# Fiber Pigtailed Lasers for Intra-Satellite Communication

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**Present and future satellite missions carry increasing number of equipment and systems that collect information in various forms about activities on earth, surrounding atmosphere, and space. This type of missions place new challenges for data analysis and transfer capabilities on-board and eventually between satellites and ground stations. Limited data transmission capacity of current satellite-to-ground links further increases demand for more efficient data manipulation and transmission between various sub-systems on-board. This work summarizes performance and space qualification aspects of fiber pigtailed communication lasers intended for intra-satellite communication links as a part of MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) Optical Harness (MOHA) on ESA SMOS (Soil Moisture and Ocean Salinity) mission. The paper will discuss the laser diode manufacturing, results of laser diode screening and accelerated life tests for AlGaInAs Fabry-Perot (FP) lasers. The paper will analyze the results achieved in harsh environment testing, i.e. in high radiation environment, under thermal stress and under vibration, in order to qualify the module for the mission.**

## Nomenclature

| | | |
|---|---|---|
| $T_0$ | = | Characteristic Temperature |
| ACC | = | Automatic Current Control |
| APC | = | Automatic Power Control |
| $I_{th}$ | = | Laser Threshold Current |
| $P_f$ | = | Optical output power |
| $V_f$ | = | Laser Forward Voltage |
| $I_m$ | = | Photodiode Monitor Current |
| $f_{(-3dB)}$ | = | Bandwidth Frequency |
| $f_r$ | = | Relaxation Oscillation Frequency |

## I. Introduction

OPTICAL fiber links provide an alternative for coaxial and other cables used to interconnect the sub-systems in intra-satellite communication. The communication link implemented using optical fiber provides advantages over the coaxial cable such as tolerance to electromagnetic interference, phase stability over temperature, lightweight and flexible routing. Also increased demand for data processing capacity on-board and transmission capacity between various sub-systems favor the usage of high-speed optical fiber data links.

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During the recent years optical transmitters operating at 1310nm and 1550nm wavelength and upto 10Gbps data rate have been developed and matured into commercial products. However, exploiting the transmitters in data links in satellite communication set new qualification aspects and requirements for the product manufacturing and product reliability. Optical link using 1310nm wavelength and 112Mbps data rate has been planned to be used in SMOS mission. The optical fiber link is to be operating between the LICEF receivers and the main data processor unit.

In this work we present the qualification and quality assurance of fiber pigtailed 1310nm AlGaInAs FP lasers operating at 2.5Gbps data rate in intention to use them as an essential part of the communication links between the sub-systems in European Space Agency Soil Moisture and Ocean Salinity mission[1]. The paper presents the laser structure design considerations, fabrication and characterization in chapter II and depicts the coaxially packaged fiber pigtailed laser module manufacturing and screening considerations in chapter III. The chapter IV is dedicated to analysis of laser diode accelerated life testing while the chapter V discusses the qualification testing of the laser module for space environment. Finally the conclusions are given in the chapter VI.

## II. Laser Structure, Fabrication and Characterisation

The lasers in this project were Fabry-Perot AlGaInAs active region devices grown by molecular beam epitaxy, specifically designed for 2.5Gbps operation. In the design of the laser structure attention has been paid to the development of the temperature characteristics of the laser by optimizing the main laser parameters, threshold current, slope efficiency, output power and the bandwidth characteristics against temperature. The actual AlGaInAs laser structure is presented elsewhere[2]. The devices were processed into ridge waveguide devices and cleaved and provided with low reflectivity (30%) and high-reflectivity (70%) facet coatings for optimum power, front-to-rear facet power ratio and temperature performance. The laser chips were screened 100% at bar level using an automated bar characterization system for light power and voltage vs. operating current (ILV), emission spectrum and beam divergence at 25°C and 85°C.

