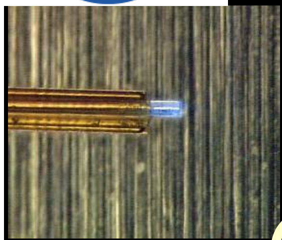
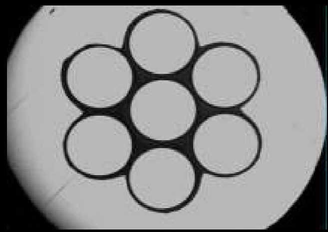

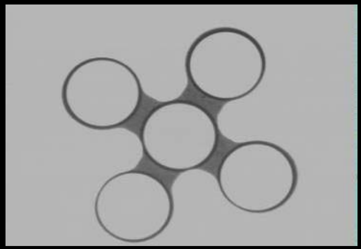
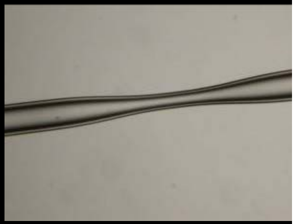

Qualification and Lessons Learned with Space Flight Fiber Optic Components

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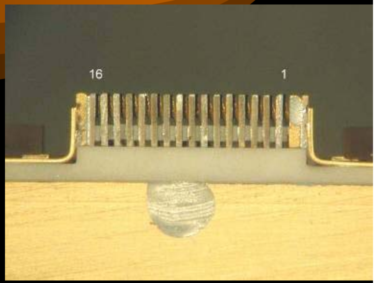
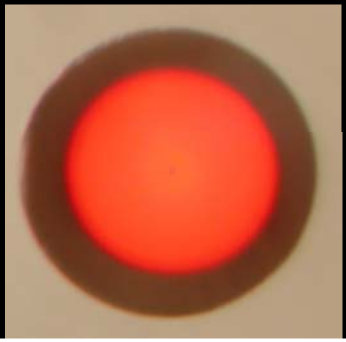
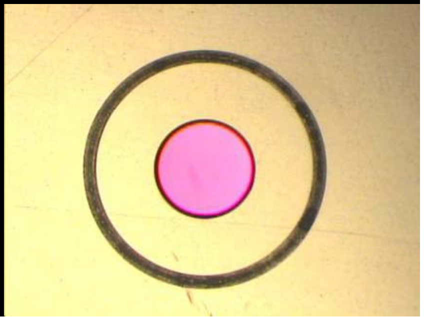


misspiggy.gsfc.nasa.gov/photonics

September 20, 2007

Tutorial for the Optical Society of America

Frontiers in Optics 2007/Laser Science XXIII

Outline

- Introduction
- NASA COTS Photonics Validation Approach
- Construction Analysis
- Vacuum Validation
- Vibration Parameters
- Thermal Parameters
- Radiation Parameters
- Examples:
  - Materials - Shuttle
  - Vibration – Qual vs. Workmanship, LRO
  - Thermal – ISS new candidates
  - Radiation – MLA, LRO
  - Motion, LRO
  - Lessons Learned, ISS
- Lessons Learned- Passive
- Conclusion

Our Group

Photonics Group at NASA Goddard Space Flight Center

Rick Chuska

Rob Switzer, Joe Thomes, Shawn Macmurphy, Frank LaRocca, Melanie Ott, Alex Potter

Adam Matuszeski, Xiaodan “Linda” Jin

Our Focus

Design, development and manufacturing of photonic systems and components; optical fiber assemblies, fiber amps, laser diodes, packaging, testing and qualification of components.

- Lunar Orbiter Laser Altimeter, (LOLA)
- Express Logistics Carrier (ELC), Photonics Comm system
- Lunar Reconnassiance Orbiter, (LR) Receiver Telescope assemblies
- Laser Risk Reduction, (LRRP)
- Laser Interferometer Space Telescope (LISA),
- NASA Parts and Packaging Prgm., (NEPP)
- International Space Station, (ISS)
- Shuttle Return to Flight Heat Tile Sensor Camera, Fiber Assemblies
- Sandia National Labs, Fiber Optic Systems
- AFRL for photonic systems
- Los Alamos National Labs, JPL for Mars Science Lab Chemcam
- Instrument Incubation Program, for Arrays and Fiber Amp Components (IIP)
- Robotics and LIDAR TRL enhancement using Fiber Lasers
- Mercury Laser Altimeter, (longest laser communication on record)

Introduction

Changes in NASA Environment

Short term projects, low budgets in new cases

Instruments like MLA, VCL, LOLA, LRO, Shuttle

10 years ago changes to the Mil-Spec system, NASA relied heavily.

Military needs vs. NASA needs different.

Vendors and parts rapidly changing as companies change.

Most photonics for NASA needs now COTS.

Unique applications, used once, not in best interest of vendors to bid.

Qualification far too expensive, won't meet schedule.

Characterization of COTS for risk mitigation.

Quality by similarity where possible.

Issues to Consider

- Schedule, shorter term
- Funds available,
- Identify sensitive or high risk components.
- System design choices for risk reduction.
- Packaging choices for risk reduction.
- Quality by similarity means no changes to part or process.
- Qualify a “lot” by protoflight method—you fly the parts from the lot qualified, not the tested parts.
- Telcordia certification less likely now.

COTS Technology Assurance Approach For Space Flight

System Requirements (Instrument System Engineer) : Define critical component parameters and the quantity by how each can deviate from optimal performance as a result and during testing -- Performance requirements.

Environmental Requirements (Mechanical, Thermal, Radiation Engineers)

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, (Components Engineer)

- Conditions and Parameters,

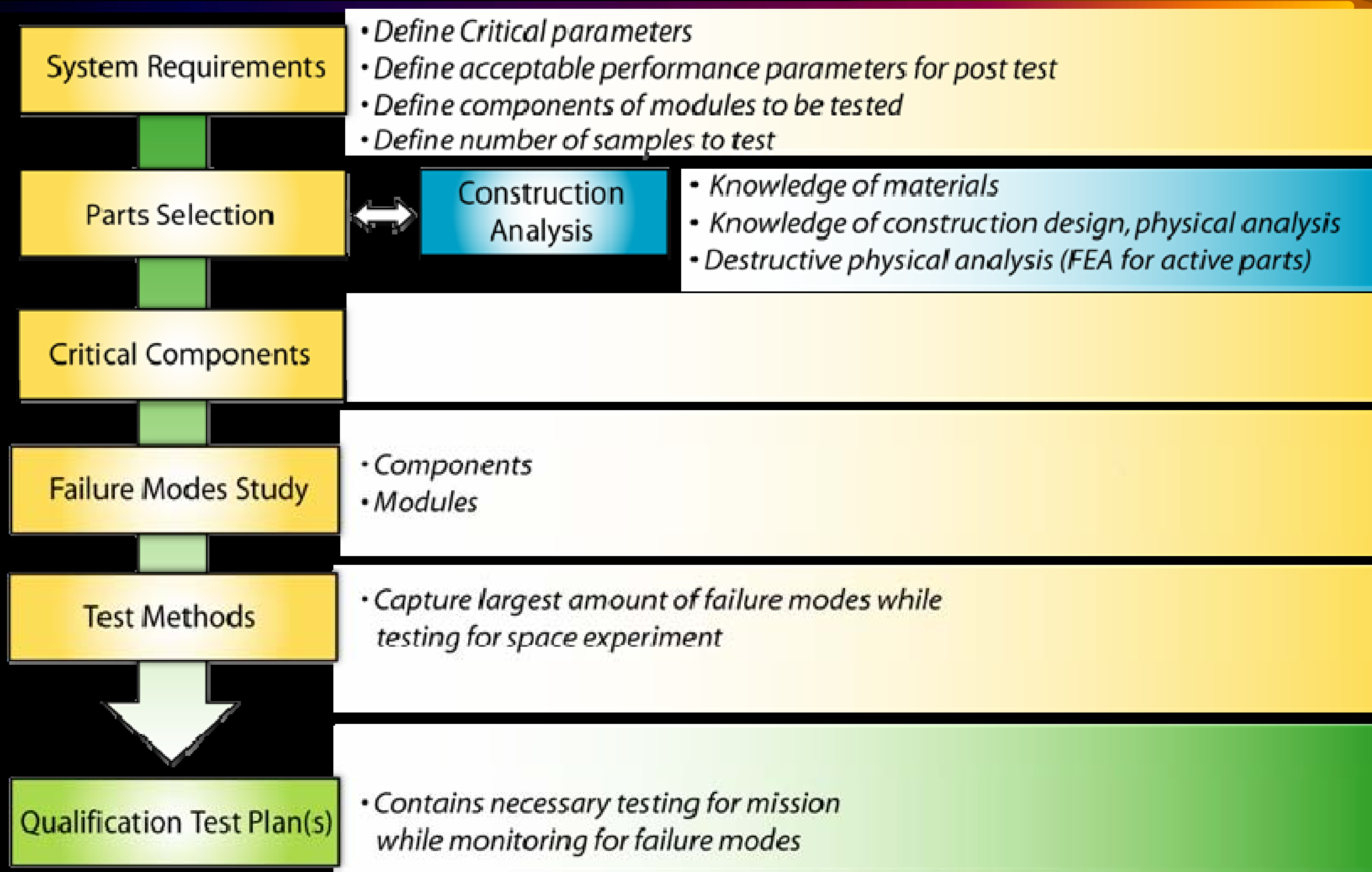
Test Methods

- 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.

