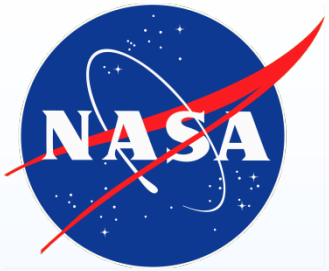


Fiber Optic Cables for Transmission of High Power Laser Pulses in Spaceflight Applications

William “Joe” Thomes Jr.
Melanie N. Ott
Richard F. Chuska
Robert C. Switzer
Diana E. Blair

NASA Goddard Space Flight Center
Code 562 Photonics Group
E-mail: Joe.Thomes@nasa.gov, Melanie.N.Ott@nasa.gov
http://photonics.gsfc.nasa.gov

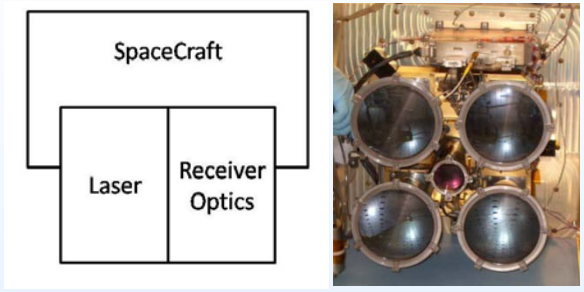
Overview

- Spaceflight Use of High Power Fibers
- Figures of Merit for High Power Laser Injection
- Proper Methods of Injecting High Power Laser Pulses
- Methods of Improving Fiber's Optical Damage Threshold
- Custom Designed High Power Fiber Connectors
- Conclusions

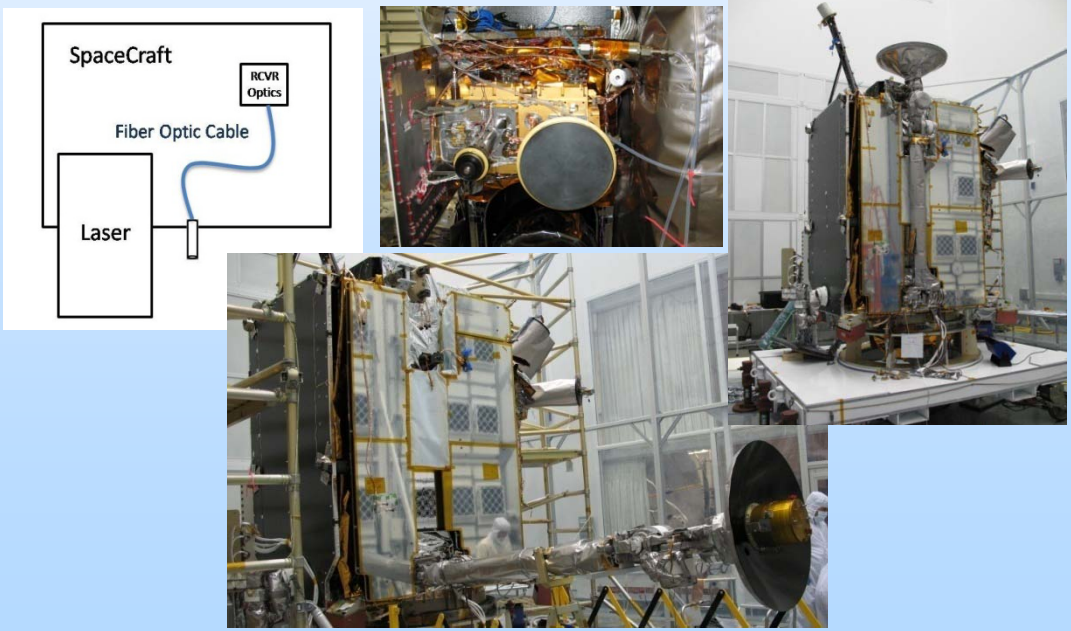
Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Spaceflight Uses for High Power Fiber Optics

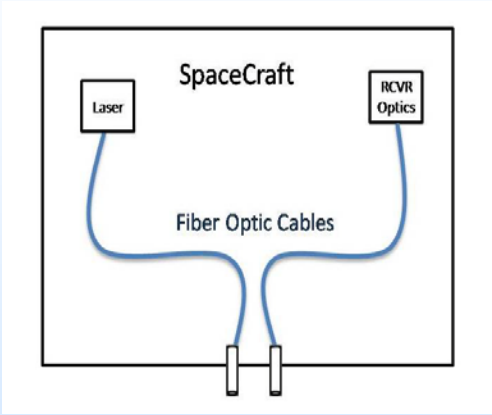
Past



Present



Future



- **Relocate laser and receiver optics to preferred spacecraft locations**
  - **Improved shielding**
  - **Better thermal management**
- **Allows reduction of size, weight, and power**
- **Less mass to manipulate**
- **Ruggedization**
- **Integration Flexibility**

