# Qualification and Reliability Testing of a Microchip Laser System for Space Applications

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**Abstract**

A compact microchip laser pumped by a single fiber coupled diode laser was developed for a scanning laser radar instrument called Laser Mapper (LAMP) to be used as a guidance and control sensor in future JPL/NASA missions [1]. The system involves commercial-off-the-shelf components that were packaged and qualified for space applications. In particular, the system has to meet a 5000 hour minimum life requirement on a LEO platform. This paper discusses the process being used and the results of the selection and qualification of a low cost prepackaged diode laser with a custom packaged microchip laser crystal. The environmental testing would be applicable to a variety of commercial photonic systems.

The topics to be discussed include:

- The selection of the diode pump laser
- Upscreening of commercial parts
- Qualification sampling tests including temperature cycling, vibration, outgassing
- Physical construction analysis

The testing requirements and screening flow to ensure the lifetime reliability will be presented. This was determined based on input from Telcordia standards that apply to optoelectronic systems used in the telecommunications industry but upgraded to account for the unique aspects of the devices, such as the high optical power. The key elements in packaging high power optoelectronic devices for harsh environments include managing the thermal loading through the expected spacecraft temperature extremes and addressing the die mounting, optical fiber coupling and jacket assembly. Each of these aspects will be discussed in light of the testing results.

## Introduction

Future space missions are increasingly relying on commercial technology for next generation instruments. This means that technology that has not been designed for the extreme environments of space necessarily has to be integrated and tested to ensure the desired performance is sustained within strict environmental requirements. So called upscreened parts are attractive due to the maturity of the technology but requires the budget to be balanced with the inherent risk.

This paper deals with the qualification, test procedures and results of a compact microchip laser pumped by a single fiber coupled semiconductor diode laser developed for a scanning laser radar instrument. The pump laser consisted of a commercial semiconductor laser package fiber coupled to a custom packaged solid state crystal. The cw pump is focused into the microchip crystal integrated with a passive Q-switched material to produce short but energetic pulses. The pulsed output is time tagged and fed through a scanning mirror and reflected off a target to produce a 2 dimensional map with range information. The experiment is a technology demonstration for satellite ranging as well as autonomous rendezvous and docking. An eventual application is also as a ground target ranger and mapper for a future Mars lander. Commercial laser packages are available that integrate the pump laser and gain crystal with thermal electric controller in a single TO-3 can. However, due to severe power constraints, a power inefficient TEC is not able to be used and since the pump laser diode requires strict temperature control it must have its own thermal management system separate from the optical head assembly. It is therefore placed remotely from the microchip laser via an optical fiber with spacecraft radiators and heaters to maintain the pump laser temperature control.

The laser can be broken down into 3 parts – the commercial semiconductor laser acting as the optical pump, the fiber coupling interface and the laser head consisting of a focusing lens, the microchip gain material diffusion bonded with a passive Q-switcher and an optical filter to block the pump light propagation. The laser has to be maintained at a fixed temperature around 20° C to ensure overlap of the 808 nm cw pump with the Nd:YAG absorption band. The output of the fiber is focused into the crystal via a gradient index lens and the balance of the thermal lensing and pump mode produces a high intensity beam at 1064 nm. A Cr:YAG saturable absorber is bonded to the gain material and acts as a passive Q-switcher to produce a pulsed output. Approximately 2 W of 808 nm light is required to give an average output of 100 mW with sub nanosec pulses of 10 μJ energy. Not all the pump light is absorbed with a few hundred mW passing through unattenuated. Hence the pump blocking filter to ensure that the start pulse detector does not become saturated. The output power requirements are 100 mW at > 8 kHz with a 16 mrad beam divergence and $M^2 < 1.3$. Although stressing for the commercial TO-3 can packaged device, these are easily met with a single fiber coupled diode laser.

The first section of the paper describes the pump laser selection and qualification and then the testing flow. The next section discusses the optical fiber interface and issues involved in selection of appropriate fiber assembly. The final section discusses the application of the qualification process to other commercial photonic systems with implications for future upgrades. The qualification process and test flow is applicable to both the semiconductor pump laser and the microchip laser, however, the test results will only be presented for the pump laser.

