Fiber Laser Components Technology Readiness Overview
NASA Electronic Parts and Packaging Program

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ABSTRACT

Presented here is a summary of information concerning the usage of fiber lasers in a space flight environment. The scientific needs of NASA are addressed in reference to laser systems and applications and how fiber lasers fit those needs are summarized. The technology is explained briefly with focus on harsh environment reliability of the components that are used in typical fiber laser systems towards the goal of assessing the technology for space flight missions.

1. INTRODUCTION

Some of the more revolutionizing commercial technologies whose further development was spawned during the expansion and success of the telecommunications market is the fiber laser, fiber amplifier and its associated components. Fiber laser technology is an emerging technology primarily comprised of commercial off the shelf components with fusion spliced optical fiber links between components. The technology utilizes rare earth doped optical fiber for amplification purposes with pumping provided by compact diode lasers. Fiber lasers can provide broadband or narrow linewidth light depending on the system components utilized in the configuration. A wide variety of configurations exist that cater to different applications. However, the main components used in contriving many of these configurations are common among these various systems. A full understanding of the component structures of typical fiber laser constructions will allow investigation of these systems from a components level perspective. Through further investigation of these components for degradation modes as a result of exposure to harsh environments, a knowledge base for establishing performance and enabling the technology for space flight missions will be achieved.

1.1 Future and Current Space Flight Needs

The fiber laser is an advanced newly available technology and there is no space flight certification testing requirements available for establishing which instruments and components will be suitable for harsh environments. The NASA Office of the Earth Science Enterprise Code Y conducted an independent laser assessment following the difficulties with Vegetation Canopy Lidar and determined that there was a great lack of characterization and space certification knowledge for lasers in space flight environments. The Earth Science laser assessment report also requested that in depth laboratory testing of lasers under space like conditions be extensively performed. In addition to in depth testing, other recommendations as a result of this study included:

- NASA should consider identification and intensive development of critical fundamental technology elements applicable to multiple missions,

• NASA needs to develop guidelines that define how basic laser technology development is carried out among centers and private vendors,

• A technology alliance should be formed for the development of space-based lasers. As a result of this study the Integrated NASA Lidar Systems Strategy Team (INLSST) was formed with multi-center participation to provide guidance with enabling Lidar technology for better risk assessment during proposal process. [1,2].