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

High Power Laser Injection

- **Laser Constraints**
  - **Wavelength, Pulse Width, Energy, and Spot Size**
- **Laser Beam Mode Structure**
- **Laser to Fiber Injection Optics Design**
- **Injection Optics Alignment**
- **Fiber Endface Preparation**
- **Fiber Routing and Fixturing**

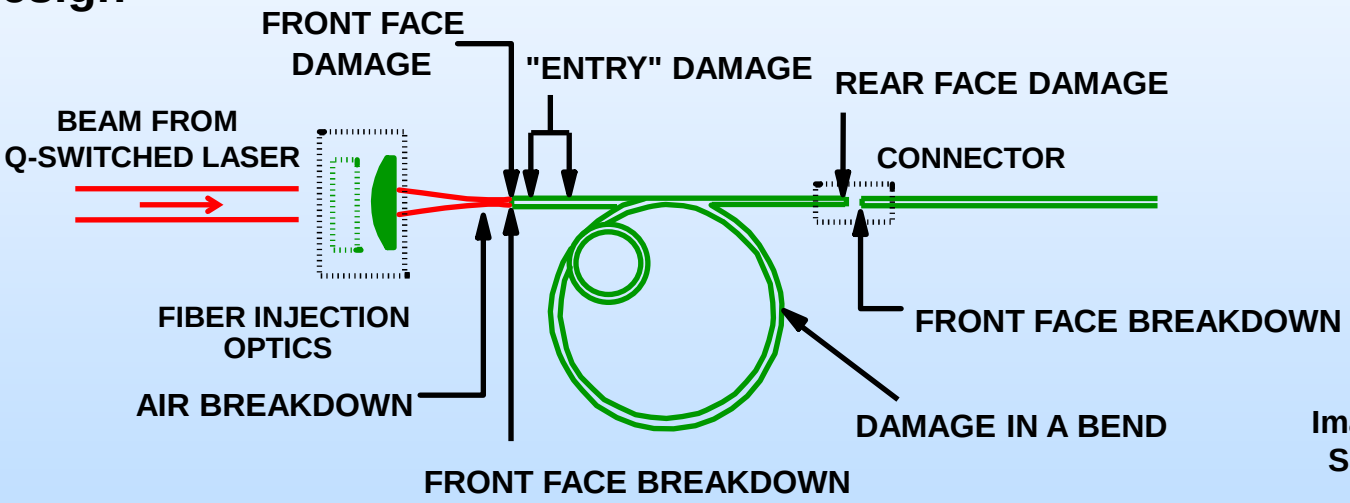


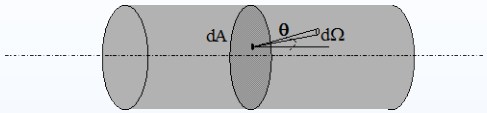
Image courtesy of Sandia National Labs

Control of these parameters determines the optical damage threshold of the fiber optic cable

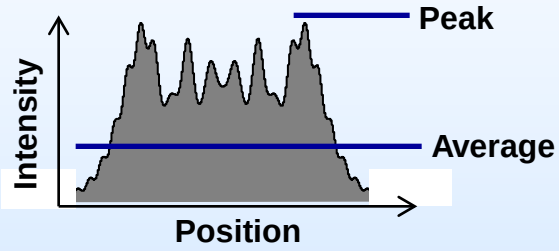
Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Laser to Fiber Injection Optics

