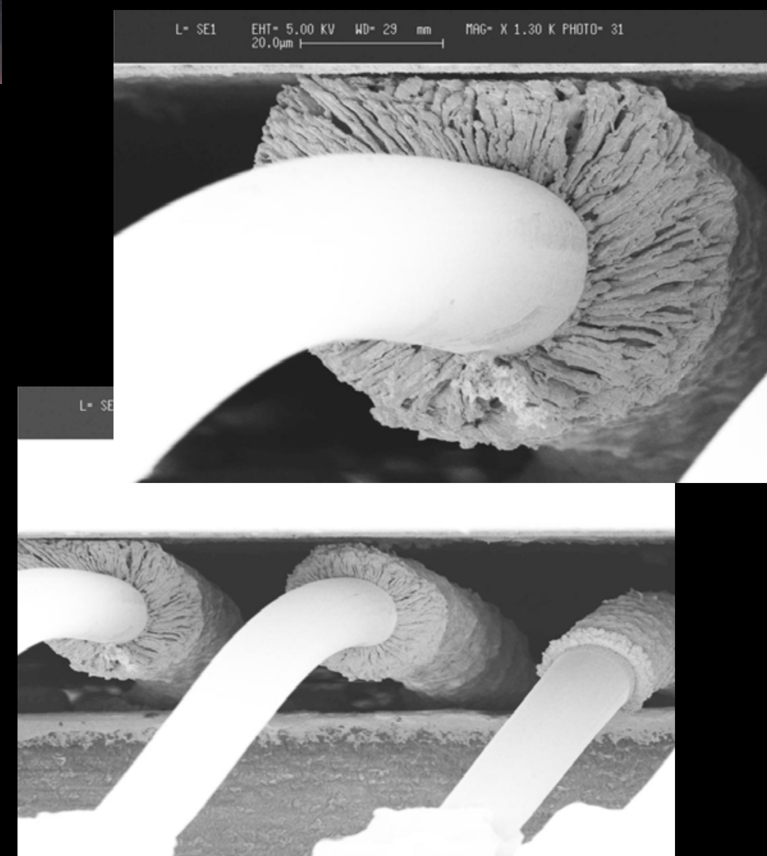


Geoscience Laser Altimeter (GLAS): Fiber, Assemblies, Diodes

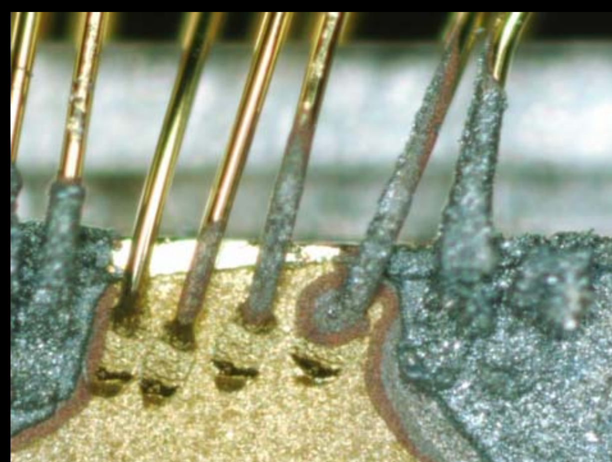
- Fiber
  - Variety of candidates, radiation analysis based on previously published data, quality by similarity.
  - Database funded by NEPP,
    - IEEE NSREC Data Workshop 2002 (misspiggy.gsfc.nasa.gov/photonics)
  - Electron testing for scintillation effects.
- Cable Assemblies (AVIMS, Flexlite)
  - Quality by similarity, tested by Lockheed-Martin.
- Laser Diodes
  - Never performed a construction analysis and devices failed in space flight.