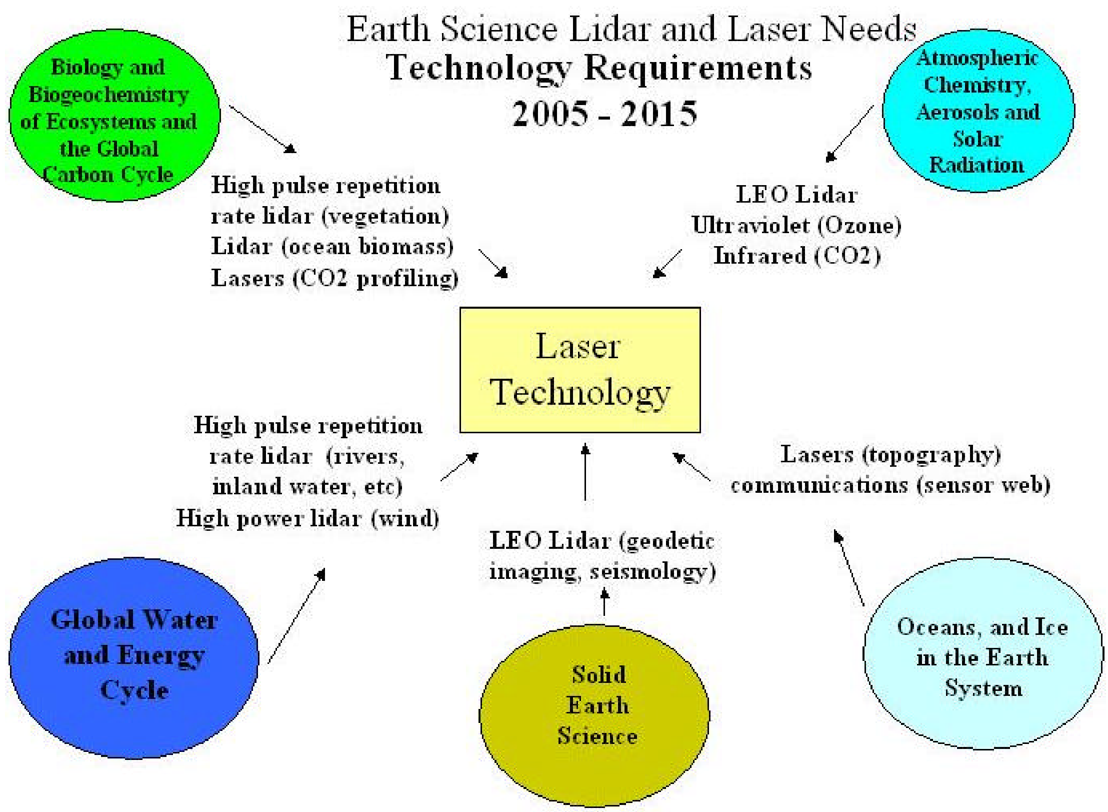

Figure 1: Earth Science Lidar and Laser Needs

Due to the large interest in utilizing compact lasers in space flight applications there are current leveraging opportunities including work being performed by the Integrated NASA Lidar Systems Strategy Team (INLSST). Currently, the NASA GSFC segment of this team is developing a platform laser technology in order the meet many of the demands shown in Figure 1. ESTO has funded a variety of laser based programs that can provide insight to some of the component issues. In particular the following projects are currently underway and funded by ESTO:

- Laser Sounder Technology for Atmospheric CO2 Measurements from Space, GSFC.
- A compact Highly-Efficient, and Rugged All Solid-State UV Source Based on Fiber lasers for UV-DIAL, JHU, Code 562 GSFC.
- High Efficiency, Double-Pulsed, High Beam Quality, Nd Laser for Global Ozone, Fibertek, Inc.

- Advanced Optical Heterodyne Receiver Development for Coherent Doppler Wind Lidar, JPL
- Efficient, Compact, Conduction Cooled Laser Diode-Pumped YB: YAG laser for Atmospheric Composition and Ozone Measurements., Standford University.
- High Efficiency Remote Sensing Laser Technology, Aerospace Corporation.
- Water Vapor DIAL transmitter at .94 Micrometers, LaRC.
- Efficient, Conductively-Cooled 2-Micron Laser Transmitter for Multiple Lidar Applications, LaRC.

All of the above mentioned projects provide leveraging opportunities and can also benefit from studies performed on any laser components, many of which are present in fiber lasers as well. The John's Hopkins Applied Physics Laboratories are currently conducting component level studies for the INLSST laser platform as well as components for fiber lasers for remote optical communications applications. The Naval Research Laboratories Optical Sciences Group has developed a state-of-the-art fiber laser for a variety of applications including high power, narrow linewidth, remote sensing usage.

1.2 Applications of Fiber Laser Technology

In many ways the available fiber laser systems perform better than typical space flight lasers currently under development with high pulse energies, high repetition rates, narrow pulsewidths, better wall plug efficiencies (20% or higher), diffraction limited output that is transverse single mode. In addition, the added advantage of smaller size and lighter weight due to the lack of requirement for an optical bench for alignment, makes them more attractive for such missions that require compact sizes as in deep space missions. Fiber lasers can be used in either continuous wave with external modulation for communications or in a pulsed capacity for lidar, resolving objects from space or for probing through dense medium for communications purposes.

There is a great need for fiber lasers for space flight usage for remote sensing and in optical communications applications. As stated previously, fiber laser instrumentation is an advanced technology recently available for applications related to space flight. For remote sensing applications the fiber laser provides: an ultra stable compact source for laser vibrometry, a multi-wavelength Q-switched source for LADAR-based imaging, a dual-wavelength optical transmitter for Differential Absorption Lidar (DIAL) for atmospheric characterization, an ultraviolet optical transmitter for fluorescence Lidar for remote detection of biological agents and a space based pulsed source for precision altimetry. For optical communications the fiber optic laser can fit into several configurations including: an optical transmission system for highly parallel optical data links for high speed computing, an optical transmission system for wavelength division multiplexed (WDM) and/or time division multiplexed communications, a WDM transmitter for very large throughput free space communications links, and as part of an all optical clock recovery circuit for high speed optical receivers. In particular, the Laser Communications Demonstration Experiment (LCDE) scheduled for ISS will demonstrate a high data rate free space communications link between a ground station and the space station. It is proposed to utilize fiber amplifier technology as part of the high speed transmitter.