Mode Power Distribution

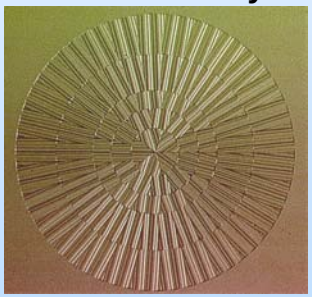


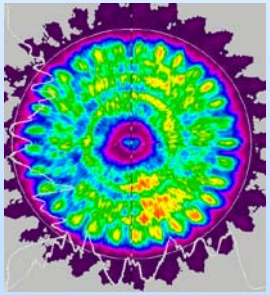
Peak to Average Power

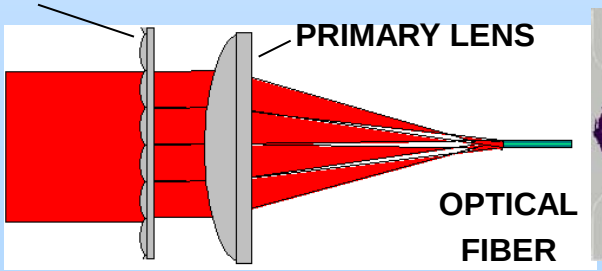


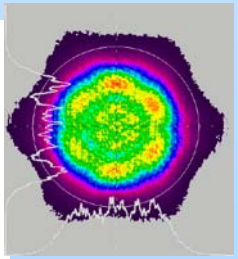
- Minimize peak fluence in air before fiber
- Minimize peak fluence on fiber endface
- Align fiber axis to incident beam axis
- Minimize laser “hot spots”
- Prevent conditions that lead to focusing within fiber
- Broaden initial mode power distribution within fiber

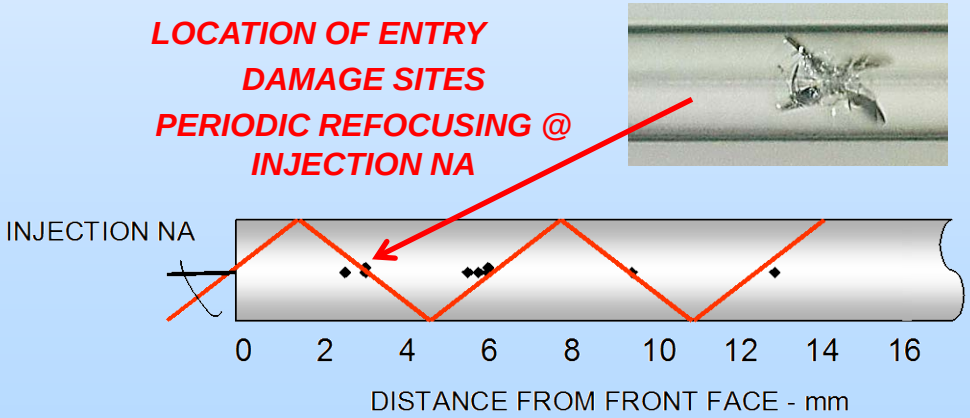
Skew Ray Generator











Images courtesy of Sandia National Labs

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

High Power Fiber Optic Cables

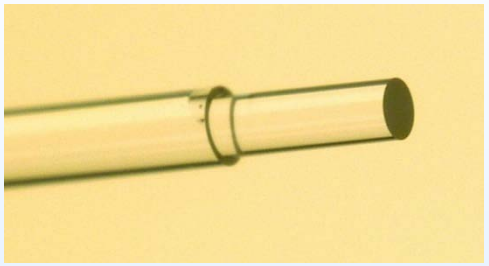
- Fiber Selection and Endface Preparation are Key
- Bare Fiber versus Connectorized
- Endface Terminations
  - Cleaved Fiber
  - Polished Fiber
  - Laser Polished Fiber

- Proper materials selection, preparation, and termination are still essential for spaceflight use

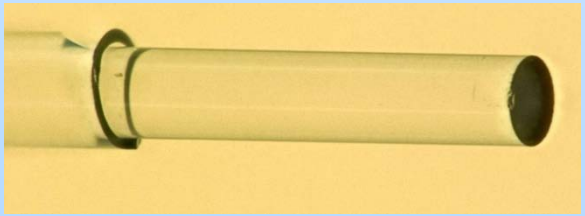
Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

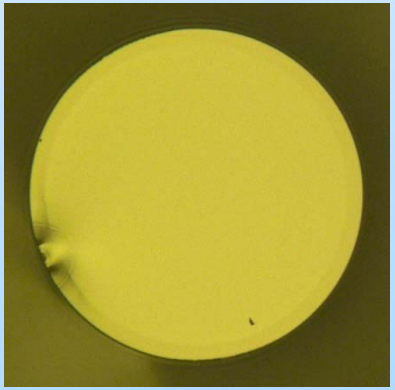
Cleaved Fiber

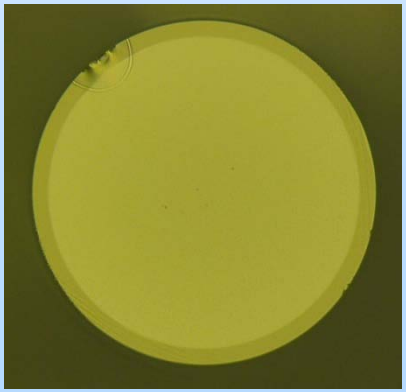
- Fiber placed in slight tension and scored (usually with a diamond blade)
- Crack propagation across fiber
- Angled cleave is possible



