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OPTOELECTRONIC MODULES FOR SPACE APPLICATIONS

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I. INTRODUCTION

Photonics is progressively becoming an enabling technology across all space segments [1] including Earth observation, telecommunications and navigation. Due to the inherent advantages offered by the technology, 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 a laser communication system [2] or a payload within a telecom, Earth Observation [3]. Specifically semiconductor laser components are used to provide the optical signals to be modulated in a laser communication 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 followed for space qualifying the module and we report on functional and environmental performance results from 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, we report on the technology readiness level of pump laser modules 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 the following fiber coupled, pump laser modules (PLM) (a) 976 nm 8-pin MiniDIL single mode (SM) high brightness PLM and (b) 915 nm 14-pin butterfly multimode (MM) low brightness PLM. 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 laser welding assembly process which delivers fully hermetic and high-rel opto-electronic modules.

II. DFB laser

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 European 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 Primes. The rationale of the programme is to firstly develop a pre-qualification lot and perform functional and a limited set of environmental tests, and then proceed to the manufacturing of a complete Flight Lot and implement the ETP campaign, as per ESCC. In this paper, we present the pre-qualification lot results.

The figure below illustrates the DFB module target optical specifications and their benchmark against the corresponding measured performance of the 5 pre-qualification lot. 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 expectations. 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 also illustrated in Figure 1. The 14-pin butterfly package is fully hermetic with hermeticity being verified in-process by fine and gross leak tests. Other in-process tests include high temperature bake-in, temperature cycling, burn-in and external visual inspection. Pre-cap inspection, PIND, and temperature cycling are also performed as part of screening tests before delivery for qualification testing.

	Spec	Pre-LAT (Qty 5)
Optical power (ex-fiber) (mW)	> 54 (EOL)	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 @ 25^{0}C (W)	< 8	< 1.3
Power consumption @ 65^{0}C (W)		< 4.1

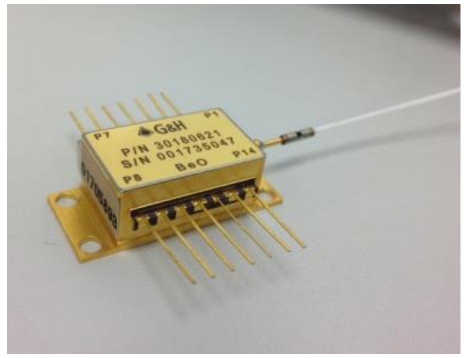

Fig. 1. (left) Target optical and opto-electronic specifications and performance of 5-piece pre-qualification lot. (right) Finished DFB module.

The figure below shows the opto-electronic performance measurements of the pre-qual lot. Fig. 2 (top) shows L-I curves at 25 degC (right) and 65 degC (left) case temperatures. 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 which is in-line with narrow linewidth requirements.