COTS Technology Assurance Approach



Flow chart courtesy of Suzzanne Falvey, Northrup Grumman, based on M Ott reference:

* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

Qualification Plan

Define critical parameters that must be stable during testing.
Define acceptable changes in performance parameters as a final result of testing and testing (dynamic and permanent). Acceptance criteria
Choose parts or system to be tested.
How many samples (sample size) can you afford to test (considering time, equipment, materials)?
Materials Analysis,
- Outgas testing for anything unknown, take configuration into account.
- Packaging!
- Destructive Physical Analysis is crucial to formulation of testing plan

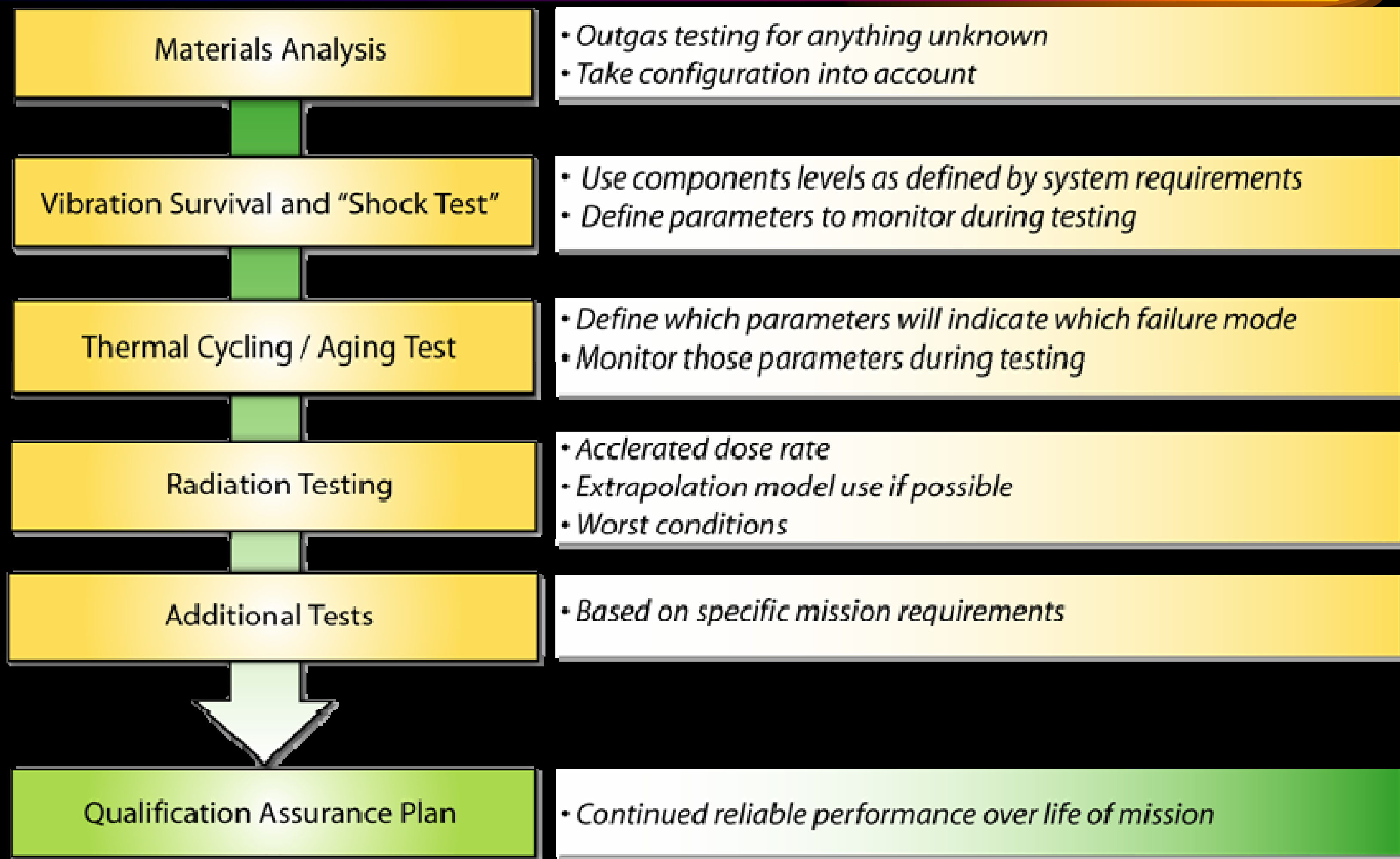
Vibration Survival and “Shock” (larger components) Test
- Use component levels as defined by system requirements
- Define parameters to monitor during testing

Thermal Cycling/Aging Test or Thermal Vacuum (depends on materials analysis)
- 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 tests based on specific mission requirements?

COTS Space Flight "Qualification"



Flow chart courtesy of Suzzanne Falvey, Northrup Grumman, based on M. Ott reference:

* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

Construction/Materials Analysis

Destructive Physical Analysis
- Identify packaging issues

Gases analysis, hermetic?

Materials identification,
- Packaging: wirebonds, die attach materials?
- Fluoropolymers?

Identify non metallic materials for vacuum exposure
- Potential contamination issues.
- Cure schedules –
  - Screening data vs. application

Construction Analysis is crucial!
- Long Term Reliability
- Will it survive harsh environments?

Environmental Parameters

- Vacuum requirements
  - (Materials Analysis or Vacuum Test or both)
- Vibration requirements
- Thermal requirements
- Radiation requirements
- Other Validation Tests

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, outgassing.nasa.gov
2) Preprocess materials, vacuum, thermal
3) Decontaminate units: simple oven bake out, or vacuum?
4) Vacuum test when materials analysis is not conducted and depending on packaging and device.

Space environment; vacuum is actually 10^{-9} torr, best to test as close as possible for laser systems. Many chambers don't go below 10^{-7} torr.

Environmental Parameters: Vibration

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

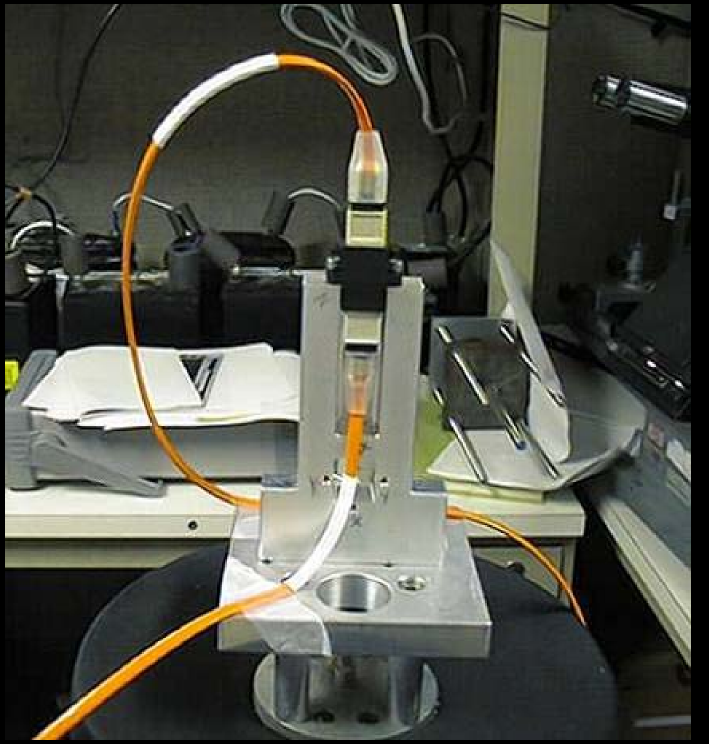
Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

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

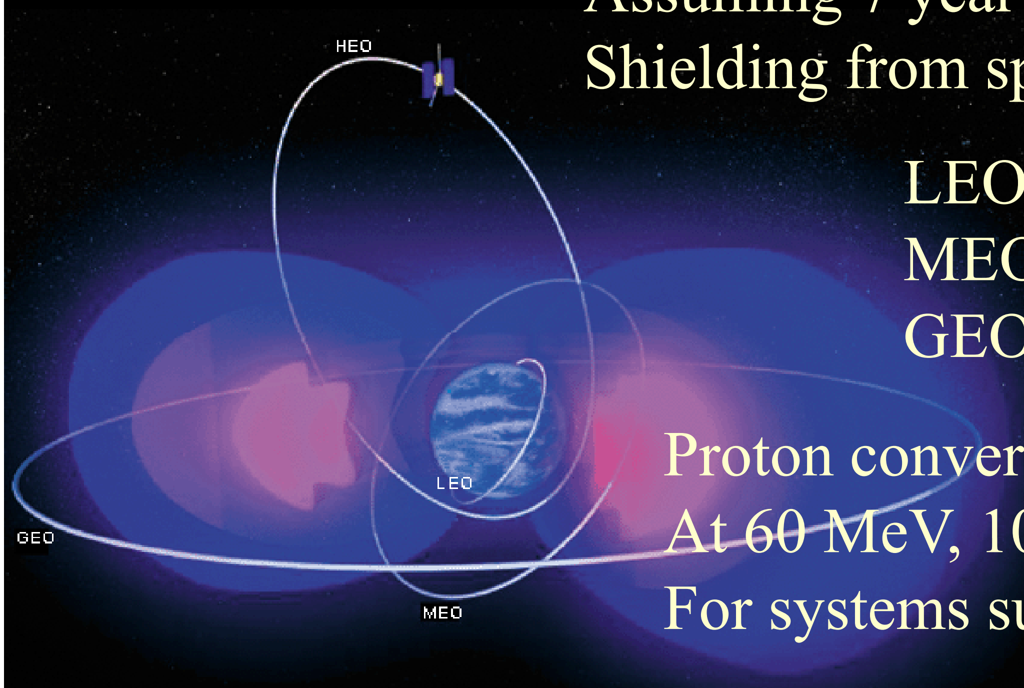
There is no standard, typical and benign –25°C to +85°C.
–45°C to +80°C, Telcordia; -55°C to +125°C, Military

Depending on the part for testing;
- Insitu testing is important,
- Add 10°C to each extreme for box level survival

Thermal cycles determined by part type, schedule vs. risk
- 30 cycles minimum for assemblies, high risk
- 60 cycles for assemblies for higher reliability
- 100 or more, optoelectronics and longer term missions.

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 silicon devices
For systems susceptible to displacement damage

Testing for displacement damage: 3 energies in the range ~ 10 to 200 MeV.
If you have to pick one or two energies stay in the mid range of 65 MeV and lower. Less probability of interaction at high energies.
Ballpark levels: 10^{12} p/cm^2 LEO, 10^{13} p/cm^2 GEO, 10^{14} p/cm^2 for special missions (Jupiter).

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,

1) radiation exposure at very cold temp, or prolonged extreme temperature exposure based on mission demands.

2) Motion during cold exposure.