## 1. Pump Laser

### a. Design

The performance requirements are given in the following Table:

| | |
|---|---|
| Wavelength, 20° C ± 3 °C | 808 +/- 3 nm |
| Wavelength stability | ± 1 nm (0.3 °C) |
| Output Power, cw | > 2 W |
| Output beam | Multi-mode Fiber coupled |

| | |
|---|---|
| Single Device | |
| No TEC integrated | |
| Overall Efficiency | > 0.3 |

Table I: Laser requirements

An internal monitor photodiode is required for power feedback control as well as a thermistor for temperature tuning the laser wavelength. The pump laser will be set at a particular operating point corresponding to the 100 mW output power of the microchip but can be adjusted through software. The temperature set point can also be adjusted through software and implemented using a heater system with closed loop control.

The critical performance parameters for the pump laser are the optical power and the wavelength stability of the output. Other parameters are the emission linewidth, beam shape of the fiber coupled output as well as the electrical efficiency.

### b. Environmental Requirements

Component environmental requirements are derived from the system level environmental requirements in the absence of any detailed spacecraft layout and analysis.

| | |
|---|---|
| Shelf life | 5 years |
| Non-operating temperature | -35 to +51 °C |
| Non-op Temperature Ramp | 5 ° C/min from cold |
| Vibration | See graph below |
| Reliability | 5000 hour lifetime |

Table 2: Laser environmental requirements

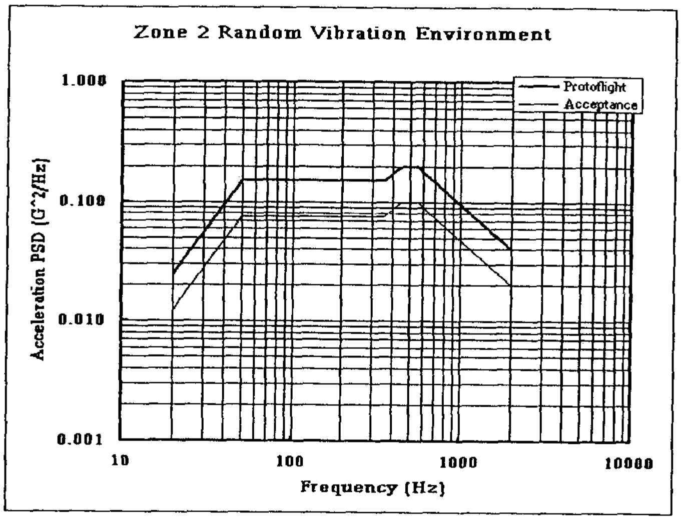


Figure 1: Vibration environment PSD

### c. Qualification and Test Flow

A space qualified design would require each step in the manufacture and packaging of the device to be compatible with the spacecraft environmental requirements. Although this is possible to undertake, there is not the commercial market to warrant large scale production of such devices. However, there exists significant markets for low cost laser devices that have a given lifetime in terrestrial applications with the ability to replace the devices when the lifetime is exceeded. The difference in this case is primarily in the packaging and mounting of such a device (although radiation tolerance does imply some alternate fabrication procedures may be advisable).

Another option is the procurement of Telcordia, or previously Bellcore, qualified components. These devices are manufactured for the telecommunications industry and tested to ensure a high reliability with typical lifetimes or mean time to failures (MTBF) of up to 25 years. For this type of device the process is qualified, not each actual component so the key aspect is a robust design with significant environmental testing to verify the reliability. For active opto-electronic devices, GR-CORE-468 is applicable and Telcordia procedures generally meet or exceed the requirements for most spacecraft environmental requirements. The only additional tests would be to address vacuum operation such as outgassing and hermeticity. Unfortunately, Telcordia qualified fiber coupled lasers at 808 nm with multi-Watt output powers are not available. For devices based at other wavelengths, the design for Telcordia qualification addresses three main areas in diode laser fabrication that are susceptible to degradation. These are the diode to submount bonding, whether the components are epoxied or welded such as the fiber holder or lens for coupling and the hermeticity of the package. The commercial equivalent part can be upscreened by focusing on tests appropriate to these known degradation causes in the fabrication and packaging process.