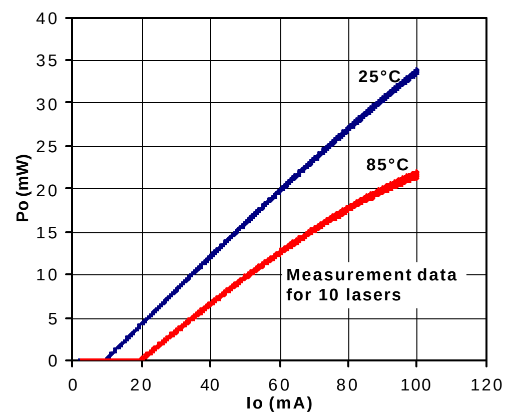


**Figure 1. Light output curves of 10pcs of 1310nm Fabry-Perot devices at 25°C and 85°C. The slope efficiency of the device is 0.33mW/mA and 0.24mW/mA at 25°C and 85°C, respectively.**

The ILV performance presented in figure 1 suggests a characteristic temperature ($T_0$) of 81K for temperature range of 25-85°C. The performance of the devices indicates extremely good fit for uncooled application[3]. The frequency response of each production lot has been characterized as single laser by mounting devices p-side up with Ag-filled epoxy onto heatsink and measuring the frequency performance against temperature and bias. The $f_{(-3dB)}$ frequency of the laser at 25°C show 9-11GHz depending on the biasing condition. The resonance of the device occurs at 7-8 GHz at 25°C with the same biasing conditions.

## III. Laser Module Packaging and Screening

The LIV screened laser chips were mounted p-side up on heatsinks and bonded into TO-56 can header together with pin-InGaAs monitor photodiode. A bake-out at 100°C for extended period of time was carried out for all parts prior to the cap sealing. The flat window cap was welded onto the header in 6N purity dry nitrogen environment monitored by dew point detection.

The sealed packages were subjected to fine and gross leak testing following military standards for semiconductor devices[4] to ensure the hermetic sealing of the package. The leak-tested devices were passed to standard ACC (Automatic Current Control) 150mA burn-in following Bellcore's Generic Requirement[5] at 100°C followed by extended burn-in for 168hours. For both tests maximum of 5% change in slope efficiency and threshold current were allowed. A sample lot of the hermetic packages were inspected using residual gas analysis for internal atmosphere of the package.

The single mode fiber was actively aligned and laser welded onto the position to achieve the maximum coupling efficiency and reliability.

A sample lot of the pigtailed modules were subject to eye-pattern testing at 1.25Gbps and 2.5Gbps, LIV and spectral test at temperatures between –20°C - +70°C.

## IV. Accelerated Life Testing of the Laser

A number of laser dies without the hermetic encapsulation was subject to accelerated aging test. In the process characterization after ILV measurements, bars are separated into single laser dies, which are attached with Ag-filled epoxy onto heatsinks for burn-in and accelerated life testing. Devices for the accelerated aging tests were selected using an automatic current control (ACC) step for screening out unstable devices and for stabilizing the selected devices with respect to their performance (burn-in). The ACC burn-in step with 80 mA constant current at 100°C case temperature was run for 96 h for the devices. The accelerated life test presented here was run on a sample batch of lasers originating from the similar epitaxial wafer and device processing as the lasers used for the modules reported in this paper.

The selection criteria are based on observed change in threshold current and slope efficiency. Reliability analysis of the lasers is based on automatic power control (APC) testing at 85°C. In the test the threshold current of the laser at 85°C is measured ever 24 hours. In the evaluation of life test data, an end-of-life (EOL) criterion of 50% increase in threshold current from its initial value has been used. Linear model[6] has been used to extrapolate the time-to-failure for each device. A lognormal distribution of failures is assumed. The figure 2 shows the $I_{th}$ of the laser at 85°C against aging time for a set of 13 laser diodes. Altogether, more than 110 000 device hours with 7 mW constant output power at 85°C have been collected for these lasers.