Materials Issues
Shuttle Return to Flight: Construction Analysis

Optical Fiber Pigtailed Collimator Assemblies

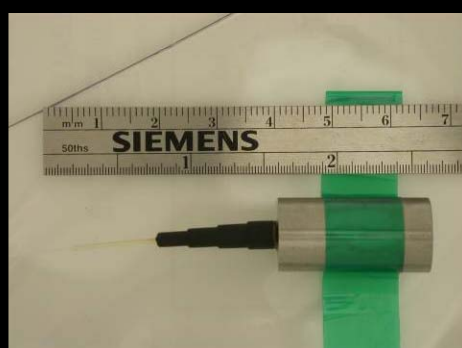
Lightpath: pigtailed fiber to collimator lens and shell

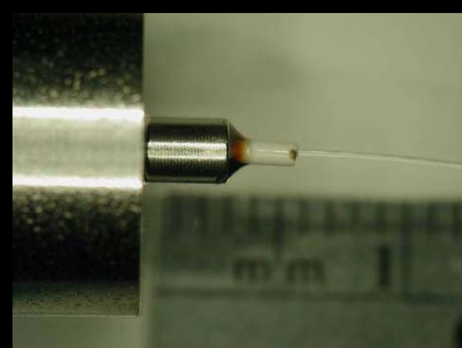
GSFC: upjacket (cable), strain relief and termination, AVIMS, PC, SM

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)





Materials Issues: Shuttle Return to Flight

Laser Diode Assemblies

Fitel: laser diode pigtails

GSFC: Upjacket (cable), strain relief, termination, AVIMS APC SM

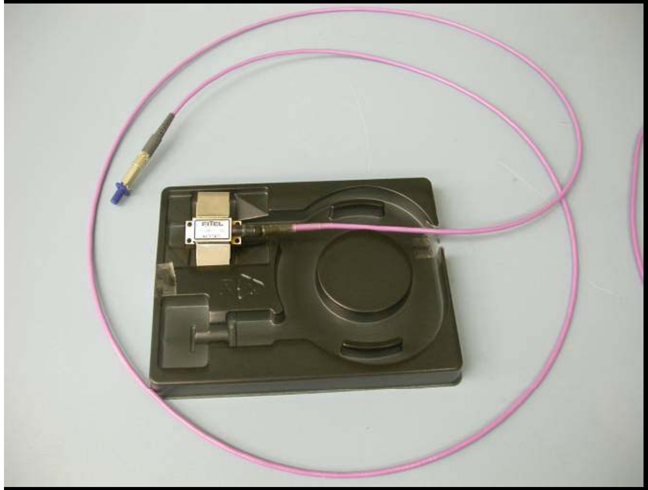
Fitel uses silicone boot, non-compliant!

Too late in fabrication process, schedule considerations to preprocess.

Cable: Thermal preconditioning, 30 cycles

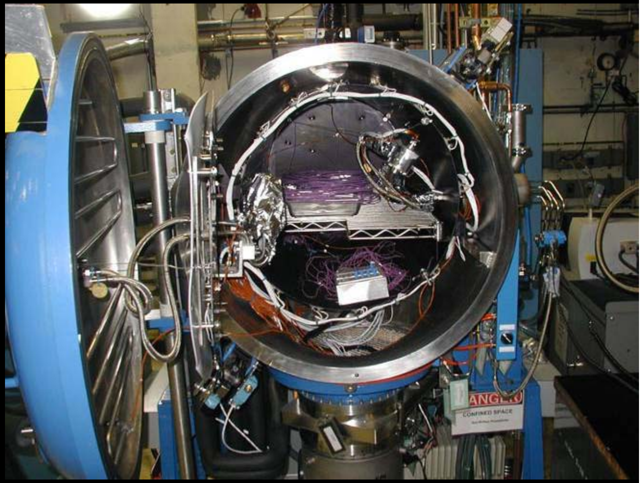
Hytrel boots: Vacuum preconditioning, 24 hours

Kynar heat shrink tubing, epoxy: approved for space use.



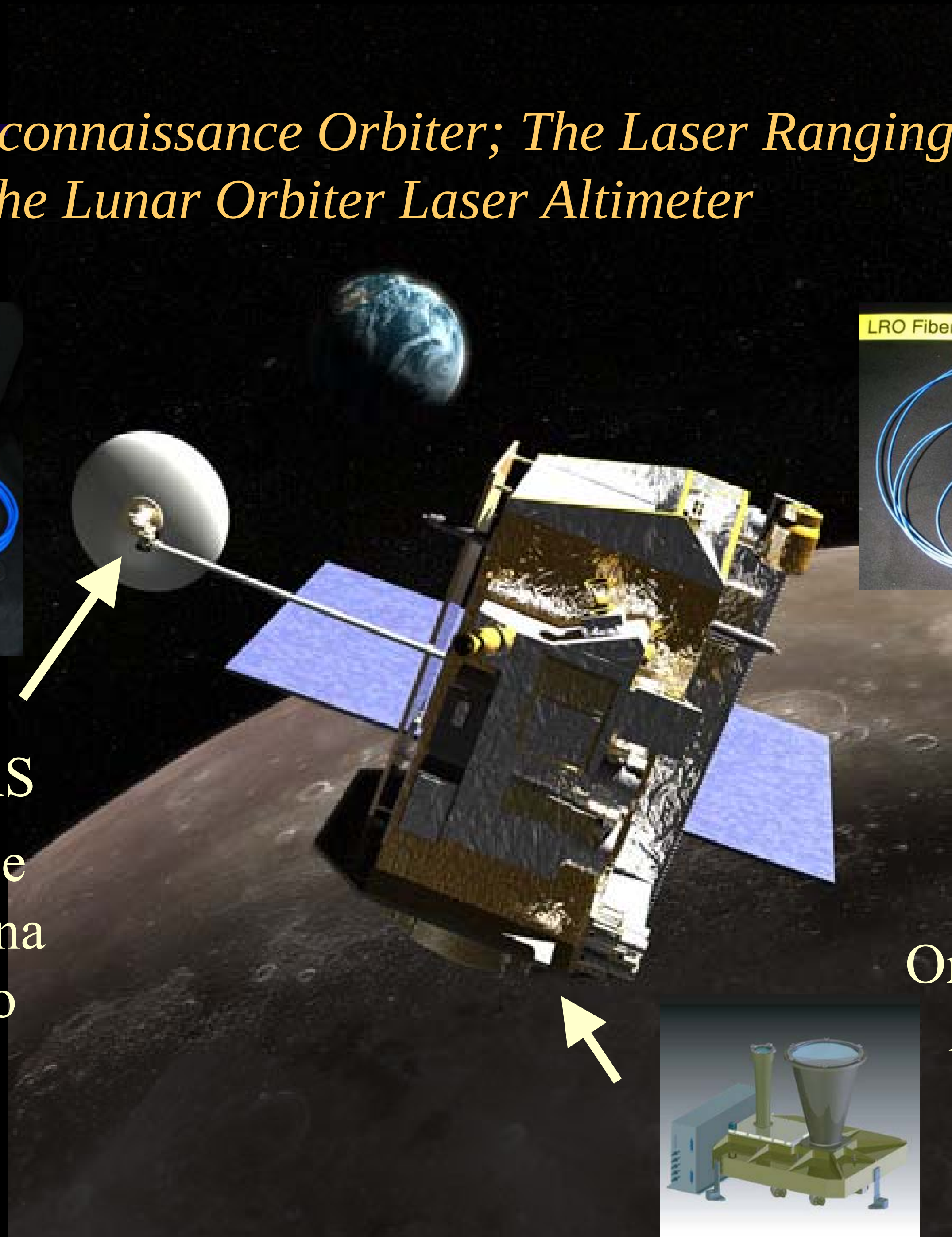
Post manufacturing decontamination of entire assembly required

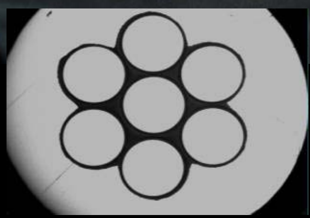
Laser diode rated for 85°C processing performed at 70°C



Introduction

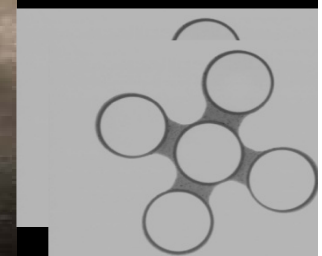
The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter





HGAS

Receiver Telescope mounted on antenna and a fiber array to route signal from HGAS to LOLA



Lunar Orbiter Laser Altimeter LOLA

Vibration Qualification vs. Workmanship Testing

We refer to "profiles" by their overall total grms values

Each test duration 3 minutes/axis, 3 axis with insitu monitoring

Frequency Range (Hz)	Test 1: ASD levels	Test 2: ASD levels	Test 3: ASD levels
20	.052 g^2/Hz	.026 g^2/Hz	.013 g^2/Hz
20-50	+6 dB/Octave	+6 dB/Octave	+6 dB/Octave
50-800	.32 g^2/Hz	.16 g^2/Hz	.08 g^2/Hz
800-2000	-6 dB/Octave	-6 dB/Octave	-6 dB/Octave
2000	.052 g^2/Hz	.026 g^2/Hz	.013 g^2/Hz
Overall	20 grms	14.1 grms	10 grms

LOLA Qualification– 20 grms test

LOLA Workmanship – 9.87 grms (X), 8.08 grms (Y), 12.89 grms (Z)

