Transmission and pump laser modules for space applications

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ABSTRACT

We present progress on the design, development and space qualification of high-power Distributed Feedback (DFB) lasers and single- and multi-mode pump laser modules that can be used in diverse applications, such as laser communications, navigation and flexible photonic payload systems.

Keywords: DFB lasers, 980nm pump lasers, free-space communications, satellite communications, optical amplifiers

1. INTRODUCTION

Photonics technology can find application in diverse space segments[1] including Earth observation, telecommunications and navigation. Due to the inherent advantages offered, new generation of photonic-enabled systems are being deployed or are ready to proceed towards the demonstration phase. Optoelectronic components are indispensable elements in such systems, either being part of laser communication systems[2] or payloads within Earth Observation and telecom satellites[3]. Specifically, semiconductor laser components are used to provide the optical signals to be modulated in a free space optical link, as well as the optical pump source used to excite doped fibers or crystals for signal generation and amplification[4].

In this paper, we present progress on the design and development of high-power Distributed Feedback (DFB) lasers that can be used in diverse applications including laser telemetry, navigation and flexible photonic payload systems. In this context, we present the evaluation test plan to be followed for space qualifying the module and we report on functional and environmental performance results from a pre-qualification batch of manufactured devices. The DFB lasers output 80mW of optical power, achieve a side mode suppression of >25dB and worst case linewidth and relative intensity noise of <1MHz and <-150dB/Hz respectively. The DFB module is specifically designed to achieve >50% power consumption reduction compared to conventional terrestrial equivalent parts.

In addition to transmission lasers (AA14xx series), we report on the technology readiness level of pump laser modules (PLM) for space applications that can be used as pump sources in fiber amplifiers and fiber lasers. We report on the functional and environmental performance of 976 nm 8-pin Mini-DIL single mode (SM) high brightness PLMs (EM278-03) and 915 nm 14-pin butterfly multimode (MM) low brightness PLM (EM3xx series). The SM and MM PLMs are capable of generating >240 mW at 976 nm and >7 W optical power at 9xx nm respectively. Both modules are coolerless and include a back-facet photodiode and a thermistor for measuring optical power and temperature respectively. We present functional test results over temperature, including post-irradiation performance following exposure to non-ionizing radiation for both pump laser module types. All the semiconductor lasers presented in this paper are manufactured using Gooch & Housego assembly processes which deliver fully hermetic and high-rel opto-electronic modules.

2. DFB LASER

2.1 Development framework

In order to respond to the space industry need for a European supply of space qualified DFB lasers, the European Space Agency (ESA) has launched the "Space validation of High-power DFB Laser at 1.55 μm" programme as part of the European Components Initiative (ECI) framework. The programme is dedicated to the fabrication of 1.55 um DFB laser modules and their evaluation as per ESA ESCC 23201[5] test programme for laser diode modules. Gooch & Housego, the supplier of high-rel space photonic components and sub-systems, is leading the programme by delivering and testing DFB modules that meet the specifications set by the Agency and the European space Prime contractors. The rationale of the programme is to firstly develop a pre-qualification lot and perform functional and a limited set of environmental tests, and

Free-Space Laser Communication and Atmospheric Propagation XXIX, edited by Hamid Hemmati, Don M. Boroson,
Proc. of SPIE Vol. 10096, 100960I · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2252150

then proceed to the manufacturing of a complete Flight Lot and implement the Evaluation Test Plan (ETP) campaign, as per ESCC. In this paper, we present the pre-qualification lot results.

2.2 Evaluation test plan

A total of 57 modules have been manufactured and are ready to undergo evaluation as per ESCC 23201. Following the ETP, possible failure modes are going to be detected through accelerated overstress of functional parameters of the module.