2. STATUS OF AVAILABLE TECHNOLOGY

The fiber laser market has shifted from focus on the telecommunications industry in the 1990's to focusing on needs of the medical industry in the early 2000's to a current focus on military and space lidar and communications as well as industrial manufacturing. There is currently more opportunity for space flight instrument development with less dependence on the telecommunications market wavelengths now that the focus has changed. With greater focus on alternative markets there will be more emphasis on providing stability, narrow line widths, short pulses with high repetition rates to accommodate these market. Higher power developments mean higher power at doubled and tripled wavelengths to accommodate more science applications for all enterprises.

One great advantage of fiber lasers is that they are comprised of commercial off the shelf components and therefore provide easily manufacturable platform technologies that can be utilized in a variety of applications. Laser wavelengths can be tailored to a variety of purposes if enough power output is achieved in the platform laser. A variety of fiber lasers exist to cater to different applications. Advances in providing higher powers without damaging optical fiber have emerged to accomplish this as well as methods to provide stability.

There are a variety of vendors who provide fiber laser components making many of the common components readily available. Since fiber lasers are simply comprised of commercial components linked together with fiber optics and some small bulk optic pieces, construction and manufacturability is non complicated. For commercial procurements, IPG and IMRA America seem to be among the more prominent manufacturers of state of the art fiber lasers currently available. Other manufacturers such as Spectra Physics, Synchronous Inc, Southwold Enterprises, and Optigain Inc. are providers for fiber amplifiers that can be used in fiber laser systems. The next generation of fiber laser technology is being developed by non commercial research groups such as one at the Naval Research Laboratory. By groups such as this, many of the road blocks that kept fiber lasers from achieving higher powers are overcome, in prototype form and close to being fully manufacturable.

2.1 Key Components

In order for this technology to become space flight ready there is a need to comprise characterization methods and achieve an understanding of the failure and degradation modes of optical fiber lasers from a component perspective. Towards that goal several available designs are being studied to identify the most common components used.

2.1.1 Amplifier Laser Fiber:

Most rare earth doped fiber lasers and amplifiers consist of either Erbium or Erbium/Ytterbium fiber with fewer consisting of Ytterbium. Erbium based fiber lasers are more closely related to typical fiber communications wavelengths in that they emit near around 1550 nm while Ytterbium type fiber lasers emit near 1060 nm making them more closely related to Lidar applications or free space communications where diffraction limited beams are necessary. For applications that require wavelengths in the

UV range either type of fiber laser can be utilized by frequency conversion using nonlinear crystals.

2.1.2 General Components:

For applications that require shorter wavelengths (visible or UV), the larger the output power of the amplification stage to the nonlinear crystals the more likely crystals can be used that not require additional thermal control for frequency conversion to those wavelengths. Fiber lasers can also include fiber bragg gratings for control of narrow linewidths. Other passive optical components are used in a variety of designs. In many designs, single mode doped laser fiber is used with double cladding to protect the fiber from optical damage but also to allow coupling from multimode pump sources. The ability to couple multimode sources allows for higher pump powers. In more recent state of the art designs under development, multimode rare earth doped optical fiber is being utilized to overcome problems with creating enough gain in the amplification stage in addition to the advantages of coupling greater power.

2.1.3 Pumping methods

There are several methods of coupling pump laser diodes to the amplification fiber and a wide variety of pump diodes available at select wavelengths. In many cases wavelength division multiplexing couplers are used for pumping laser diodes into the amplification fiber. Less common are side pumping methods in which part of the fiber is etched in a manner than allows for pump light to enter the fiber through the cladding or in such way to allow for the ends of the amplification fiber to be available to the other components in the system. The pump diode wavelengths are chosen based on which rare earth doped fiber is selected for the amplification stage. The idea is to pump with the highest power, laser diode available for maximum efficiency to the output power. Pump diodes range from simple laser diode modules to bar diodes and arrays. Pump laser diode wavelengths are typically near or in close range to 808 nm, 980 nm, 1064 nm, and 1480 nm.