LR Qualification - 3 Total Tests; 20 grms, 14.1 grms, 10 grms

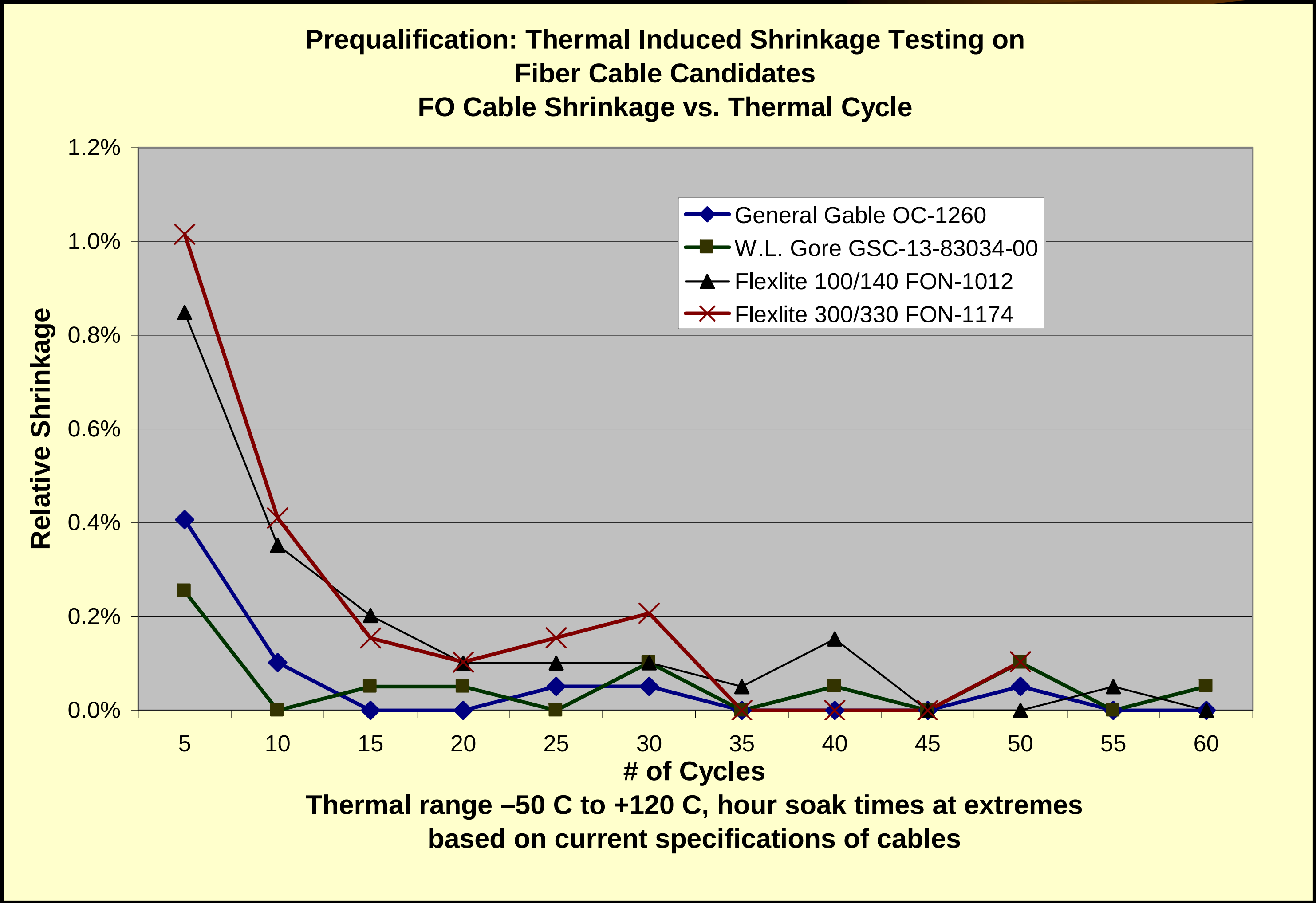
LR Workmanship – 6.9 grms

Thermal Effects

Thermal stability is dependent on;

- Cable construction
  - Outer diameter (smaller=more stable).
  - Inner buffer material (expanded PTFE excellent).
  - Extrusion methods (polymer internal stresses).
- Preconditioning
  - 60 cycles usually keep shrinkage less than 0.1%
  - Survival limits (hot case) is used for cycling.
  - Cut to approximate length prior.
- Termination
  - Ferrule – Jacket isolation necessary.
  - Polishing methods (especially at high power).

ISS Cable Candidates; Thermal Screening for Shrinkage



Because fluoropolymers have thermal shrinkage issues.

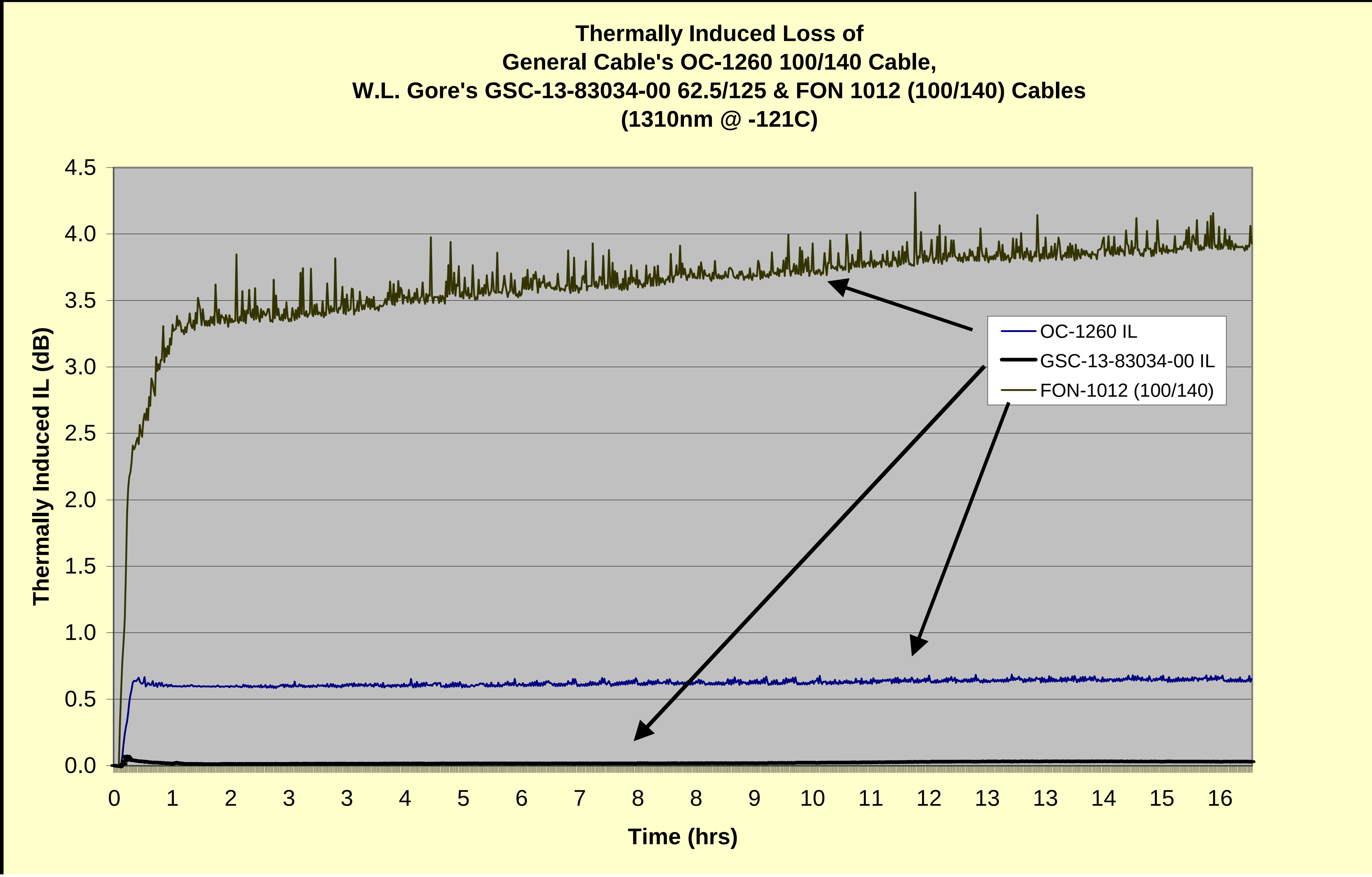
ISS Cable Candidates; Thermal Pre Qual, -121°C

Manufacturer	Part Number	Fiber Type	Thermal Range
W.L Gore	FON1012, FLEX-LITE™	OFS BF05202 100/140/172	-55 to +150°C
General Cable	OC-1260	Nufern (FUD-2940) 100/140/172	-65 to + 200°C
W.L Gore	GSC-13-83034-00 1.8 mm	Nufern (FUD-3142) 62.5/125/245	-55 to +125°C