Laser Diode Packaging Issues

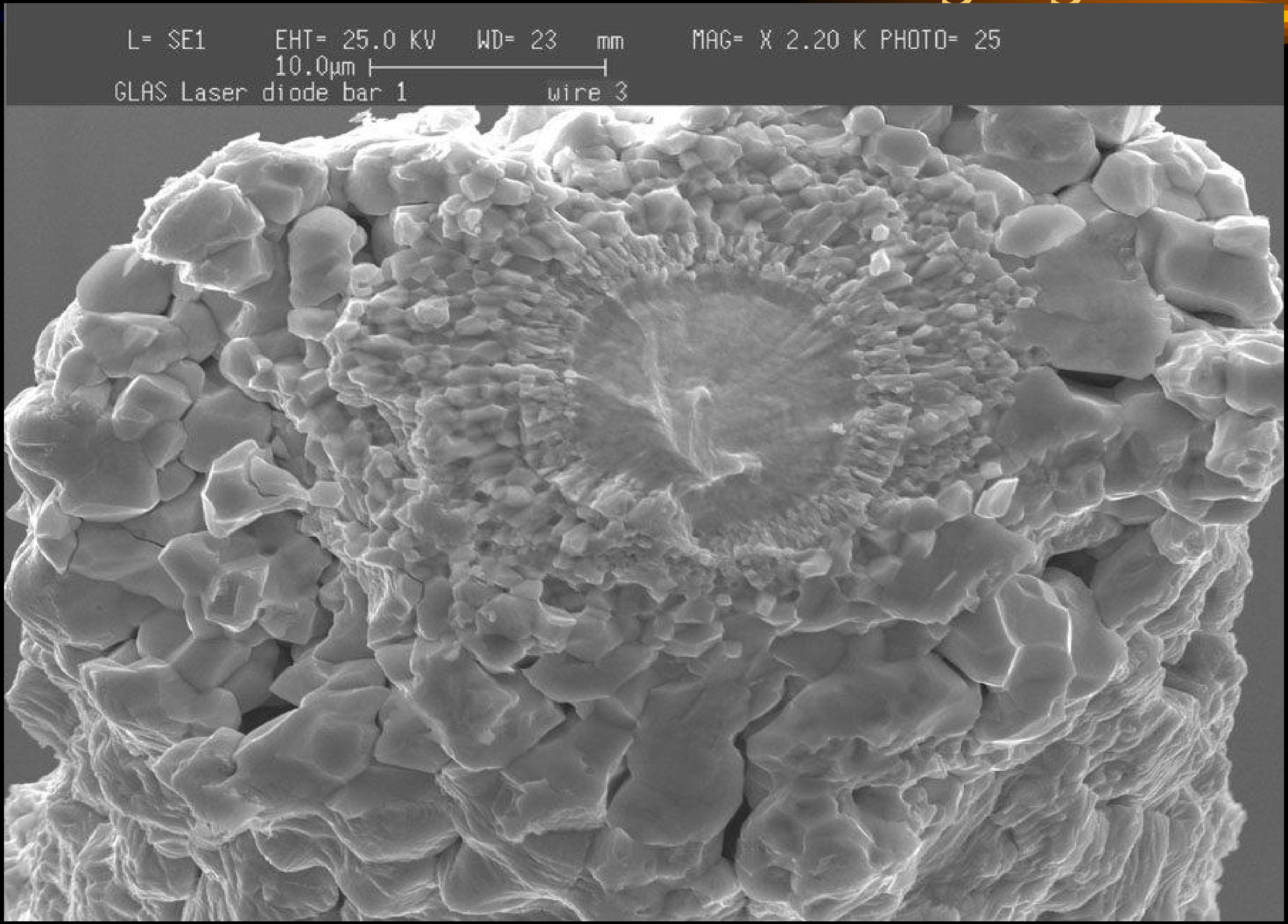
Device Short
Indium creep
into bolt holes



Indium creep
onto the gold
wires
Intermetallic
Gold/indium



Laser Diode Packaging Issues



Intermetallic-Indium attack of gold wire

Laser Diode Operation

Project	Pulse width	Rep. Rate	Peak Current	Stress ~(I^2*PW)	Damage/Pulse ~($Stress^8$)	Damage Rate ~(D/P * RR)
MOLA	150 μs	10 Hz	60 Amp	$5.4*10^5$	$7.23*10^{45}$	$7.23*10^{46}$
GLAS	200 μs	40 Hz	100 Amp	$2.0*10^6$	$2.56*10^{50}$	$1.02*10^{52}$
Calipso	150 μs	20 Hz	60 Amp	$5.4*10^5$	$7.23*10^{45}$	$1.45*10^{47}$
MLA	160 μs	8 Hz	100 Amp	$1.6*10^6$	$4.30*10^{49}$	$3.44*10^{50}$

Why did the GLAS laser 1 fail while others did not?