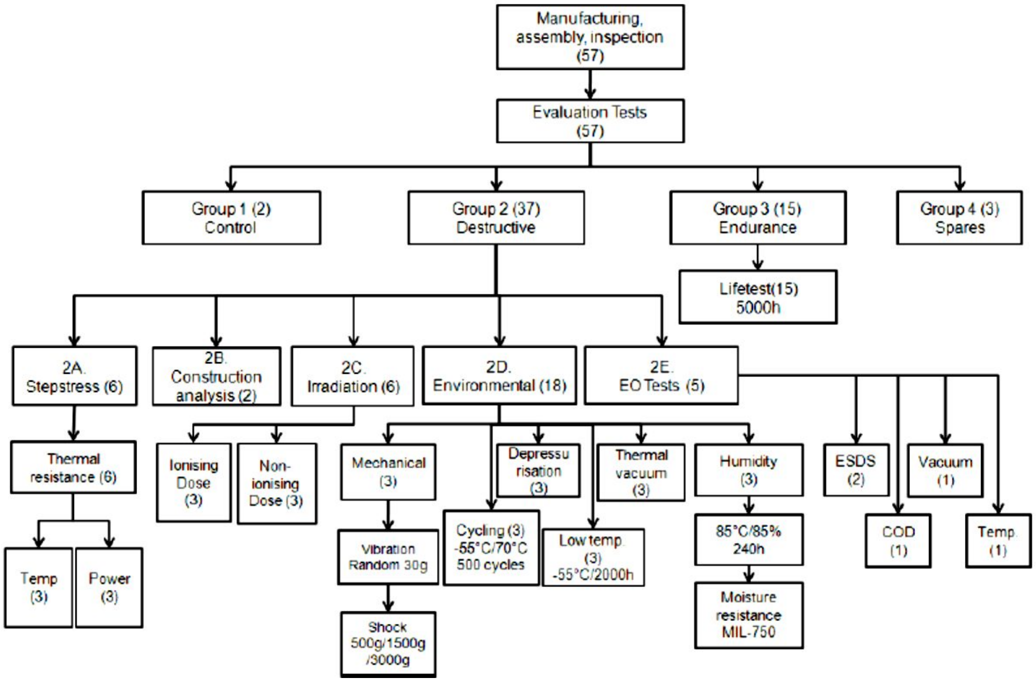


Figure 1. ETP planned after ESCC 23201.

2.3 Target specifications

The specifications are set according to the envisaged applications for this type of laser in remote sensing and communication mission scenarios. Prior to the fabrication of the lot to be used within the ETP, five devices were manufactured to perform a preliminary assessment on the operational performance. The key specifications and preliminary results from the pre- qualification batch are provided in the table below.

Table 1. Target specifications and performance of 5 pre-qualification lot

Parameter	Target specification	Pre-Qual (5)
Optical Power (ex-fiber) (mW)	> 54	80
Side Mode Suppression Ratio (dB)	>25	>55
Relative Intensity Noise (dB/Hz)	<-150	<-150
Linewidth (kHz)	<1000	<650
Isolation (dB)	>30	>32
Power consumption @ 25oC (mW)	<8	<1.3
Power consumption @ 65oC (mW)	<8	<4.1

The pre-qualification lot measurements indicate that performance is well within target specifications. In particular, electrical power consumption is measured as low as 4.1 Watt at case temperature as high as 65 degC, which is well below the target requirement. The drastic reduction of the power consumption is attributed to the internal sub-assembly arrangement, which optimizes the temperature control efficiency.

A fully packaged and pigtailed DFB sample is illustrated in Figure 2. The 14-pin butterfly package is fully hermetic with hermeticity being verified in-process by fine and gross leak tests. The specific ETP is intended to expose flaws in unscreened products and to help define screening parameters that can then be applied to post-ETP production samples. As such, no bake-out will be performed on the module-level and only limited thermal treatment will be applied prior to delivery for the ETP. Following module qualification, the (post-ETP) flight batch will be subjected to in-process tests including high temperature bake-in, temperature cycling, burn-in and external visual inspection. Pre-cap inspection, PIND, and temperature cycling are planned to be performed as part of screening tests before delivery of the flight lot.