The above cable candidates were tested for 16 hours at -121°C

ISS Cable Candidates; Thermal Pre Qual, -121°C

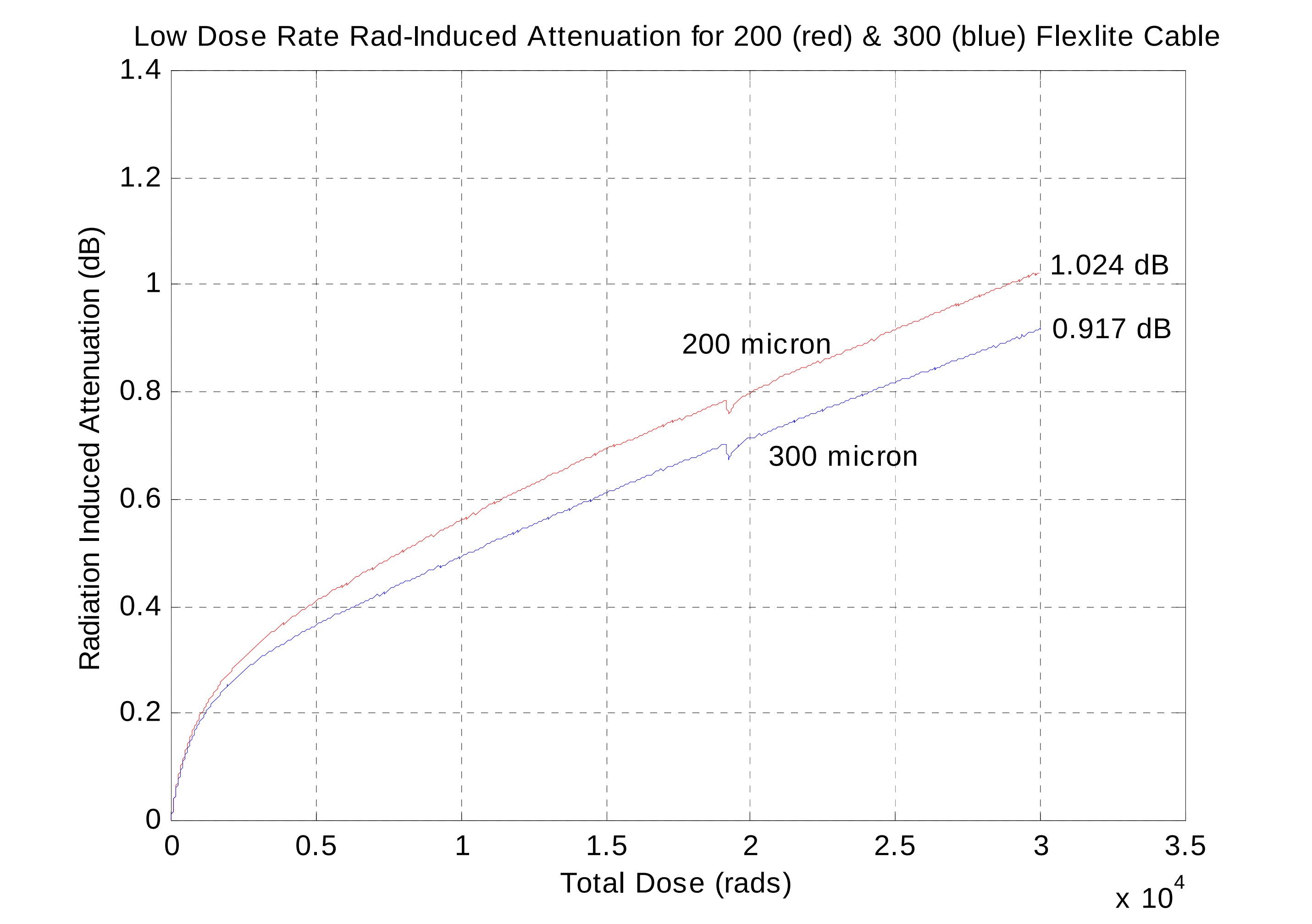
9 meters



Thermal Life Performance

Project/Type	Range	Cycles	Highest Δ IL	Post Result
Sandia/MTP with Ribbon Mated pairs, ~ 6 m, 100 micron GI @ 850 nm	-25°C to +80°C	60	< 2.0 dB	Ave gain
FODB/MTP with Ribbon Mated pairs, 5.25 m, 100 micron GI @ 850 nm	-20°C to +85°C	38	< 2.0 dB	Ave gain
MLA, Flexlite, AVIM, Mated pairs, 1 m, 200 micron, SI @ 850 nm	-30°C to +50°C	90	< 0.09 dB	Gain < 0.04 dB
LOLA / .75 m Flexlite, AVIM 5- Array to Fan Out, 200 um SI@ 850 nm	-30°C to +60°C	60	< 0.6 dB	< 0.06 dB, mostly gain
LR / 8 m Bundle, AVIM 7-Array, 400 um @ 532 nm	-55°C to +80°C	100	< 0.5 dB	Ave gain

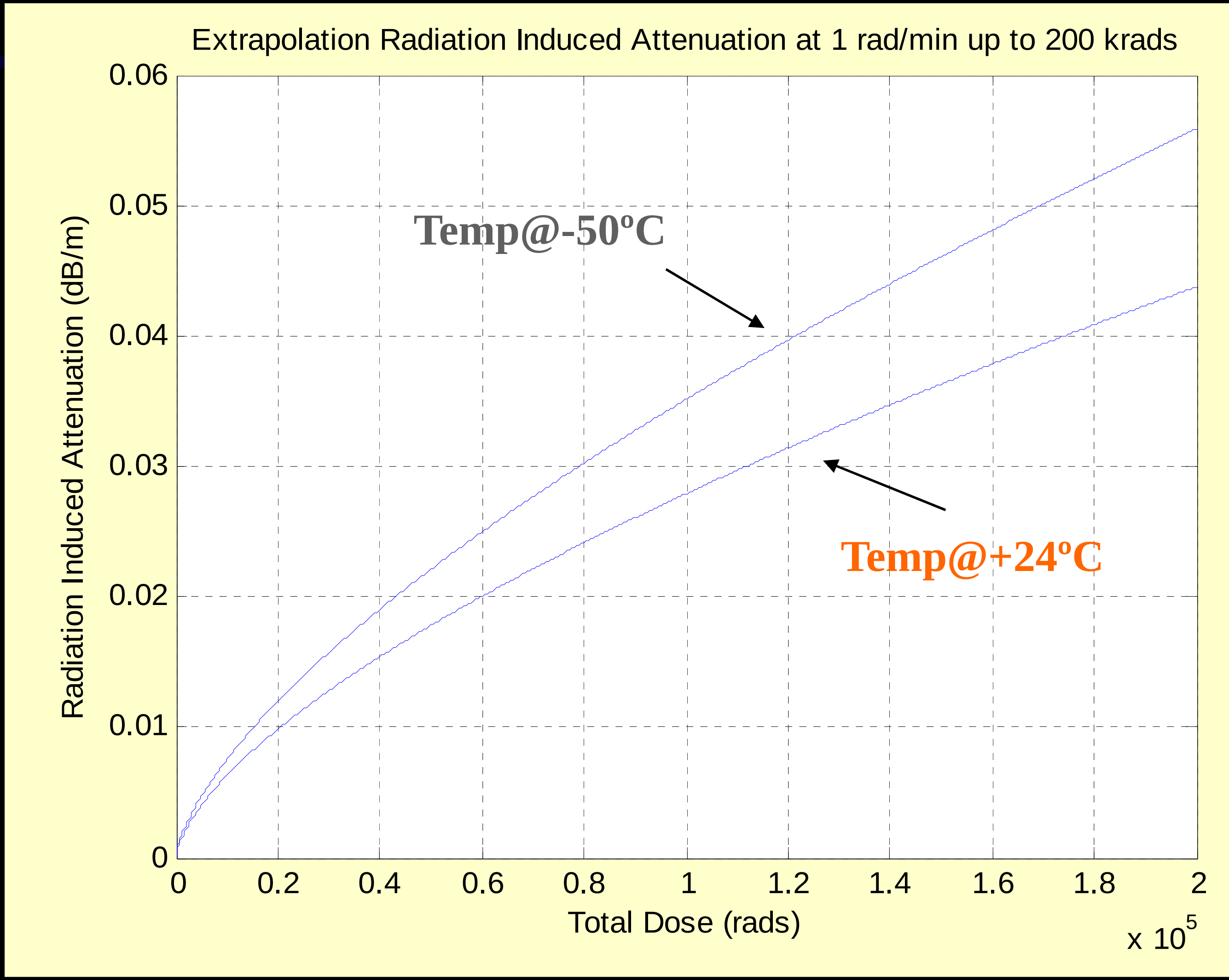
Radiation Effects Mercury Laser Altimeter



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

Radiation Effects Laser Ranging Array Assemblies



400/440 micron polymicro Technologies flexlite @ 532 nm

For 1 rad/min, -50°C up to 200 Krads, Radiation Induced Atten ~ 0. 56 dB for 10m
For 1 rad/min, 24°C up to 200 Krads, Radiation Induced Atten ~ 0. 44 dB for 10m

Radiation Testing at GSFC on Optical Fiber Candidates

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**

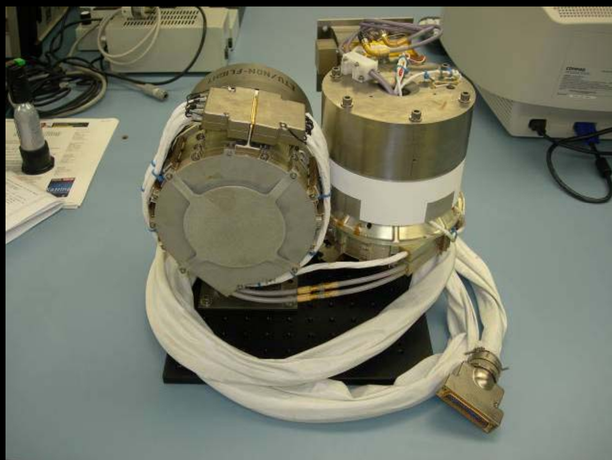
Also shows wavelength dependence, consistent with other COTS fiber.

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.

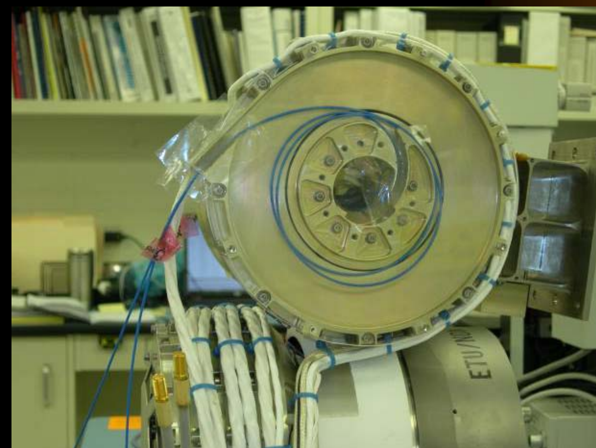
To compare sensitivity to typical 100/140 at 100 Krads

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.

LRO Laser Ranging Cold Gimbal Motion Life Testing



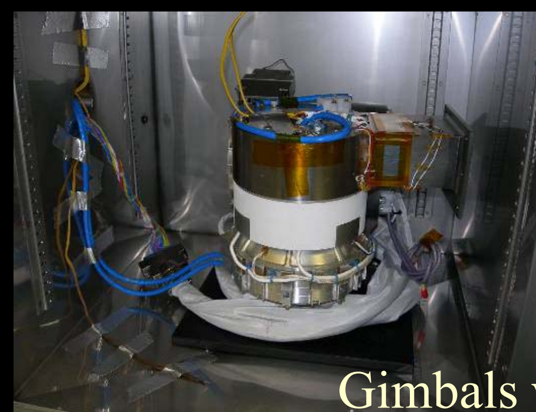
Gimbals



Window inside gimbal;
Flexlite cable inside

Window inside gimbal;
Bundle cable inside.