Conclusion

Performance Requirements (System Engineer, Top level Spec)

Environmental Requirements

- Thermal Engineer
- Contamination Engineer
- Radiation Physicist

Physics of Failure

- Components Engineer
- Materials Experts
- Can save $$$$

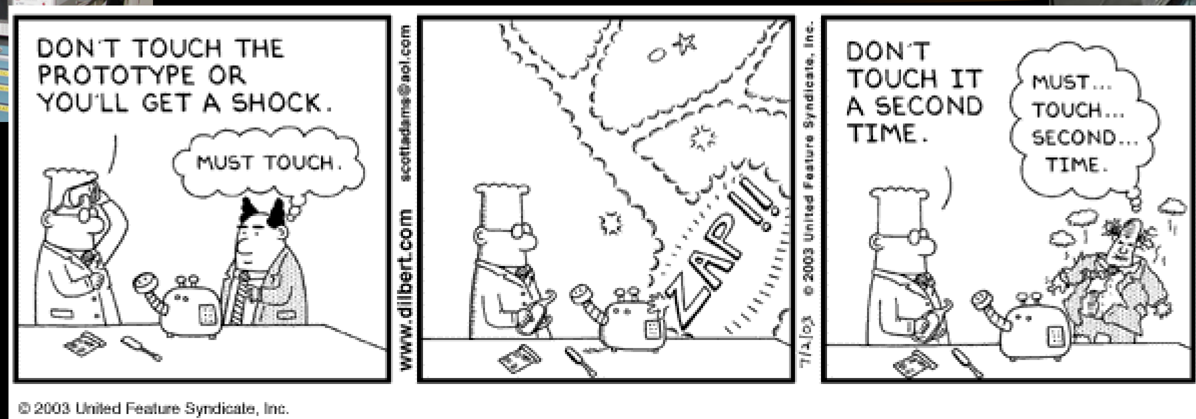
Materials Analysis (crucial!)

Test Plan tailored to above,

- Define criteria or range of performance allowable.
- Quality by similarity for environmental testing.

Choose Telcordia qualified when you can.

Thank you for the invitation!



Thanks to our GSFC support team

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Robert Zannini @ Diamond USA

For more information please visit the website:

misspiggy.gsfc.nasa.gov/photonics

Back up slides start here

Laser Diode Packaging Issues

GLAS, MOLA, MLA, Calipso use high power laser diode bar arrays for pumping of solid state lasers.

Indium creep (shorting, intermetallics)

Cracking of semiconductor from wedgebonds

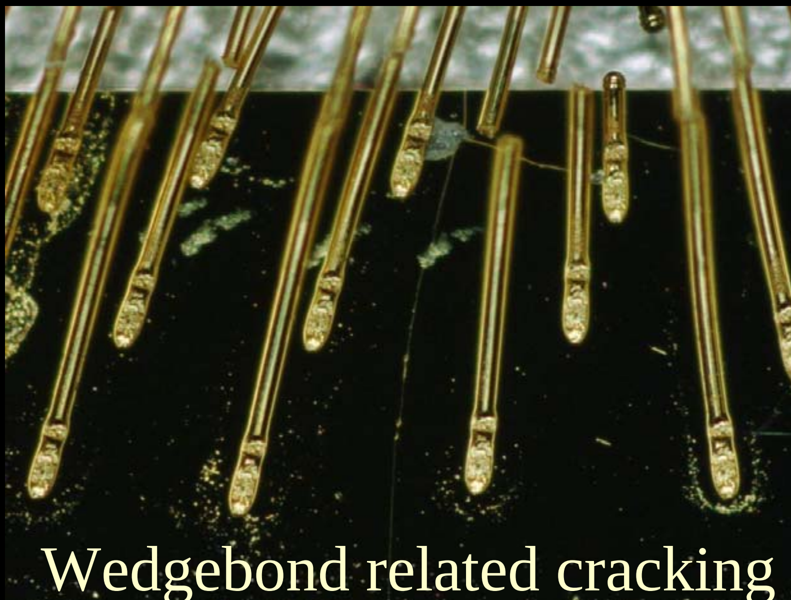
Diffusion layer pinholes

Dendrite growth of tin/lead solder

Contamination related failure (hermetic packaging)