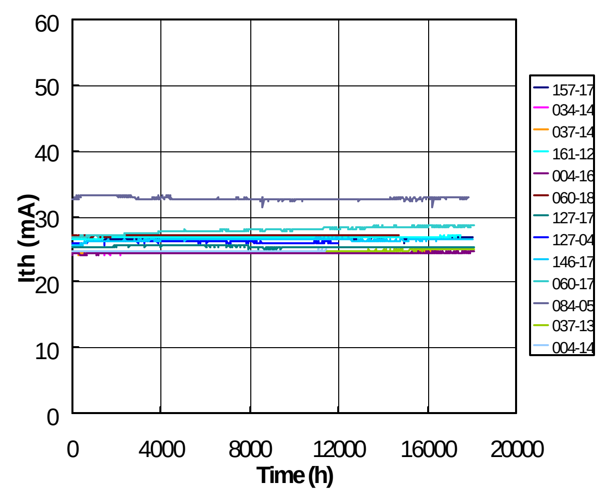


**Figure 2. Threshold current of the laser diode at 85°C in the long-term aging test.**

Figure. 3 shows expected times-to-failure at 85°C for the devices in the form of a lognormal probability plot. Median life is determined as a time for which 50% of the population has failed. This is obtained from the point where the linear fit intercepts the 50% line in the probability plot. Thus predicted median life at 85°C for the lasers is 1.06 $\times10^6$ hours (120 years). Only 9 pcs of the lasers out of 13pcs tested show a trend of degradation and only these lasers could have been included in the analysis of the median life.

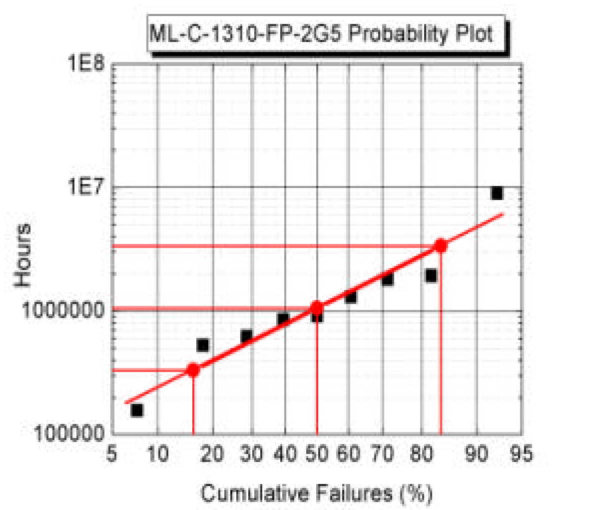


**Figure 3. Lognormal probability plot for expected time-to-failure for laser chip.**

At other temperatures median life can be estimated using an Arrhenius relationship[5]. Using the default activation energy of 0.4 eV given in Bellcore's generic requirement[5], expected median life for the lasers is 1633 years at 25°C and 775 years at 40°C.

In addition to the above-presented accelerated life test data, a shorter life test is being performed on module level for the transmitter modules intended to be used for intra-satellite links.

## V. Fiber Pigtailed laser testing in harsh environment

This chapter presents the results of the laser module testing in purpose of qualifying the module for use in harsh environment.

Gamma irradiation test was performed at GSF Neuherberg, Munich using Munich using $^{60}Co$. A total dose of 40.8 krad(Si) has been applied at a dose rate of 3.6krad/h.

The optical output power ($P_f$), threshold current ($I_{th}$), monitor photodiode current ($I_m$) and the laser forward voltage ($V_f$) were monitored after 10.2 krad, 20.4 krad and 40.8krad total dose and after annealing for 24 and 168hours. The optical power of the module after each step has been drawn in figure 4, which shows that no degradation due to gamma irradiation has occurred to the LI performance of the module.