Gimbals w/ single flexlite in thermal chamber

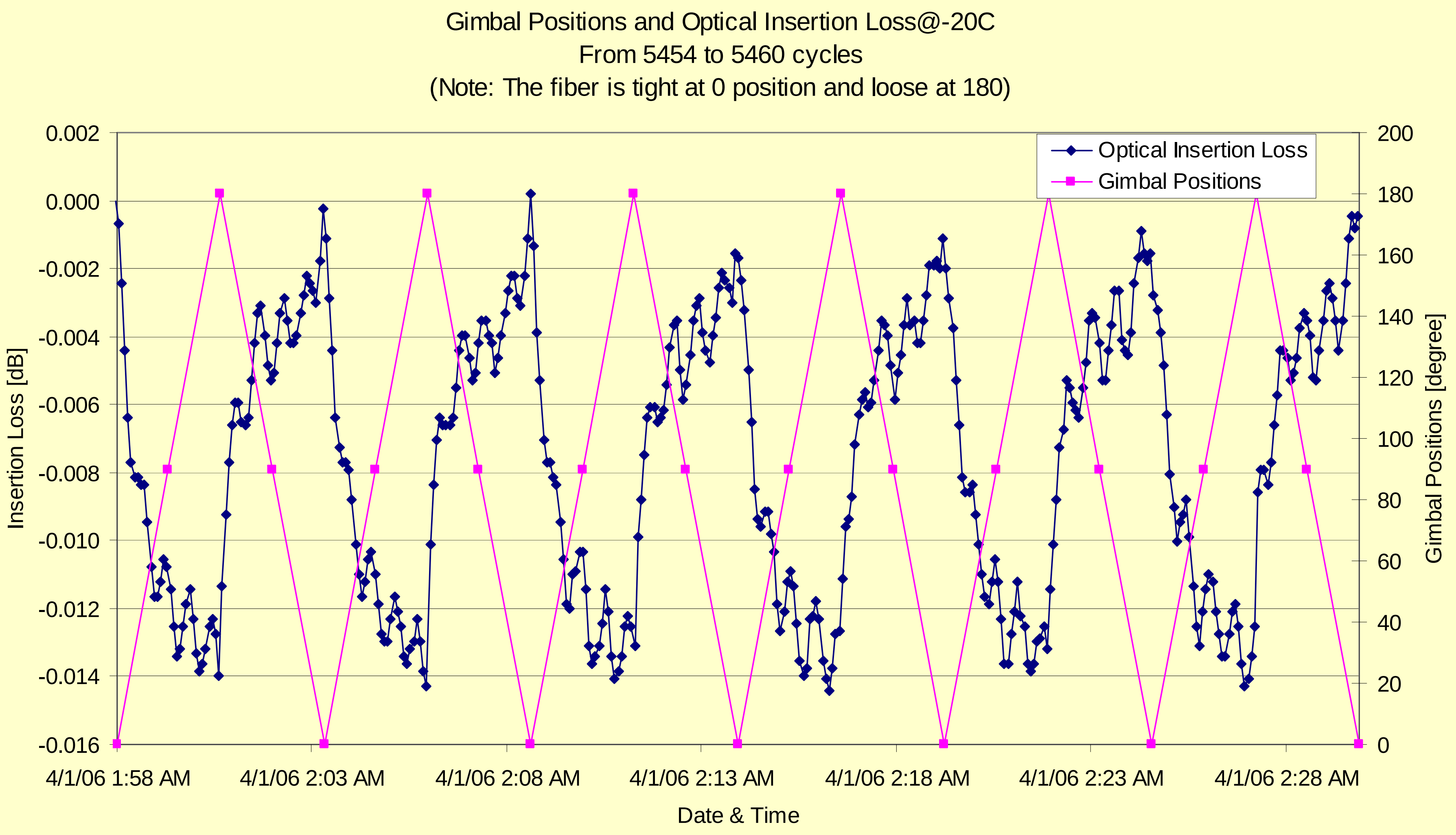


Gimbals w/ bundle in thermal chamber

LRO Laser Ranging Simplex Cold Gimbal Motion Life Test

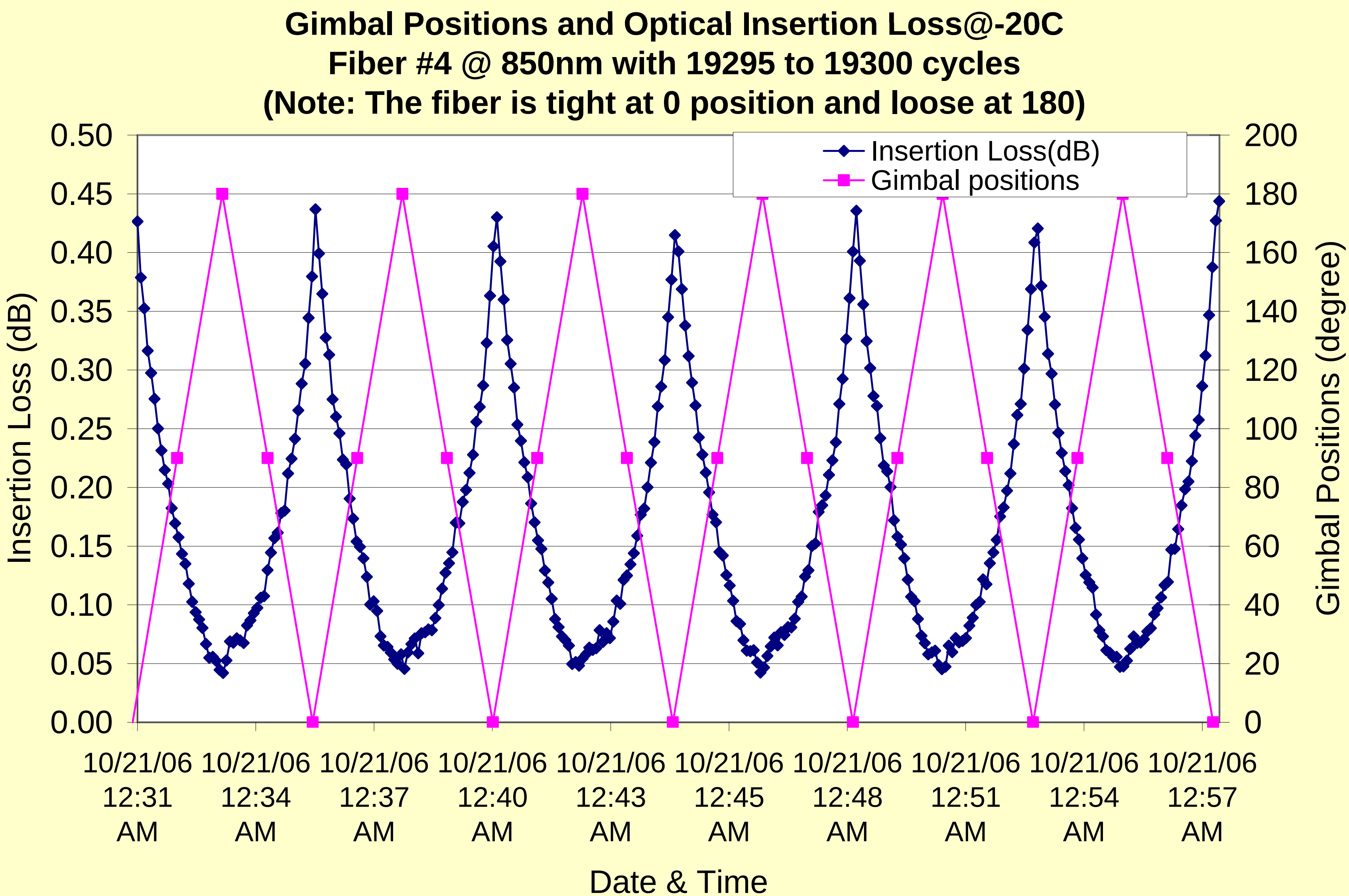
Single Strand of 300/330 FI Polymicro Series Flexlite Cable

Results of Test 3 at -20°C, Last few gimbal cycles, flex losses =< 0.014 dB



LRO Laser Ranging Bundle Cold Gimbal Motion Testing Results

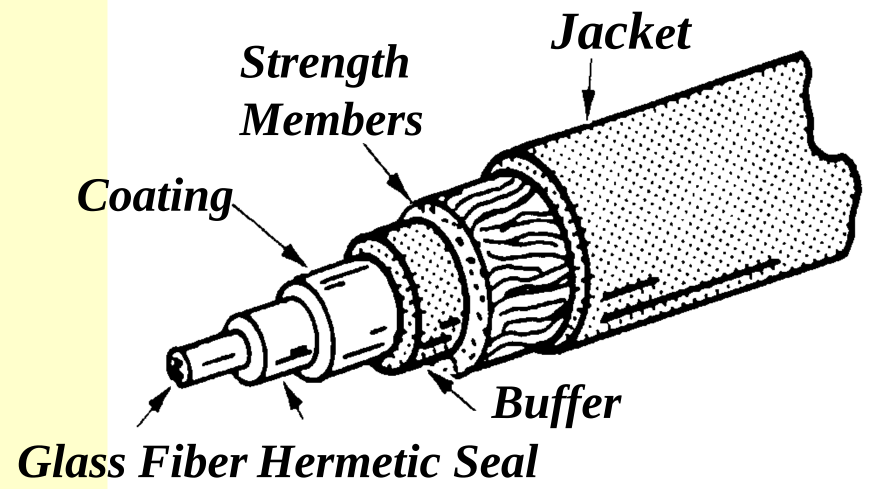
End of Test, relative IL ~ 0.50 dB, @ 850 nm, -20°C, 400/440 FV flexlite in Bundle



International Space Station 2000

Failure Analysis: Optical Fiber Cable 1999-2000

Failure Analysis: Optical Fiber Termini 2005-2006



Bad Combination

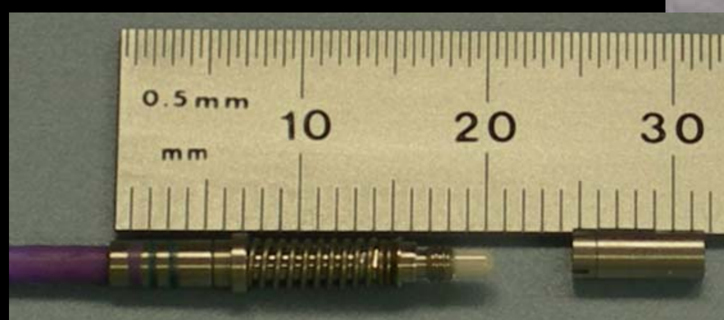
Fiber Optic Cable "Rocket Engine" Defects

- Hermetic coating holes,
- Polyimide coating holds water
- Fluorine generated during extrusion of buffer
- Hollow tube construction
  - water and fluorine interaction results in HF acid
- HF etches pits into fiber getting through holes in coating
- Etch pits deep into the core caused losses and cracks

International Space Station Study on Termini 2006

Vendor provided termini that somehow passed integration QA
During integration by the contractor. Node 2 welded into place.
Cost of changing termini on Node 2 more than $1 M. Node 3 fixed.