Workmanship Issues (application of indium solder)

Laser Diode Packaging Issues



Wedgebond related cracking

Crack resulted in low res. Path to wires

BeO

Indium solder

Copper

Indium solder bond broke

Workmanship: application of Indium solder

Pictures from Dr. Henning Leidecker's presentation
"Failure Analysis of GLAS Laser Diode Arrays,"
Community Forum on Laser Diode Arrays in Space-Based Applications, 2004

Radiation Testing @ 1300 nm, OFS optical fiber

Part	Dose Rate	TID	Temp	Attenuation
BF05444 100/140/500	0.1 rads/min	100 Krad	25°C	0.0048 dB/m
BF05202 100/140/172 RH	14.2 rads/min	5.1 Krad	-125°C	0.14 dB/m
BF05202 100/140/172 RH	42 rads/min	100 Krad	-125°C	1.5 dB/m
CF04530 100/140/172 S	14.2 rads/min	5.1 Krad	-125°C	0.053 dB/m
CF04530 100/140/172 S	42 rads/min	100 Krad	-125°C	0.064 dB/m
BF04431 62.5/125/250	0.1 rads/min	100 Krad	-25°C	0.91 dB/m
BF04431 62.5/125/250	0.1 rads/min	100 Krad	25°C	0.59 dB/m

“Radiation Effects Data on Commercially Available Optical Fiber,” M. Ott, IEEE NSREC 2002

Radiation Effects on Rare Earth Fiber for Lasers Paper Survey

Aluminum content increases radiation induced effects [1]

Yb (mol %)	Al_2O_3 (mol %)	P_2O_5 (mol %)	TID Krad	Rad Induced Atten.
0.13*	1.0	1.2	14	1 dB/m
0.18	4.2	0.9	14	12 dB/m

*** Fiber also contains 5.0 mol% Germanium. Data at 830 nm, 180 rads/min.**

Rare Earth dopant (Er) does not dominate over radiation performance [2]

Part	Er Content	Al (%mol wt)	Ge (%mol wt)	Sensitivity 980 nm, dB/m Krad	Sensitivity 1300 nm, dB/m Krad
HE980	$4.5\ 10^{24}$ /m^3	12	20	.013	.0041
HG980	$1.6\ 10^{25}$ /m^3	10	23	.012	.0038

84 rads/min upto 50 Krad, 3 m under ambient

[1] H. Henschel et al., IEEE Transactions on Nuclear Science, Vol. 45, Issue 3, June 1998, pp. 1552-1557.
[2] T. Rose et al., Journal of Lightwave Technology, Vol. 19, Issue 12, Dec. 2001, pp. 1918-1923.

Radiation Effects on Rare Earth Fiber for Lasers Paper Survey

Low Dose Rate, .038 rads/min extrapolation for HE980

Wavelength	Total Dose	Radiation Induced Attenuation
980 nm	100 Krad	**0.91 dB/m**
1300 nm	100 Krad	**0.26 dB/m**
1550 nm	100 Krad	**0.14 dB/m**

Also shows wavelength dependence, consistent with other COTS fiber.

Yb and Er doped fibers are equivalent in terms of sensitivity.

Lanthanum doped fibers are extremely sensitive at ~10's dB/m.

Yb and Er doped fibers exhibit saturation behavior.

Proton and gamma exposures show similar results.

To compare sensitivity to typical 100/140 at 100 Krads

Temp	λ nm	Dose rate	Sensitivity	Reference
25°C	1310	.01 rads/min	$1.7\ 10^{-4}$ dB/m	M. Ott, SPIE Vol. 3440.
50°C	850	.032 rads/min	$2.0\ 10^{-4}$ dB/m	M. Ott, IEEE NSREC Data Workshop 2002.