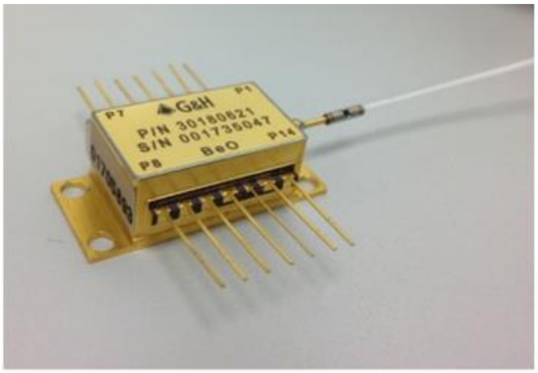
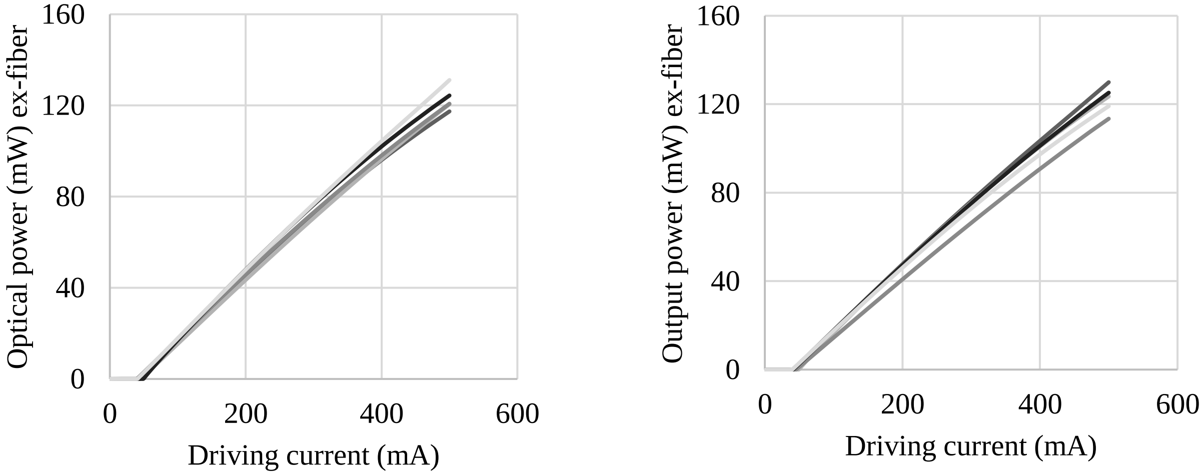


Figure 2. Packaged and pigtailed G&H high-power DFB laser for space applications

2.4 Preliminary performance results

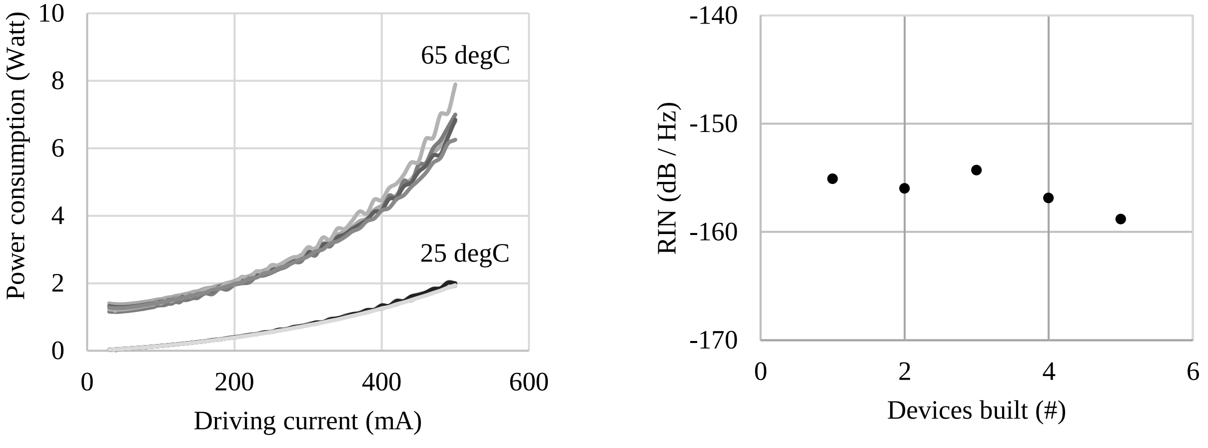
The figure below shows the opto-electronic performance measurements of the pre-qualification lot. Specifically, Fig. 3(a) and Fig. 3(b) show L-I curves at 25 degC and 65 degC case temperatures respectively. The DFB delivers an ex-fiber optical power of 80 mW at a driving current of <350 mA. The output power scales to >100 mW at 500 mA. A RIN <-150 dB / Hz is recorded.



(a) (b)

Figure 3. L-I curves for the 5 pre-qual units at (a) 25degC and (b) 65degC case temperature