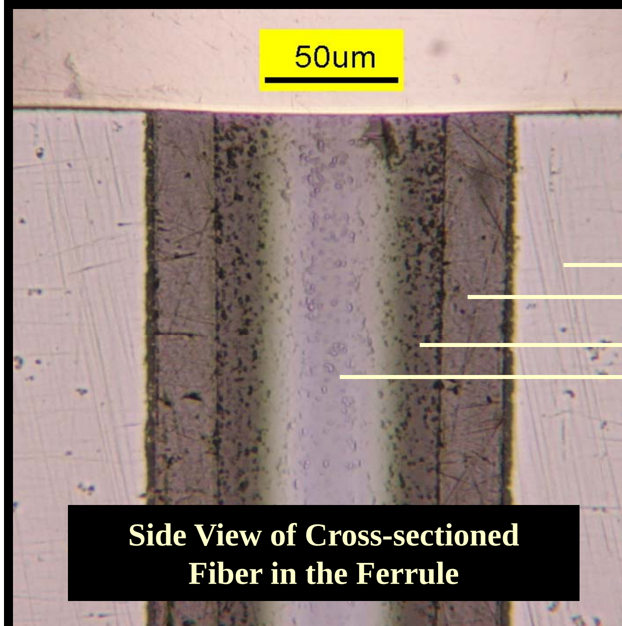
32 termini are installed into one "MIL-C-38999" type connector.



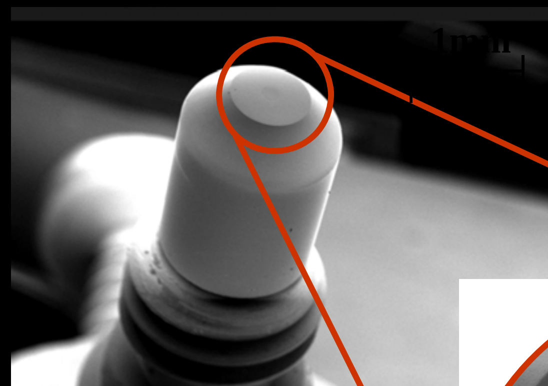
Termini end faces were found to be cracked after failing insertion loss testing during integration.

ISS Termini Failure Analysis

The below cross section of the terminus shows a concave end-face. This is per specification. If the end-face were convex, the glass would likely experience an impact when connected, causing a fracture.

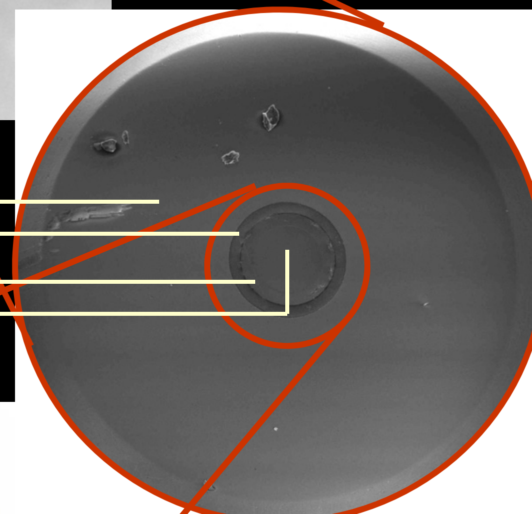


Side View of Cross-sectioned Fiber in the Ferrule

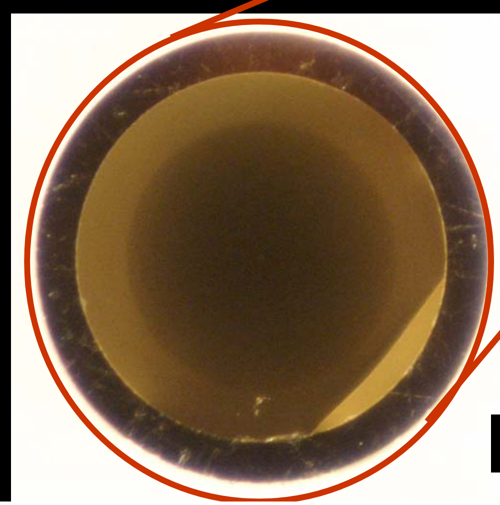


The fiber must be free of cracks in order to prevent a degraded or blocked optical signal. If a glass fiber has a crack after the polishing process, the crack will grow over time.

The termination is made up of:
- A zirconia ferrule
- Polyimide coating
- Pure silica cladding
- Germanium doped core



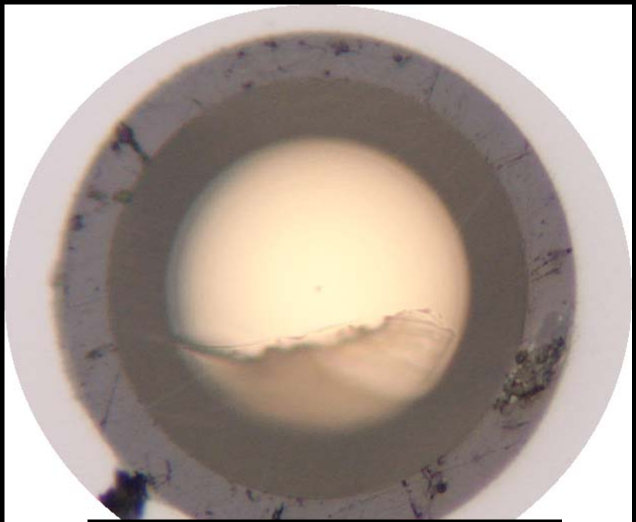
Ferrule & Fiber End View



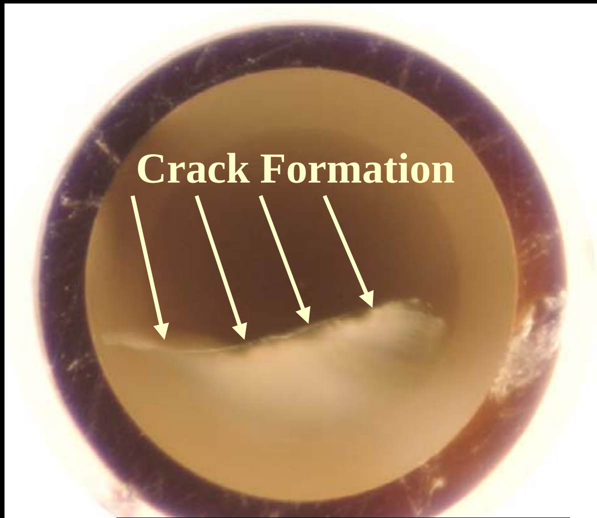
Core, Cladding, & Coating End View

The end-face of this optical fiber is 140µm. If dirt is present, the optical signal would be degraded or blocked.

ISS FA Optical Microscopy



Bright Field Image at 200X



Dark Field Image at 200X

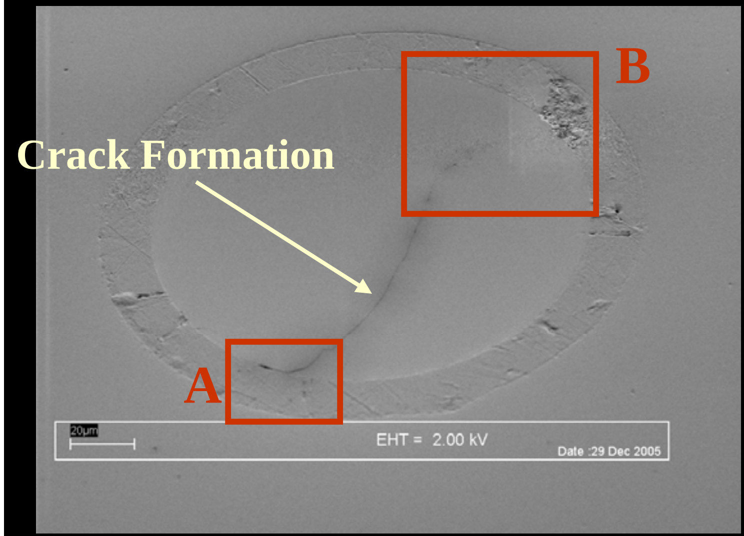
Fiber Most Likely to Fail Because of Crack

Optical Microscopy:

- Bright field (Top) & dark field (Bottom) illumination (taken at 200X) can be used to enhance certain features of the terminus.
- At 200X, a crack formation can be seen, and the "smudge" appears to be sub-surface cracking.
- More information is required to characterize the crack.
- Optical microscopy is not enough to identify an origin of the crack, so SEM will need to be performed.