2.2 Reliability Concerns for a Space Flight Environment

Under current study are the failure and degradation modes of fiber laser components to further the flight readiness for current and future fiber laser designs. Most systems are designed to function in the thermal range of 0ºC to 70ºC because they are based on commercially available components. How much of a harsh environment a system can withstand will always depend on the most vulnerable component or components present in the system. Since this study is currently underway, full reliability assessments that are not currently available, will be available in future reports.

2.2.1 Vibration and Vacuum Considerations:

It is expected that fiber lasers will be very robust against vibration since most of the components are linked together with fiber fusion splices. However, different coupling methods require some bulk optic parts and additional study of the packaging methods for the bulk optical component alignment will be necessary. In most cases there are very few parts that are coupled with bulk optics and are usually limited to the initial pump coupling if a side pumped method is used and the coupling to and from the nonlinear crystals if wavelength conversion is necessary. To assure stability in a vacuum environment additional study is require for materials analysis on key components.

2.2.2 Thermal Considerations:

Thermal transients in a vacuum environment may effect the performance and stability of components such as bragg gratings, and the wavelengths of the absorption and emission band of the amplifier fiber, for example. For gratings the effects can be limited by thermally annealing the components during manufacturing. The changes in the spectrum of the amplifier fiber can be characterized to see how much of an effect will be transferred to the system performance. The double clad fiber has an external polymer cladding over a silica material causing a CTE mismatch and this too will be affected during thermal transients. In spite of the fact that thermal transients may have an effect on the components, it is expected that these effects will produce minor performance changes.

2.2.3 Radiation Considerations:

In general, when Erbium fiber laser amplifiers were tested as a system in a radiation environment along with other passive components, the results showed that the majority of the damage was a result of color center formation in the Erbium fiber. The pump power as well as the amplified signal were absorbed.[6] In other studies, Erbium and Erbium/Ytterbium fiber were tested in a radiation environment but far less data exists on Ytterbium fiber. In several cases of study, models that are typically used for telecommunications optical fiber were applied to extrapolate the high dose rate exposure data for the rare earth doped results to a lower dose space flight environment. It was concluded that when this modeling was applied that the extrapolation results over estimated the expected absorption based losses and that other models were necessary. Some of this has been documented.[7-8]

Gamma radiation is used to simulate the worst case exposure for materials and parts that will be exposed to total ionizing dose in a space environment which includes protons. Another assumption applied to the testing and modeling of radiation effects on rare earth doped fiber is that as with telecommunications optical fiber, gamma radiation should provide a worse case scenario than proton exposure. In past studies of telecommunications optical fiber in a gamma radiation environment and a proton environment it was indeed the case that silica and some doped fiber performed the same if not worse during gamma exposure. It may be the case that this assumption is also incorrect for erbium doped fiber and further study is necessary.[8]. It is however, true of rare earth doped fiber as it is with telecommunications grade fiber, that the dopants do have an enormous effect on the radiation induced performance. There are currently a wide variety of available optical fiber choices for usage in fiber amplifiers. Due to the vast number of choices available, it will be necessary to study the effects of the most common types of fiber used since the dopants used among these different products can also contain wide variations. Different Ytterbium fiber products in particular were shown to behave differently in a radiation environment based on the different dopants contained in each.[9]

Double clad rare earth fiber, which makes the injection of higher pump powers possible, have outer claddings comprised of fluorine doped polymers with low optical index.

Polymers are typically more sensitive to radiation in general than silica optical materials and fluorine doped fiber is typically more sensitive to radiation effects than fiber not containing fluorine. The fact that polymers are used for this outer cladding will also make them more prone to embrittlement as a result of radiation exposure.

Pump laser sources will have to be characterized for proton induced displacement damage but in general are considered quite robust against typical environments. More research is necessary to assess the other components of the fiber laser system and will be available in future reports.

3. CONCLUSION

At present there are no qualified fiber lasers for usage as a platform technology for space flight missions. The studies currently underway will enable space flight usage of fiber laser technology within the next five years. Advanced designs currently underway will also enable more reliable performance in that they do address thermal and vibration issues as a matter of component and packaging selection.

In future reports, more information will be provided on what type of fiber lasers are currently available based on key parameters such as wavelengths, linewidths, power output for continuous wave and energy outputs for pulsed systems, pulse repetition rates and other critical specifications. The designs and components associated with these different systems will be outlined as well.

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