| | Qualification Test | Comment |
|---|---|---|
| Sample | Accelerated life test at the performance requirement level<br>500 hours at 2 W output, 40 °C | This ensures the design is compatible with the desired reliability |
| Sample | Destructive Parts Analysis<br>Visual Inspection<br>Bond Pull Test<br>Die Shear test<br>Fiber Pull test<br>Tin on leads verification<br>Fine and Gross leak check<br>RGA - Internal Moisture | <br><br><br><br>If fiber coupled<br><br>If hermetic |
| | | |
| 100% screening | Serialization | |
| 100% screening | Opto-electrical characterization, 20 °C<br>(λ, Power, Beam Quality) | |
| 100% screening | X-ray or C-SAM Scan | Checks chip attach, voids and cracks |
| 100% screening | Opto-Electrical Characterization | As above |
| 100% screening | Burn-in<br>100 hours, 2 W, 40 °C | Accelerated at high temperature to eliminate infant mortality |
| 100% | Temperature Cycle | 8-10 times, low rate (< 2° C/min |

| | | |
|---|---|---|
| screening | -40 ° C to 60° C | with 10 min dwell at mission temperature extremes), non-op |
| 100% screening | Opto-Electrical Characterization | As above |
| | | |
| Sample | Particle Impact Noise Detection | Mil Std 883 Meth 2020 B |
| Sample | Vibration<br>20 g, 20 – 2kHz | Mil Std 883 Meth 2007.2<br>Telcordia GR-468-CORE |
| Sample | Temperature Cycle<br>-40 ° C to 60° C | 50 times |
| Sample | Opto-Electrical Characterization | As above |
| Sample | ESD susceptibility | |
| Sample | Constant Acceleration | Mil Std 883 Meth 2001.2 |
| Sample | Mechanical Shock | Mil Std 883 Meth 2002 |

Table 3: Laser qualification test flow

**d. Test results**

The DPA is summarized in the following table:

| | | |
|---|---|---|
| External Visual | Mil Std 883 Meth 2009 | Pass |
| Hermiticity | Mil Std 883 Meth 1014.1 C | N/A fail He fine leak. |
| RGA | Mil Std 883 Meth 5009 | N/A |
| Internal Visual | Mil Std 883 Meth 2017 A | Pass |
| Bond Pull | Mil Std 883 Meth 2011 | Multiple, avg. pass |
| SEM Analysis | Mil Std 883 Meth 2018 | Pass |
| Die Shear | Mil Std 883 Meth 2019 | Pass |

Table 4: DPA results

Three devices were cycled by a standard 2 °C/min temperature rate of change for electronic parts over 8 cycles followed by a more aggressive 10°C/min fro 8 cycles. The later was necessary as the spacecraft radiator and heater design underneath the pump laser was such that the laser may see a more rapid temperature increase than 2°C/min prior to laser turn on. Thermal cycling while the laser was non-operating revealed no loss of power from the fiber pigtail as shown for one device in Fig. 2 below. However, on pumping the microchip laser, which effectively is a measure of any wavelength change of the pump laser due to thermal effects, the temperature and hence wavelength had to be tuned to regain the original output power. Figure 2b shows that this device required cooling to 17°C from 20°C. This could be due to a variety of reasons such as stress on the fiber or the die. However, it is not consistent since another laser pumping the same microchip laser required heating to 25°C following thermal cycling to maintain the microchip laser output power. A more conservative 2°C/min was specified until further testing is performed.

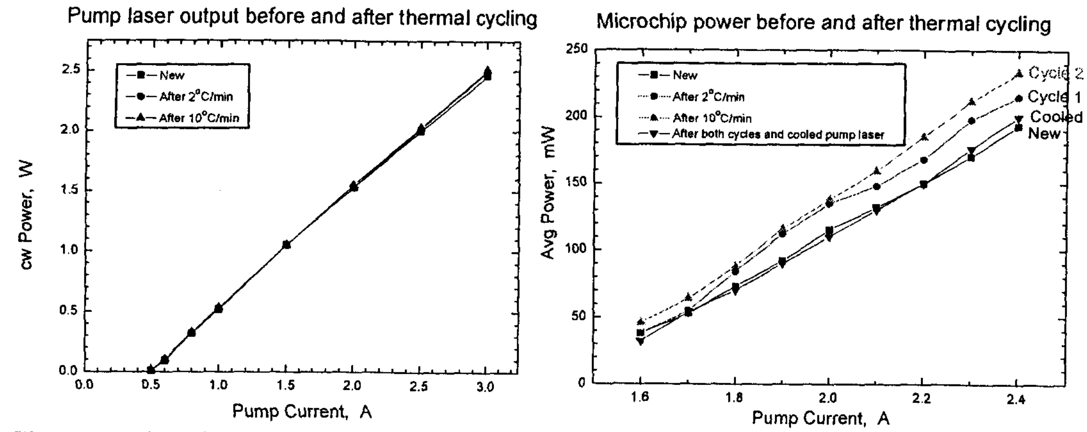


Figure 2: Initial thermal cycle test results

Other qualification test results are pending and will be presented.