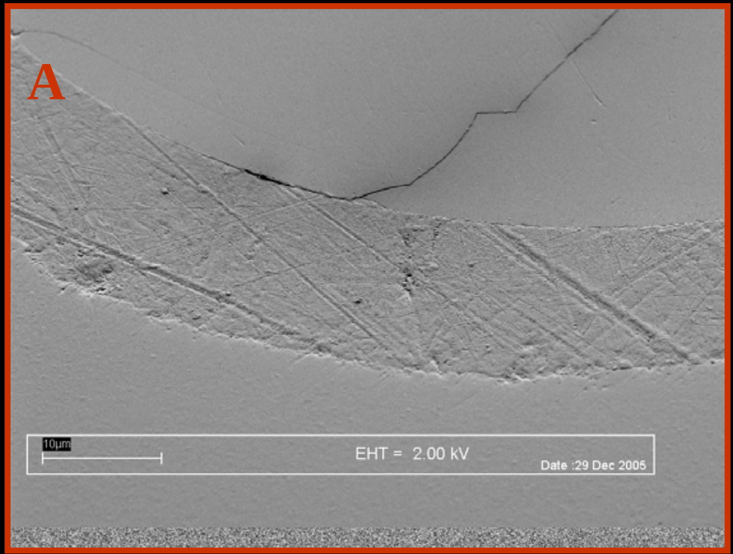
ISS FA Scanning Electron Microscopy

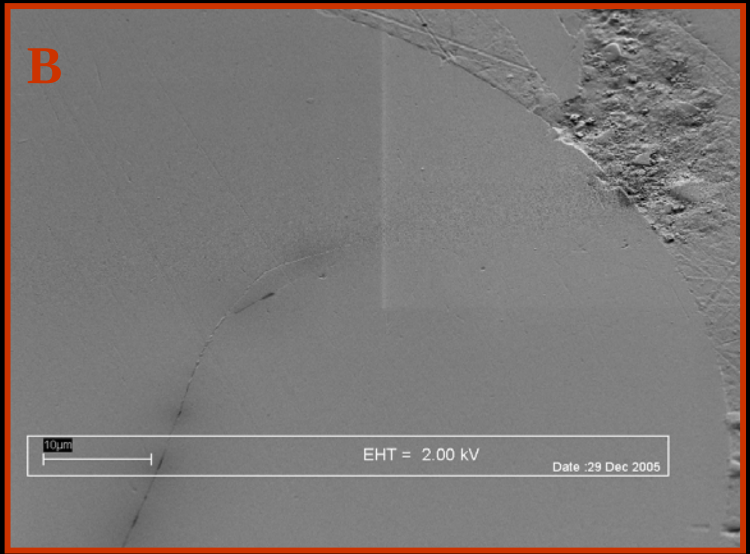
Fiber Most Likely to Fail Because of Crack



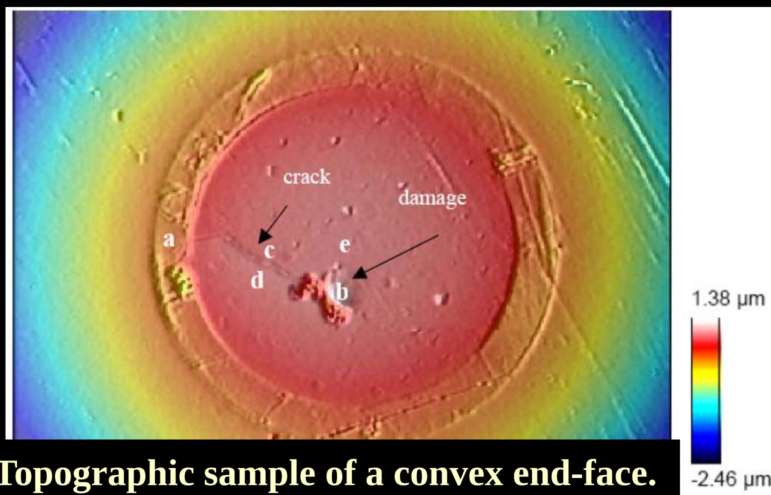
Scanning Electron Microscopy (SEM):

•SEM gives a clear image of the crack, and could be observed at over 50000X magnification.
•At 500X, the ends of the crack can be observed and analyzed.
•A concave or convex profile of the end-face cannot be determined using the SEM, so the terminus must be evaluated using confocal microscopy.





ISS FA: Confocal Microscopy

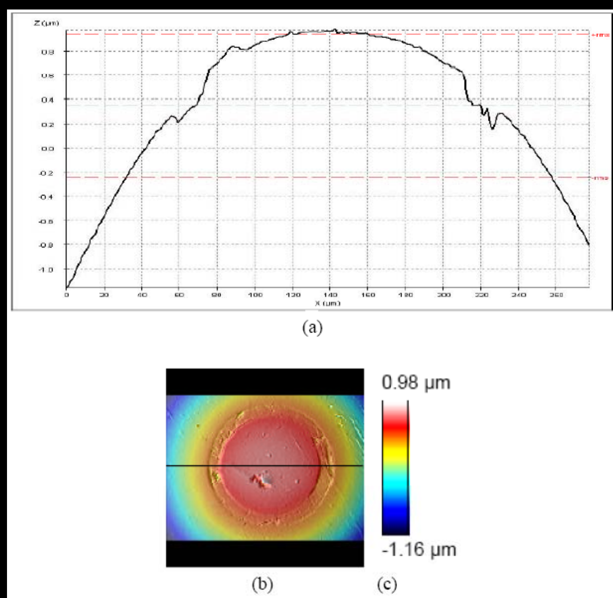


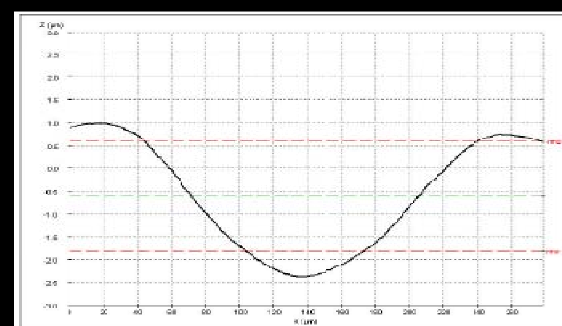
Topographic sample of a convex end-face.

Confocal Microscopy:

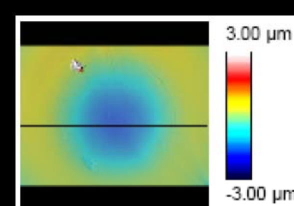
• Confocal microscopy scans the surface of the terminus & displays the contour of the fiber end-face.
• The convex surface shown at the bottom left, would increase the likelihood of an impact when connected.
• The specification for end-face geometry is to be concave (bottom right) to reduce the risk of impact damage. 4 out of 10 termini returned, violate this spec.

Sample of a convex profile (noncompliance with specification)



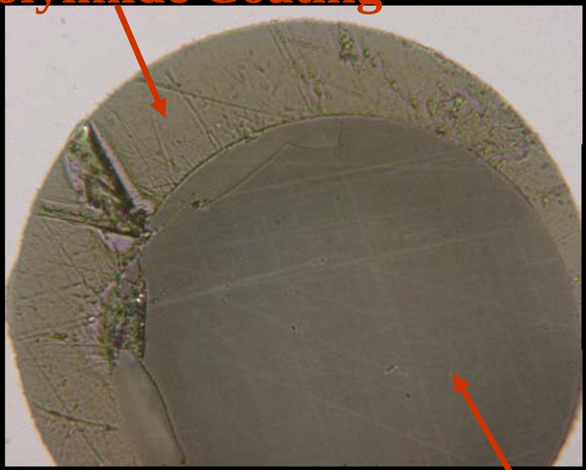


Sample of a concave profile (specification compliant)



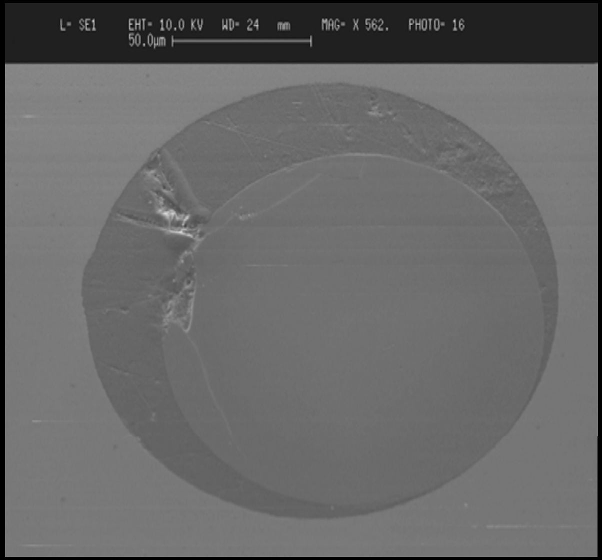
Manufacturing of Fiber

Polyimide Coating



Optical Image at 500X

Glass



SEM Image at 562X

Fiber Manufacturing:

•Note the off-center orientation of the fiber to the coating. This would cause measurable signal loss if mated to a fiber that has a concentric coating, and higher loss if mated to an identical fiber with the eccentricity 180º out.

• This eccentricity is a violation of the spec.

• Spec #SSQ 21654 sec 3.7 indicates that there should be no “thin spots” in the coating of the fiber.

• The terminus should not have passed QA and should have been rejected at the manufacturer’s site.

• GSFC would have rejected this termination & would have required a re-termination be performed.

• Note how the cracks emanate from the thick coating.

• Unbalanced stress would have been applied to this fiber during the epoxy cure process, accelerating crack growth.

Manufacturing Lessons Learned Summary

- **Identified Process Issues:**
- Fiber Manufacturing – Added stress induced by non-concentric coating application.
- Epoxy cure –GSFC uses epoxy cures as low as possible to reduce the CTE stress.
- End-faces should be verified.
- Polishing –GSFC uses low grit lapping film and never more than 0.5µm grit for rework.
- Quality Assurance – If end-faces cannot be cleaned, they should be inspected at higher magnifications for possible damage, 200X is the GSFC requirement.

Lessons Learned and Learning: Passive Components

- Always perform materials analysis which may include a destructive physical analysis.
- If materials analysis is not performed please plan to do thermal cycling vacuum testing.
- Failure mode of delamination for LD coupled fiber or gain fiber may not show up during insitu monitoring as a degradation or failure mode.
- Final inspections on termini end faces shall be performed at 200 X prior to shipment for integration and inspected prior to integration for cleanliness.
- Cure schedules for larger core graded index fibers especially should be as close the lower bound of the operation temperature range as possible. High temp cure sets up a high stress situation.
- Just because you see a cure schedule in the outgassing.nasa.gov database that passes TML and CVCM requirements, doesn't mean you have to follow the cure schedule listed.
- Graded index 100/140 is extremely brittle..special care required during termination and integration.
- Connector assemblies; decouple cable stresses from connector body

Conclusion

All components are not appropriate for all applications. Knowledge of failure modes and materials is crucial to making feasibility decisions as well as design, manufacturing procedures and test plans.

Thank you
for the invitation!

For more information please visit the website:

misspiggy.gsfc.nasa.gov/photonics