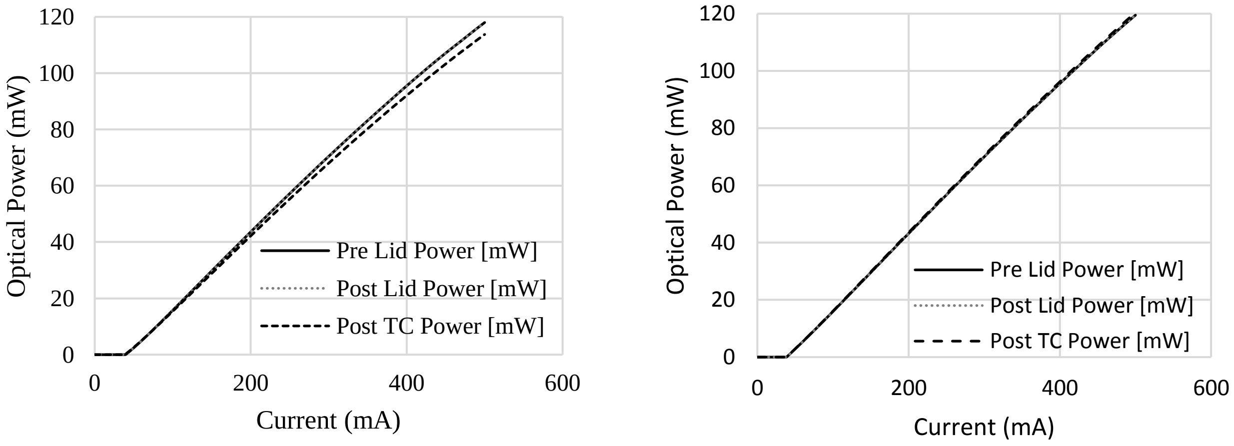
At 25 degC the power consumption is dominated by the laser and the TEC contribution becomes evident at driving currents as high as 500 mA. On the contrary, at 65 degC the power consumption from the TEC accounts for ~80% of the total module power consumption.



(a) (b)

Figure 4. (a) Power consumption and (b) RIN for the 5 pre-LAT DFB modules.

The pre-qualification lot has been subjected to 20 thermal cycles from -40 to +85 degC to assess the device sensitivity. The figure below illustrates typical L-I curves from 2 devices before lidding, after lidding and after temperature cycling, where a power drop from 0.1% to 3.6% was recorded.

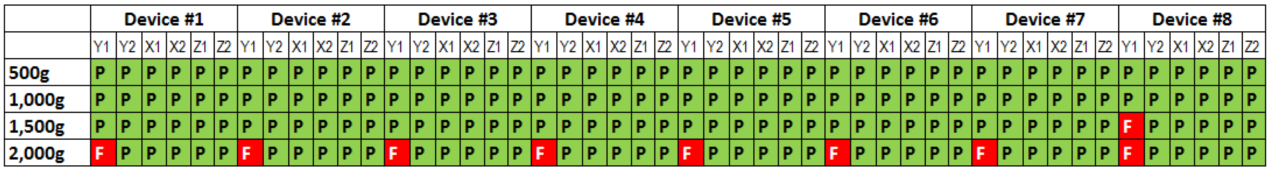


(a) (b)

Figure 5. DFB module L-I performance before and following temperature cycling

2.5 Shock testing

In order to assess the robustness of the build process, a mechanical shock test was performed in 8 sample modules following MIL-STD-883, Test Method 2002. Testing was conducted up to 2,000 g in all axes. The figure below summarizes the results obtained.



	Device #1						Device #2						Device #3						Device #4						Device #5						Device #6						Device #7						Device #8					
	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2	Y1	Y2	X1	X2	Z1	Z2
500g	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
1,000g	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
1,500g	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	F	P	P	P	P	P
2,000g	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P	F	P	P	P	P	P

Figure 6. Mechanical shock results.

All samples passed at 500g and 1,000g. There were no failures on the non-critical axes (X1,2 and Y2 and Z1,2) up to and including 2000g. On the critical Y1 axis, there was one failure at 1500g, and all remaining devices failed at 2000g in the specific axis.

3. PUMP LASERS

3.1 SM Mini-DIL pump laser

Uncooled SM PLMs are developed primarily for optical pumping of core-pumped Erbium doped fibers. They are ideal candidates of use in EDFAs or ASE sources which are used typically in satellite laser communication systems or fiber optic gyroscopes. The components are manufactured using Gooch & Housego laser welding process and are packaged into small form factor 8-pin Mini-DIL packages. The device is hermetically sealed with the optical sub-assembly carrying the laser diode, monitor and thermistor. The fiber attachment method ensures extended operating temperature behaviour. The fiber pigtail is polarization maintaining which allows for scaling of pump power through a single fiber with polarization multiplexing of PLMs. The pigtail also employs a grating for wavelength stabilization. Finally, emission wavelength is 976 nm which coincides with Erbium doped fiber absorption spectra.

The figure below illustrates a typical L-I curve of the Mini-DIL PLM over -5 to +65 degC temperature range. A manufactured module soldered on PCB is also shown. The PLM delivers an ex-fiber power of >235 mW at a case temperature as high as +65degC and at a maximum de-rated driving current of 480 mA. The ex-fiber power scales to 264 mW at room temperature and at the same driving conditions. The ex-fiber power at room temperature and at a maximum driving current of 600 mA is 325 mW.