- Good for fiber permanently packaged with a device
  - Such as mounted on a v-block
- Sharp edges are prone to chipping
- Extreme care must be taken to avoid residual damage from cleave

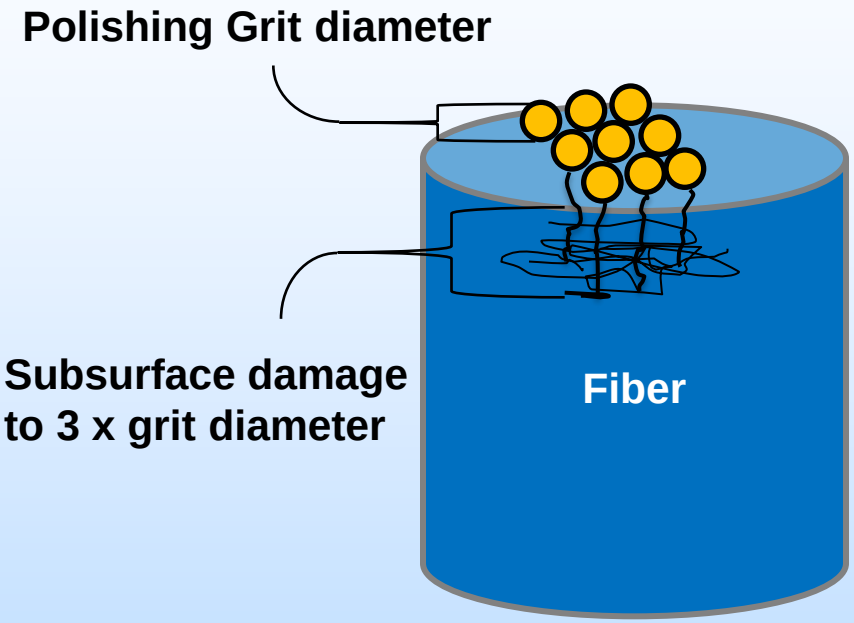






Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

High Power Mechanical Polish



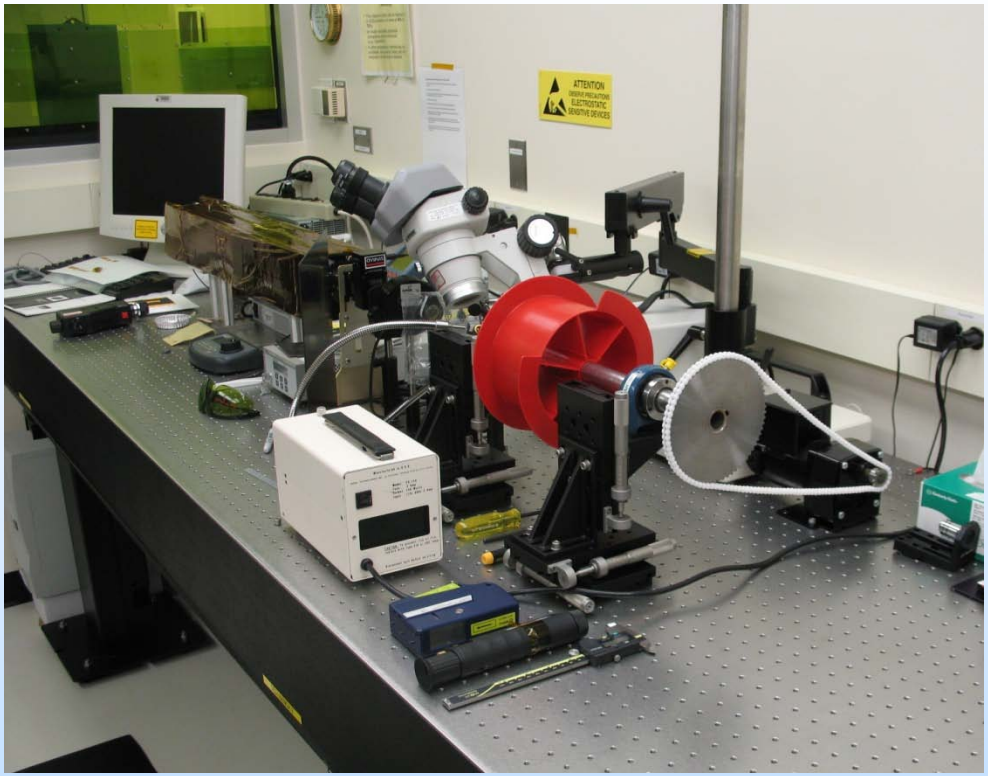
- Start with small grit
  - Initial polish 3 μm or less
- Polishing takes much longer than normal
- Experience and very good procedures determine final geometry
- Scratch free at 400x