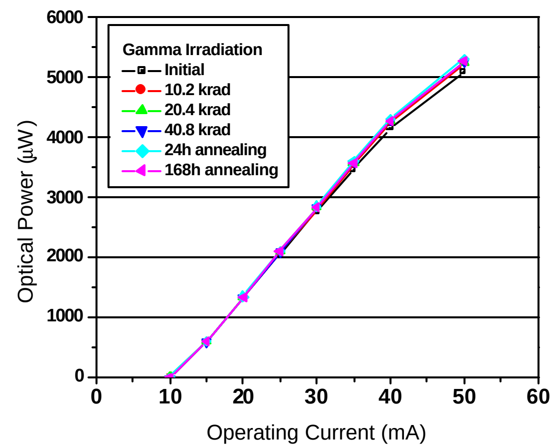


**Figure 4. Optical output power of the module after each gamma irradiation testing step.**

Proton irradiation test was performed at PSI Villingen. The 64.52 MeV protons were used with a mean proton flux of $2.01 \pm 0.19 \times 10^7 s^{-1} cm^{-2}$ and with a cumulative fluence of $\sim 4.5 \times 10^{10} cm^{-2}$. In this case the same critical laser parameters were monitored after a cumulative fluence of $2.24 \times 10^{10} cm^{-2}$ and $\sim 4.5 \times 10^{10} cm^{-2}$. Figure 5 presents the photodiode monitor current against the laser diode operating current after each irradiation dose and after 24hour annealing of the module. Based on the proton irradiation results the degradation of the module was observed in the monitor photodiode. However, the decrease of the monitor photodiode current is not considered significant.

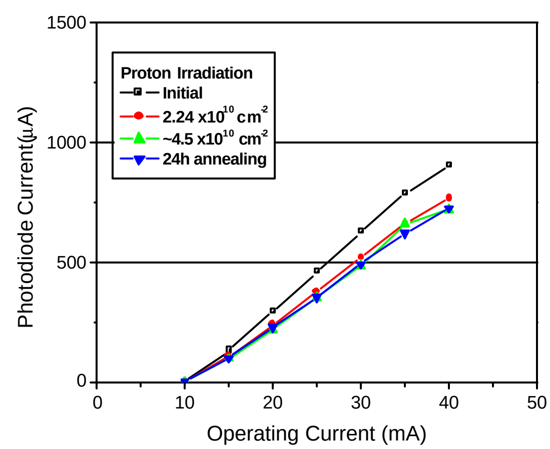


**Figure 5. Monitor photodiode current after each proton irradiation step.**

Thermal vacuum and vibration testing were performed at Astrium GmbH, Munich. In the vibration test the laser modules were subject to both sinusoidal (4 sweeps in each axis) and random vibration test ($31.4g_{rms,}$ 7.5 min in each axis). In thermal vacuum the temperature of the modules was cycled 10 times between -40°C - +85°C in vacuum environment to ensure the stability of the optical alignment of the photodiode, the laser, the aspheric lens and the fiber. The optical output power, threshold current and monitor photodiode current and the laser forward voltage were measured in each temperature a -35°C, -15°C, +70°C and +85°C. The figure 6 presents the optical output power against the operating current of the module at -35°C and +70°C between the first and the tenth step of the cycling. A slight decrease of light output power can be observed at both temperatures between the recorded cycles as a result of the stress to the alignment. However, similar effect cannot be seen in the monitor photodiode current recorded, thus this would indicate a slight change in the optical axis of the laser-lens-fiber alignment and seems of acceptable level[5].

## VI. Conclusion

We have presented manufacturing, quality assurance and part of the environmental qualification steps for a laser diode module intended to be used in intra-satellite communication links. The accelerated aging test performed on the AlGaInAs laser chip used for the pigtailed laser module predicts over 120 years lifetime in 85°C temperature.

The results of the environmental tests carried out in the work and reported in this paper suggest the laser diode module designed for 1310nm 2.5Gbps uncooled applications is applicable to be used in harsh conditions like in high radiation environment.

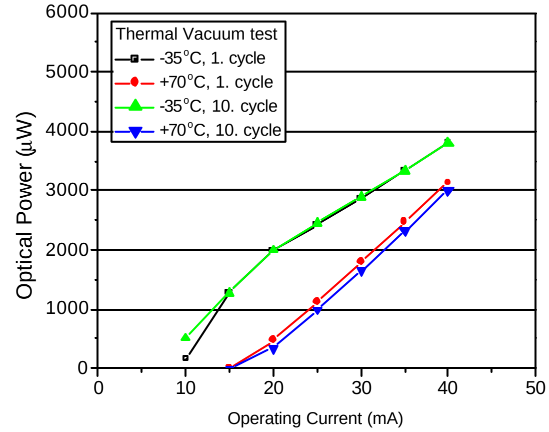


**Figure 6. Optical output power against the operatng current for thermal vacuum test. LI curves for 1st and 10th cycle at temperatures –35°C and +75°C.**

## VII. References


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