## 2. Fiber Selection

### a. Fiber and Connector Design

Many types of multimode jacketed fiber assemblies and connectors are available. The fiber requirement is driven by what the laser manufacturer uses on the pump laser. In this case the design incorporates a 200 micron core, 220 micron cladding and 240 micron polyimide buffer. The fiber is a step index fused silica which is fairly robust with respect to radiation damage. The jacket has to not only be mechanically robust with respect to thermal cycles but have a low outgassing. Even though there a many different types of connectors available commercially, only a few have any space flight heritage. Two of these are the Diamond AVIM and a customized FC connector from Johansen Fiber. Other fiber requirements include the minimum bend radius (3.3 cm) and minimizing handling due to increase in stress fractures.

The SMA connector was the original standard on the fiber but is now obsolete for many applications, especially in fiber-fiber connections as the fiber can rotate in the connector and there is no physical contact. Also, there is no pressure fitting in the SMA connector as in other types of connectors being used for single mode fibers, which require much greater alignment tolerances. Diamond connectors have been qualified for space applications [2] and have shown good reliability so this is base lined for our design on the patchcord interface.

Other issues in regards to the design relate to the mode exiting the 200 μm core multimode fiber. The fiber NA or acceptance cone, is 0.22. However, due to how the laser beam is launched into the fiber from the bare diode, the optical beam exits the fiber with an NA of approximately 0.11. Even after 1m and tightly coiling the fiber, the emerging beam did not fill the fiber NA. The routing length of the cable is critical as if no more than a couple of meters, the mode can change which affects the coupling optics of the microchip laser. A specified length is needed in the requirements and this was determined to be 2m. This mode quality along with power and wavelength stability is critical to ensure reliable operation over the spacecraft environment.

### b. Qualification

Shrinkage of fiber assemblies is known over the large temperature dynamic range in space [3]. This is mainly due to the fiber jacket outgassing. Commercially, the pump laser is available with PVC outer jacket, Kevlar strength member, and polypropylene or PVDF tubing or a 900 μm Hytrel jacket. PVC has a very poor TML from outgassing so the jacket was chosen to be a loose tube Hytrel. Loose tube also has the advantage of the fiber having stress relief inside the jacket during any thermal cycling. Other jacketed assemblies have shown good results from space qualification including Tefzel, EFTE from Gore, and PFA [3]. One of these will be used in the fiber patchcord connecting the pump laser assembly box to the optical head assembly.

The boot material, typically heat shrink tubing consisting of polyolefin, is generally suitable for flight but the epoxies have to be certified for flight along with the fabrication process. The certification process for fiber optic terminations is outlined in NASA Standard 8739.5

## 3. Discussion

Current test results confirm the ability to take commercial devices and through an upscreening and qualification testing process, derive a flight qualified laser package. The laser is mounted with an indium solder onto a copper submount and aligned to a multimode fiber through an optical lens. Each of these passive optical components is held in place with epoxy and/or solder in a non-hermetic package. This type of packaging is generic to other photonic systems whether passive, such as detectors, or active laser based. In fact, the same test flow has been used to qualify commercial Si APDs used as the sensor in the LAMP instrument. Although a space qualified design is desirable for any component, qualifying commercial devices is a lot more feasible in today's budget conscious space flight projects. As long as the material composition is relatively immune to radiation effects and low outgas materials can be substituted where needed, an appropriate qualification and reliability program can allow the integration of commercial devices into spaceborne instruments.

## Summary

A robust fiber coupled diode pumped microchip laser has been qualified for a technology demonstration experiment on board an Air Force XSS-11 satellite. The test flow was tailored from the Mil Std 883 for hybrids, Telcordia GR-CORE-468 for opto-electronic parts and previous laser space flight systems.

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