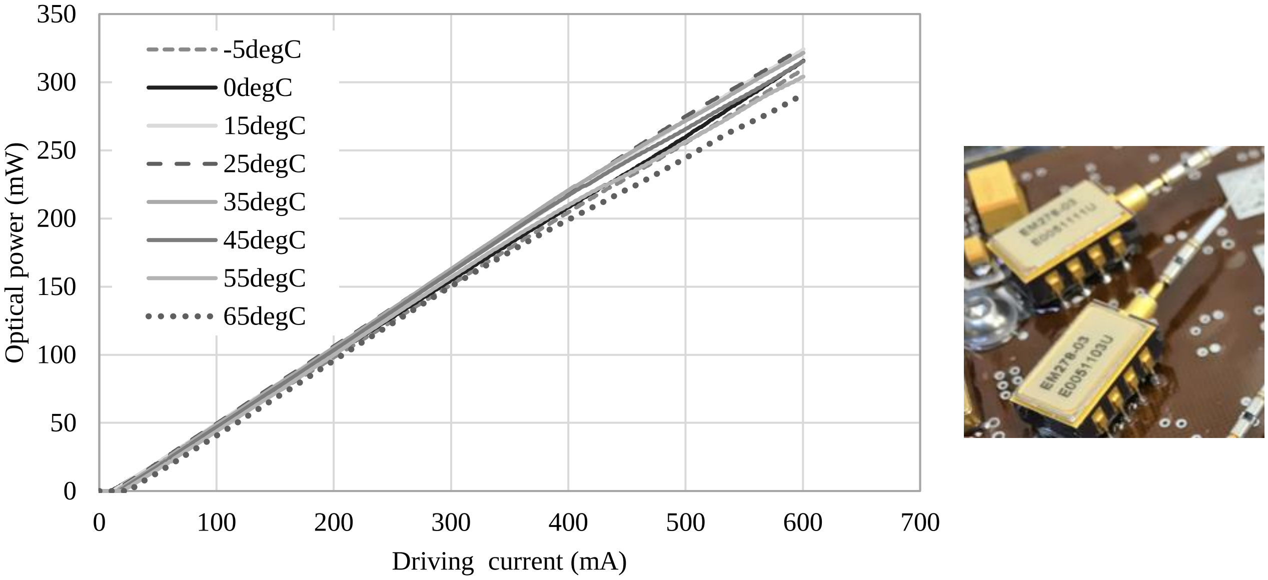


Figure 7. Mini-DIL PLM L-I curve over -5 to +65 degC (left) and Mini-DIL PLMs soldered on PCB (right)

The Mini-DIL PLM has been tested against non-ionizing radiation which is considered detrimental for opto-electronic components. With respect to laser diodes, the degradation due to displacement damage is expressed through a threshold current shift. The tests have been performed in collaboration with ALTER Technology using the proton radiation facility at UCL. The table below illustrates the test conditions and measured parameters. One device has been used and measured at three different fluence steps. The device was not biased during beam exposure.

Table 2. Irradiation parameters

STEP	**60Mev Beam flux ($cm^{-2}\ s^{-1}$)**	**Beam time (s)**	**Accumulated beam time (s)**	**Cumulative fluence (p/cm^2)**
1	10^8	100	100	10^{10}
2	10^8	900	1000	10^{11}
3	10^8	6670	7670	10^{12}

The center wavelength and L-I curve were measured before the test and at each irradiation step. The L-I curve has been recorded into fine steps of 0.05 mA up to 55 mA in order to capture the drift in threshold current. The Mini-DIL PLM under test is shown in the figure 8. The PLM was mounted on a prototyping board in order to get access to its electrical pins.

Table 3. Parameters measured

Parameter	Test condition
Centre wavelength	Measured @ laser driving current of 400mA
L-I curve (regime 1)	Driving current step of 0.05mA up to 55mA
L-I curve (regime 2)	Driving current step of 5mA up to 600mA