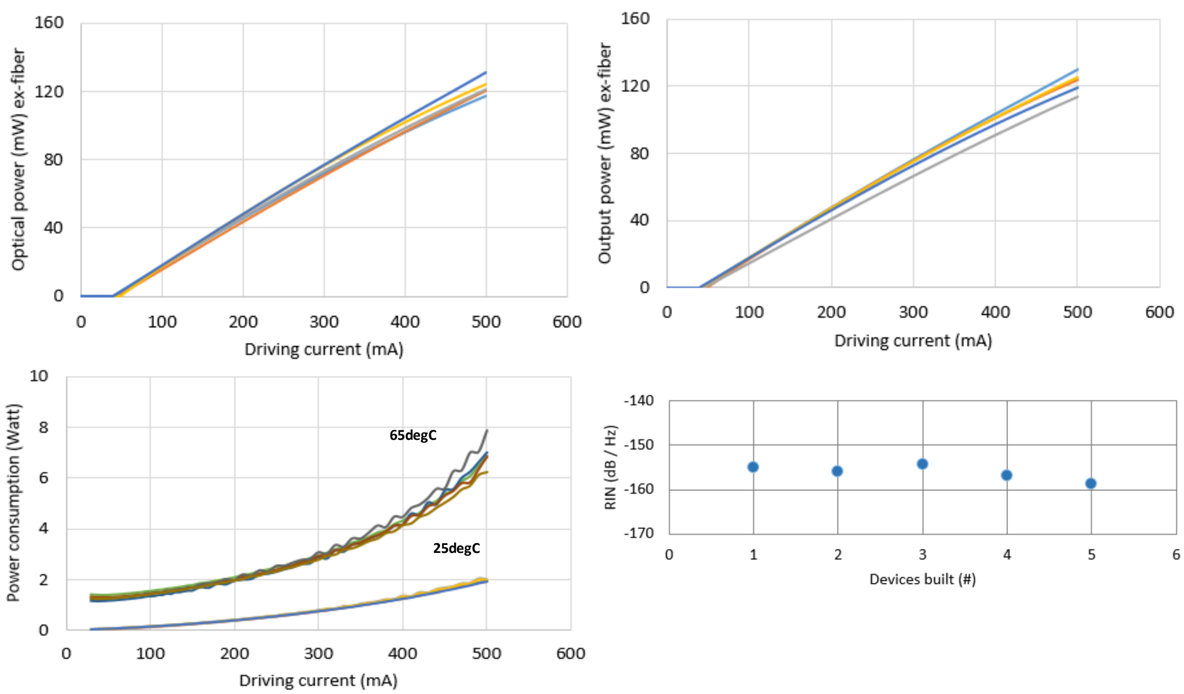

Fig. 2. (top) L-I curve at 25 degC (left) and 65 degC (right). (bottom) power consumption (left) and RIN (right) for the 5 pre-LAT DFB modules.

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 TEC power consumption accounts for ~80% of the total module power consumption.

The pre-qual lot has been subjected in 20 thermal cycles from -40 to +85 degC as screening test. The figure below illustrates typical L-I curves from 2 devices which demonstrate a stable performance before and following temperature cycling.

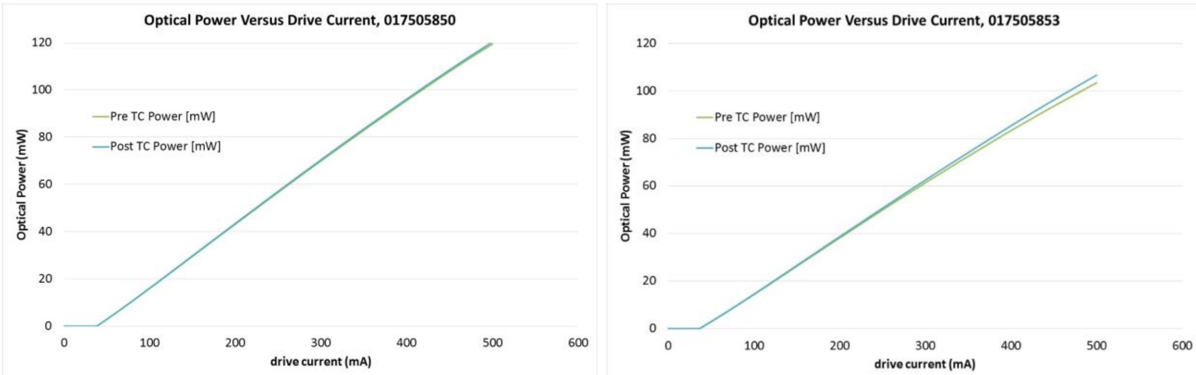

Fig. 3. DFB module L-I performance before and following temperature cycling.

III. SM MiniDIL 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 MiniDIL 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 MiniDIL PLM over -5 to +65 degC temperature range. A MiniDIL PLM soldered on PCB is shown in the inset. The PLM delivers an ex-fiber power of >235 mW at a case temperature as high as 65 degC 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.