Initial subsurface damage by polishing with a large grit will not be removed during subsequent polishing steps

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Laser Polishing

- Start with mechanical polish for high power
- Finish with laser polish
- Due to laser wavelength, laser energy is absorbed at fiber endface and causes heating
- Stop when fiber has just started to reflow
- Requires control of laser beam parameters and exposure conditions



- *CO_2 laser at 10.6 µm*
- *Multiple systems to stabilize output power*
- *Measure beam profile and power*
- *Electronic shutter control of exposure duration*

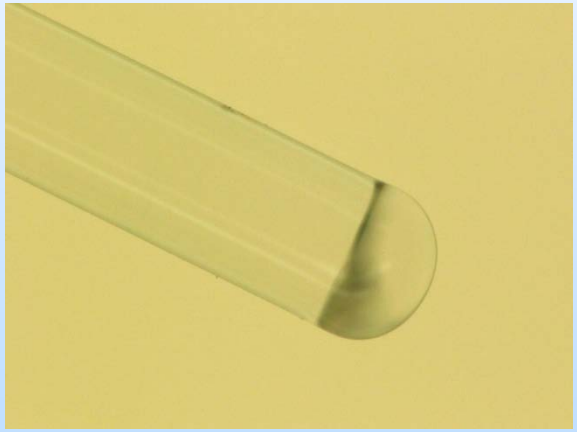
Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Know When to Quit

Bare Fiber

Surface tension will cause edges to pull back

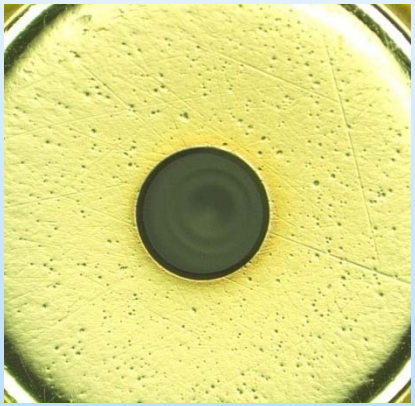
Lensing of fiber tip leads to refocusing inside the fiber

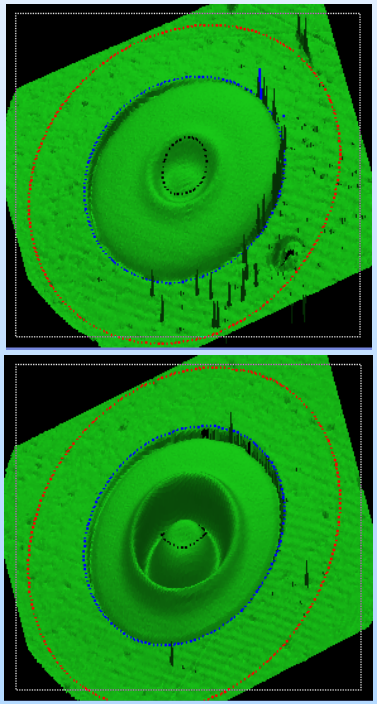


Fiber in Connector

Heat flow into and out of the connector will determine fiber endface heating profile