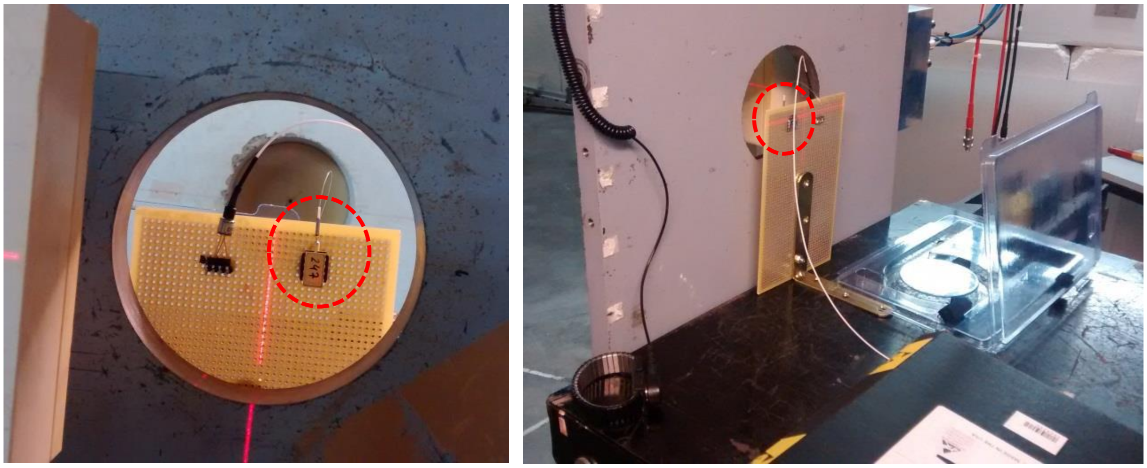
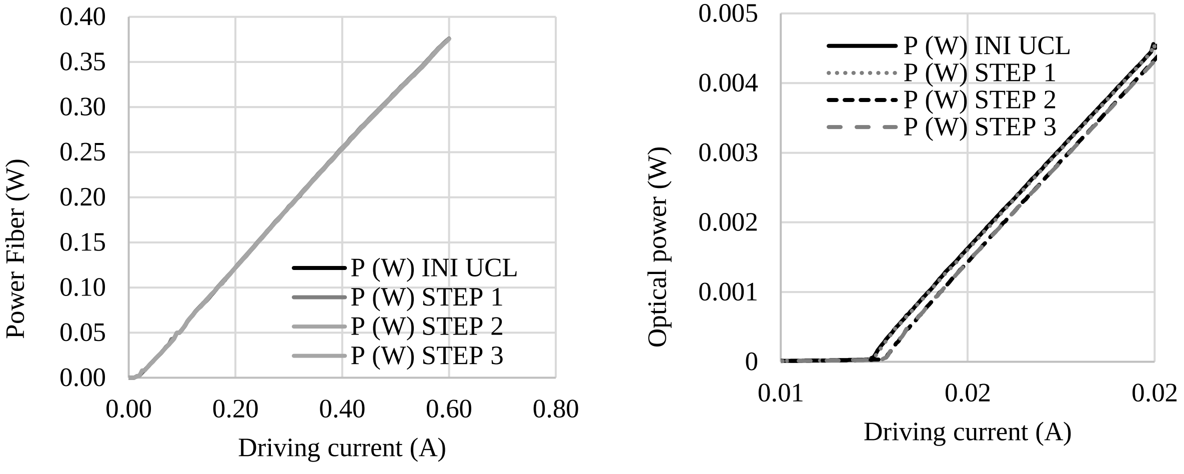


Figure 8. Mini-DIL PLM under beam irradiation: (left) front view and (right) rear view

The figure below illustrates the L-I curve at initial and intermediate steps. Figure 8 (left) shows that there is no detrimental impact on the laser performance with a very good matching of the initial and intermediate L-I curves. Figure 8 (right) probes into the 10 - 20 mA region with a measurement step of 50µA. A negligible shift of the threshold current is evident only after step 2. Figure 9 shows the optical spectrum at each step. A negligible shift of 0.1 nm is recorded after step 3, which is, however, close to the wavelength accuracy specification of the Optical Spectrum Analyser (OSA).



(a) (b)

Figure 9. Proton radiation results for the mini-DIL PLM at three irradiation levels: full driving current span of 0 - 600 mA (left) and span between 10 to 20 mA driving current (right).