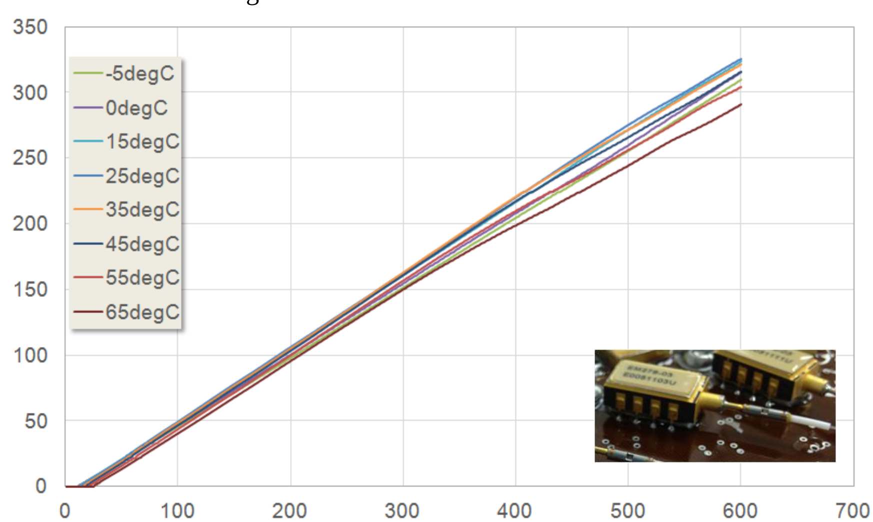

Fig. 4. MiniDIL PLM L-I curve over -5 to +65 degC. The inset shows a MiniDIL PLM soldered on PCB.

The MiniDIL 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 using the proton radiation facility at UCL. The table below illustrates the test conditions and measured parameters. One device has been used through the three different steps. The device was unbiased during beam exposure.

STEP	60Mev Beam flux (cm-2s-1)	Beam time (s)	Accumulated beam time (s)	Cumulative fluence
1	$1{\cdot}10^{8}$	100s	100s	$1{\cdot}10^{10}$
2	$1{\cdot}10^{8}$	900s	1000s	$1{\cdot}10^{11}$
3	$1.5{\cdot}10^{8}$	6670s	7670s	$1{\cdot}10^{12}$

Parameter	**Test condition**
Center Wavelength	Measured @ laser driving current of 400 mA
L-I curve (Fiber coupled power Vs driving current)	Measurement of Output power for: Driving current step of 0.05 mA up to 55 mA Driving current step of 5 mA up to 600 mA

Table 1. (top) proton radiation test conditions, (bottom) measured parameters.

The center wavelength and L-I curve were measured initially and at each step. The L-I curve has been recorded into fine steps of 0.05 mA up to 55 mA in order to capture any drifts in threshold current. The figure below illustrates the MiniDIL PLM under test. The PLM was mounted on a PCB to get access to its electrical pins.