Surface irregularities cause poor beam quality inside fiber

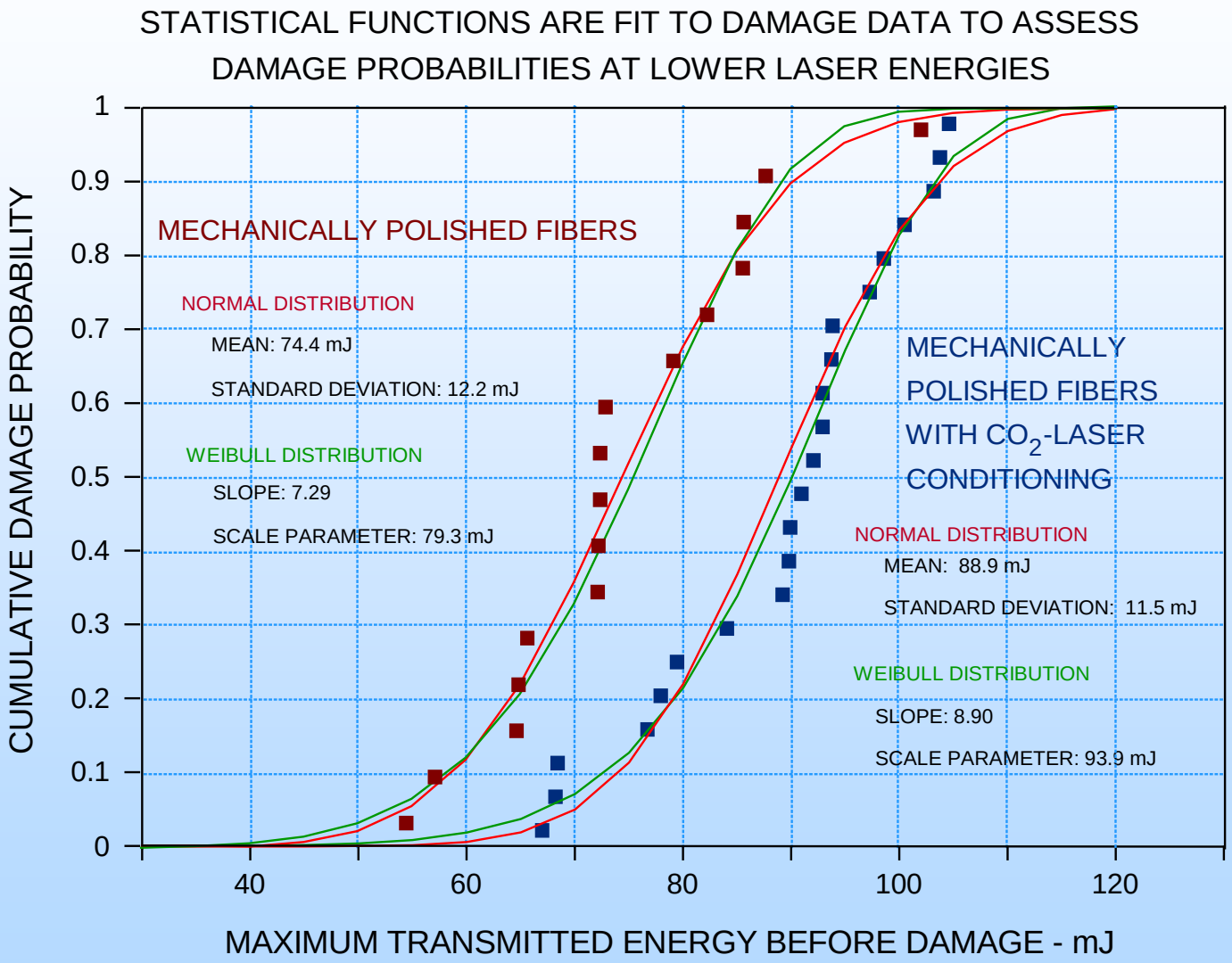




Strict control of laser polishing process implemented to avoid these issues

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Laser Polishing Improves Damage Threshold Energy



Data courtesy of Bob Setchell and Dante Berry, Sandia National Labs

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

New High Power Fiber Ferrules

- New connectors designed, manufactured, and undergoing testing
- Information will be available at our website http://photonics.gsfc.nasa.gov once approval for public release is obtained

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.

Conclusions

- **Techniques for each laser power range**
  - **Below 1 GW/cm^2 – standard flight termination + simple injection**
  - **1-3 GW/cm^2 – high power implementations necessary**
  - **3-9 GW/cm^2 – Extreme care to ensure reliable operation**
  - **9-12 GW/cm^2 – Very difficult to implement outside of lab environment**
  - **Above 12 GW/cm^2 – Start exceeding inherent damage limit of fused silica glass**

For Reference: 80 mJ , 12 ns pulse width, 300 μm fiber core $\rightarrow$ 5.3 GW/cm^2

- **New laser polishing setup and connector designs enable coupling of high power laser energy for future spaceflight designs**
- **All aspects of the laser system design need to be considered**

For additional information please see our website

http://photonics.gsfc.nasa.gov

Joe Thomes, E-mail: Joe.Thomes@nasa.gov, http://photonics.gsfc.nasa.gov
To be presented at International Conference on Space Optics (ICSO), Rhodes Island, Greece, October 4-8, 2010.