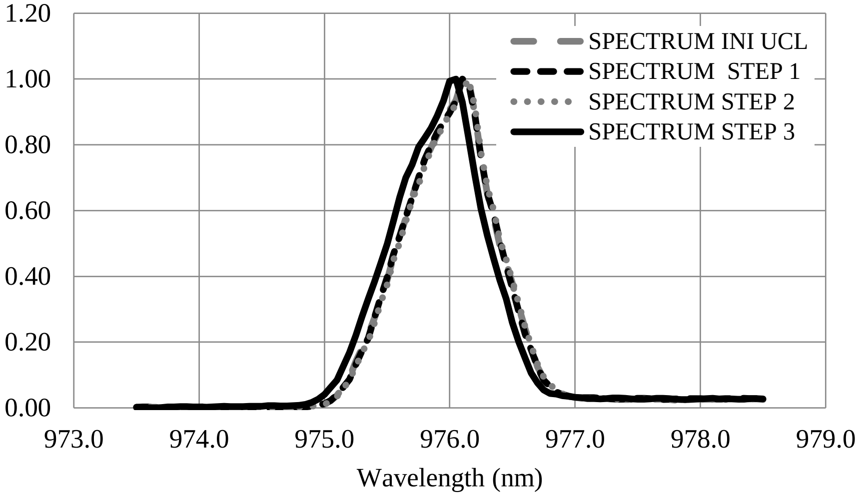
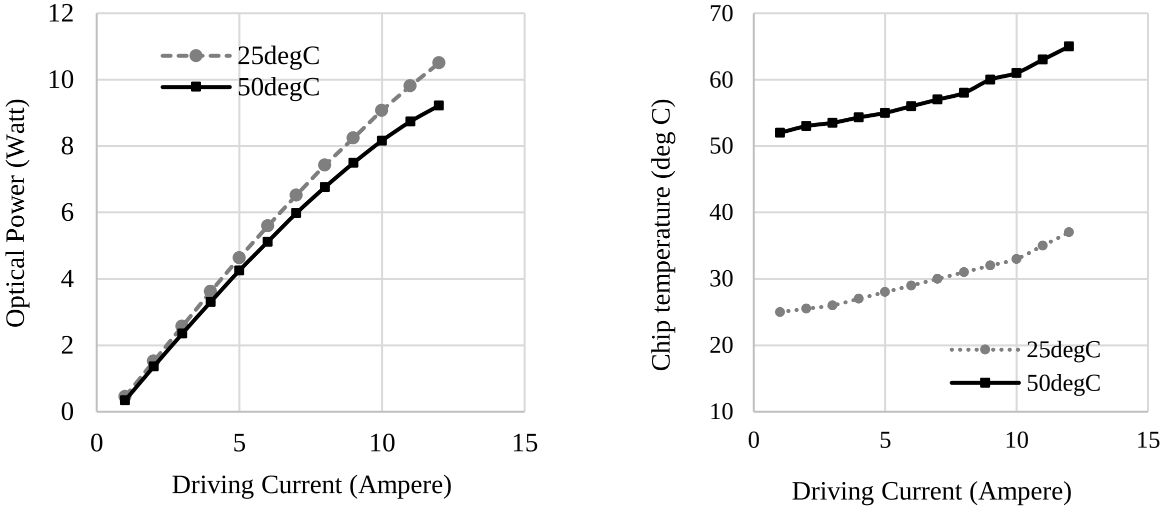


Figure 10. Optical spectrum at the different irradiation steps. The spectrum shift is within the measurement uncertainty of the instrument.

3.2 Multimode pump laser

Similar to the Mini-DIL PLMs, uncooled high power Multimode (MM) PLMs are developed primarily for optical pumping of cladding-pumped doped fibers. They are ideal candidates of use in Watt-level fiber amplifiers and lasers, which are typically used in long range satellite laser communication systems. Similar to the Mini-DILs the components are manufactured using Gooch & Housego laser welding processes. 9xx nm chips are packaged into a hermetically sealed 14-pin butterfly packages. The wavelength is selected to match the absorption of Yb and Er-Yb co-doped fibers, but it can be changed to accommodate pumping of fibers with different absorption spectra. The pin thickness is such to support high driving currents. The figure below illustrates a fully packaged and pigtailed device as well as typical L-I and temperature measurements.



(a) (b)

Figure 11. L-I curve at 25degC and 50 degC case temperature (left) and chip temperature rise as a function of driving current at 25degC and 50 degC case temperatures (right)

The L-I data show that the MM PLM can deliver >10 W ex-fiber power at a maximum driving current of ~12 A at room temperature. The temperature of the pump chip has been monitored using the internal thermistor. The temperature data shown in Fig. 11 (right) show a maximum temperature rise of ~15 degC with increasing the driving current to its maximum value. The pump chip reaches a maximum temperature of 65 degC which is within its operating temperature specifications.