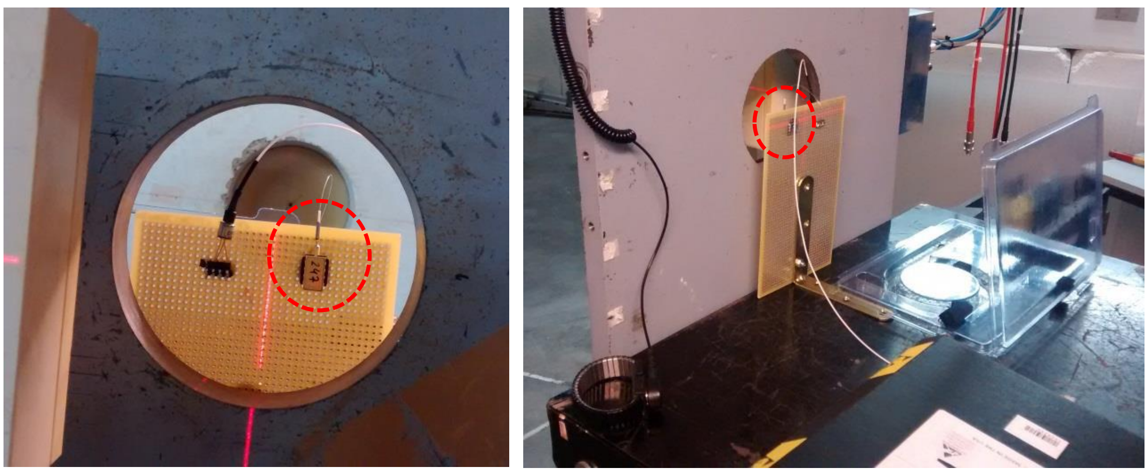

Fig. 5. MiniDIL PLM under beam irradiation: (left) front view and (right) rear view.

The figure below illustrates the L-I curve at initial and intermediate steps. Fig. 5 (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. Fig. 6 (right) probes into the 10 - 20 mA region with a measurement step of 50 uA. A negligible shift of the threshold current is evident only after step 2. The inset illustrates the measurements of the optical spectrum. Measurements show a stable center wavelength performance. A negligible shift of 0.1 nm is recorded after step 3 which is however close to the wavelength accuracy specification of the OSA.

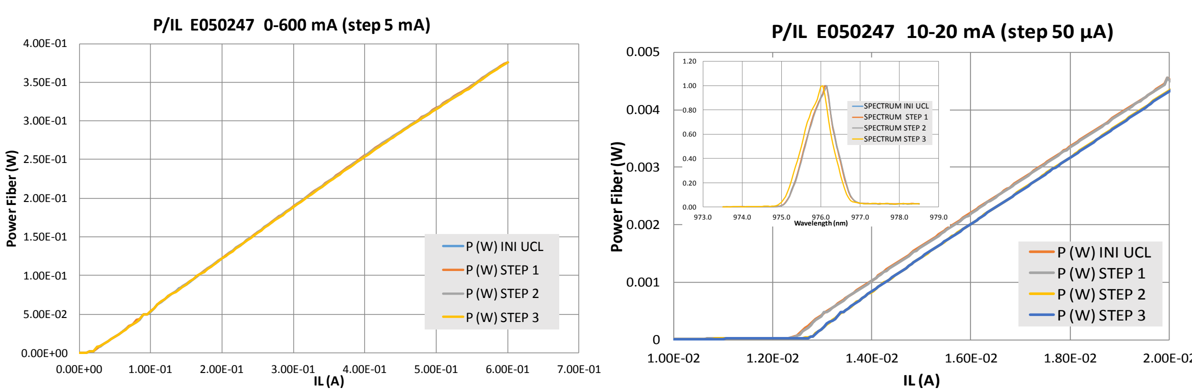

Fig. 6. L-I curves at initial, step 1, 2 and 3 of proton radiation for the MiniDIL PLM: (left) full driving current span of 0 - 600 mA and (right) zoomed area from 10 to 20 mA driving current. The inset shows the OSA trace at the various measurements points.

IV. MM pump laser

Similar to the MiniDIL PLMs, uncooled high power MM PLMs are developed primarily for optical pumping of cladding pumped doped fibers. They are ideal candidates of use in Wat-level fiber amplifiers which are used typically in long range satellite laser communication systems. Similar to the MiniDILs the components are manufactured using Gooch and Housego laser welding process. 915 nm chips are packaged into a hermetically sealed 14-pin butterfly package. The wavelength is selected to match the absorption of Yb and ErYb 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.

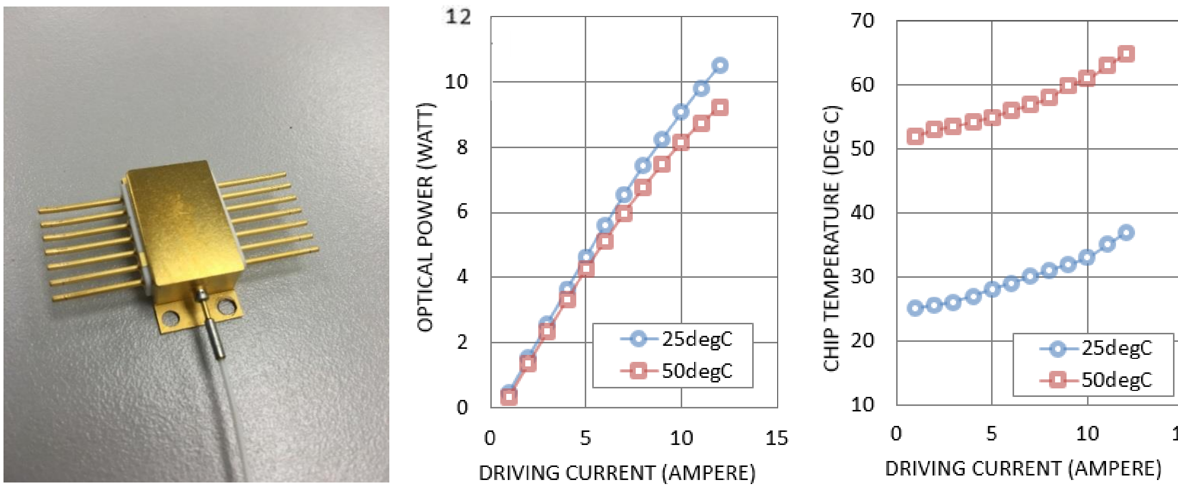

Fig. 7. (left) finished 14-pin butterfly MM pump laser, (middle) L-I curve at 25 and 50 degC case temperature and (right) chip temperature rise as a function of driving current at 25 and 50 degC case temperature.

The L-I data suggest that the MM PLM can deliver >10 W ex-fiber power at a maximum driving current ~12 A at room temperature. At a de-rated current of 9.5 A the module delivers an ex-fiber power > 10 W at case temperature as high as 50 degC. The temperature of the pump chip has been monitored through the internal thermistor. The temperature data shown in Fig. 7 (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.

A MM PLM has been subjected to proton radiation tests. The test condition is similar to the SM PLM.

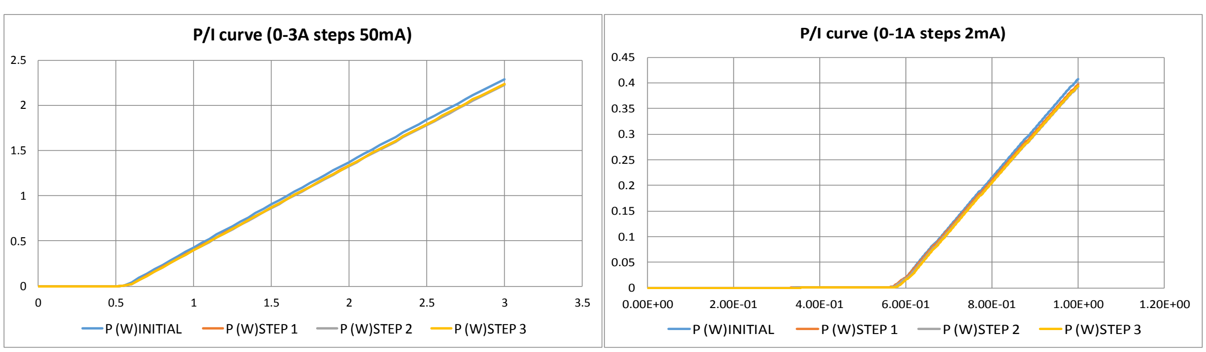

Fig. 8. L-I curves at initial, step 1, 2 and 3 of proton radiation for the MM PLM: (left) driving current span of 0 - 3 A and (right) zoomed area from 0 to 1 A driving current.

The results shown in Fig. 8, demonstrate a robust performance against radiation with a good agreement of the initial and intermediate L-I curve measurements.

V. CONCLUSIONS

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

VI. ACKNOWLEDGMENT

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