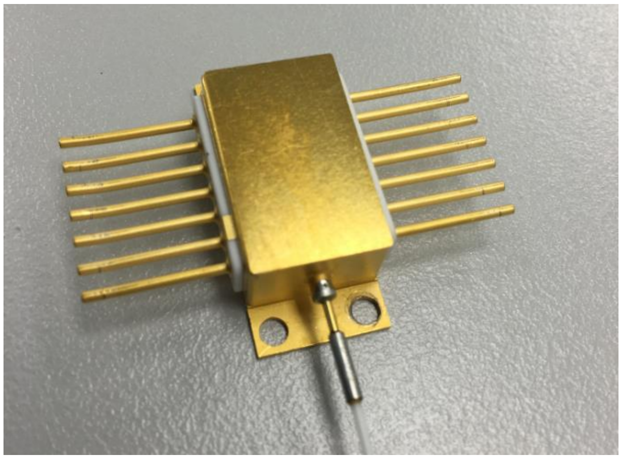


Figure 12. Packaged and pigtailed high-power 915nm MM pump laser

A MM PLM was subjected to a proton radiation test with similar test conditions to the SM PLM (Table 2). The module was measured at three different fluence levels and was compared to its pre-irradiation performance. The maximum current was set to 3A due to limitations with the experimental setup related to heatsinking and connectorization. Two sets of data with different measurement resolution were obtained in order to capture any shift in the threshold current. The figure below shows the results obtained and reveal minimal slope change and threshold shift.

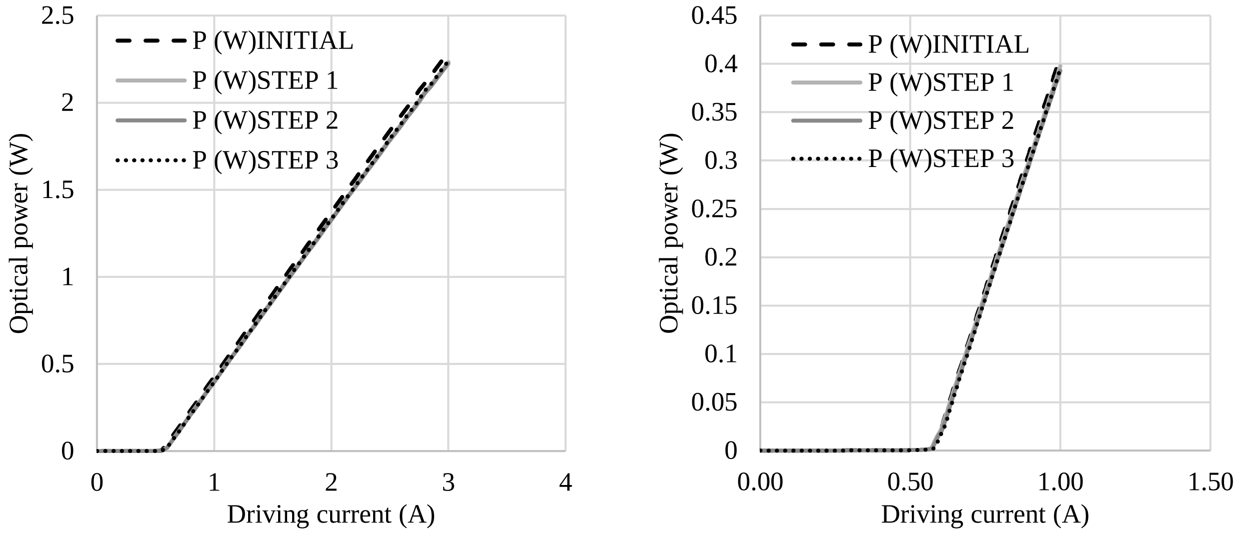


Figure 13. L-I curves from 0-3A with 50mA steps (left) and 0-1A with 1mA steps (right) for the different proton radiation steps.

4. CONCLUSIONS

We have presented the manufacturing and evaluation testing of a family of packaged laser modules applicable to diverse satellite applications. Modules are fabricated with G&H high-rel packaging processes, which comply with space requirements for fully hermetic modules. DFB lasers as well as SM and MM pump lasers have been packaged using different package types, including low- and high-current 14-pin butterfly and 8-pin Mini-DIL packages. Functional and environmental tests indicate stable performance against temperature and proton radiation.

5. ACKNOWLEDGMENT

This work has been supported by ESA through the ECI program "Space validation of Rad-Hard Erbium Optical Fiber Amplifier at 1.55 um" (ESA contract number 4000110438) and ECI program "Space validation of High-power DFB Laser at 1.55 µm" (ESA contract number 4000110310). We gratefully acknowledge ESA/ESTEC project officers Ms Charlotte Bringer and Mr Mustapha Zahir for the support and technical guidance during the contract execution. The research leading to the results in this publication has received funding from the European Union, Seventh Framework Programme for research, technological development and demonstration under the HIPPO Grant number FP7-SPACE-2013-1-606915.

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