EVALUATION OF 2.1µm DFB LASERS FOR SPACE APPLICATIONS

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This paper presents the results obtained in the frame of an ESA-funded project called "Screening and Pre-evaluation of Shortwave Infrared Laser Diode for Space Application" with the objective of verifying the maturity of state of the art SWIR DFB lasers at 2.1µm to be used for space applications (mainly based on the occultation measurement principle and spectroscopy). The paper focus on the functional and environmental evaluation test plan. It includes high precision characterization, mechanical test (vibration and SRS shocks), thermal cycling, gamma and proton radiation tests, life test and some details of the Destructive Physical Analysis performed. The electro-optical characterization includes measurements of the tuning capabilities of the laser both by current and by temperature, the wavelength stability and the optical power versus laser current.

I. INTRODUCTION

Semiconductor lasers (or laser diodes) operating in the wavelength region of 1.8 µm to 3 µm are attractive light sources for applications including remote sensing, laser spectroscopy or pollutant detection. Highly strained InGaAs Quantum Wells (QW) grown on InP substrates can operate up to wavelengths slightly higher than 2 µm. GaInAsSb active layers on GaSb substrates have potential emission in the 1.7-3.5 µm range.

GaSb based DFB lasers emitting at 2 µm were reported for the first time by the University of Würzburg in 2001 [1]. They achieved room temperature emission with output powers up to 10 mW and Side Mode Suppression Ratio (SMSR) of 31 dB. DFB laser diodes can additionally be tuned by changing the operation temperature and the driving current, as a consequence of the dependence of the effective refractive index on temperature. This makes this type of source a potential candidate for space applications and first results of investigated fibre-coupled Butterfly type devices emitting in the 2.1µm wavelength range for applications in a space environment will be described in this contribution.

II. LASER CHARACTERISTICS

Within the project, nanoplus, a company specialized in DFB laser diodes from 760nm to 2.9µm for sensing applications, has supplied 2.1µm metal-grating based DFB devices integrated in a Butterfly package with an output power of around 10mW after coupling the light to an optical fiber (SMF28). These DFB laser chips in the wavelength range of interest are based on a laser structure in the AlGaInAsSb // GaSb material system. The main typical characteristics of these lasers are summarized in table I.

Table 1. Nanoplus SWIR Laser Electro-optical characteristics

Parameter	Symbol	Typical Value	Unit	Comment
Threshold current	Ith	20	mA	@ 25ºC
Maximun operating current	Imax	140	mA	Actually, a conservative value.
Slope efficiency	ηslope	0.16	W/A	@ 25ºC at the fiber output
Max Optical Power	Pmax	10	mW	@ 25ºC at the fiber output
Emission wavelength at Iop	λ (Iop)	2096	µm	@ 25ºC
Side Mode Suppression Ratio	SMSR	>35	dB	@ 25ºC
Temperature dependence of the emission wavelength	dλ/dT	0.20	nm/K	Defined between 20ºC and 30ºC operational temperatures
Current dependence of the emission wavelength	dλ/dI	0.025	nm/mA	@ 25ºC
Temperature stabilization	TEC Control			
Package	14 pin Butterfly			
Fibre	SMF28 (9/125µm)			
Optical Connector	FC/APC			

III. TEST SEQUENCE

Fig. 1 shows the proposed test sequence, which was adapted for the number of samples available within the project budget, 20 units. This sequence has been designed to get the maximum information of the behavior of the lasers under test from each group of test (mechanical, thermal, radiation and endurance).

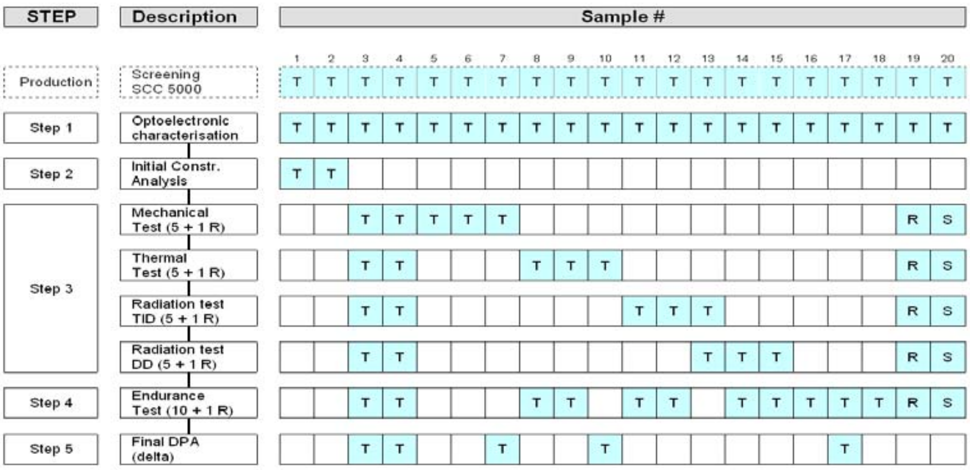

Figure 1. SWIR Laser test flow proposed for 20 samples. (T means sample to be Tested, R means Reference and S means Spare; the samples came from two different lots)

The Constructional Analysis (CA) includes inspections (external, internal, SEM), seal test, residual gas analysis tests and some other to have a good idea of the technology used and to have the possibility of comparison with the final Destructive Physical Analysis (DPA) to be performed after the completion of the test sequence. The mechanical test include vibration, both sine and random, and Shock Response Spectrum (SRS) tests. The thermal tests are based on non operation thermal cycling and thermal shock between -40ºC and +85ºC. The Total Ionization Dose (TID) or gamma radiation has been tested up to 100Krad and the Displacement Damage (DD) has been tested with proton radiation up to $2 \cdot 10^{10}$ proton/cm^2 at 60MeV. The endurance test (70ºC ambient temperature, 30ºC TEC controlled temperature and 120mA) is on going. At the moment of writing this paper more than 1000 hours life test have been monitored.

IV. TEST SETUPS CONSIDERATIONS & ELECTRO-OPTICAL CHARACTERIZATION

Considering that the typical expected values of the current and temperature dependence of the emission wavelength are dλ/dI = 0.025 nm/mA and dλ/dT = 0.2 nm/K, respectively, the required current and temperature stability to assure stable measurements has to be around 2 µA and 0.2 mK, respectively. The temperature required stability of 0.2 mK is not possible with existing commercial equipment that guarantee only 0.5 mK in the best case. Since both, the temperature and the laser current control, have therefore a strong impact on the precision of the measurements, the best available equipment has been used. The needed accuracy of the electro-optical measurements has lead to the necessity of using the best wavelength meters available. The Bristol 721 used in this project has a spectral range of 1.3 to 5 µm and an absolute accuracy of 0.2ppm (0.42pm at the laser wavelength of 2.1µm). Taking into account the accuracy of all the equipment involved, the expected uncertainty for the wavelength measurements is ± 1.3pm.

A. Electrooptical characterization

The following electro-optical parameters are being measured before and after each group: variation of wavelength with temperature (nm/ºC), variation of wavelength with current (nm/mA), threshold current (mA), optical power at 120 mA (mW) and the slope efficiency (mW/mA). Fig. 2 shows an example of the variation of wavelength with laser current and temperature.

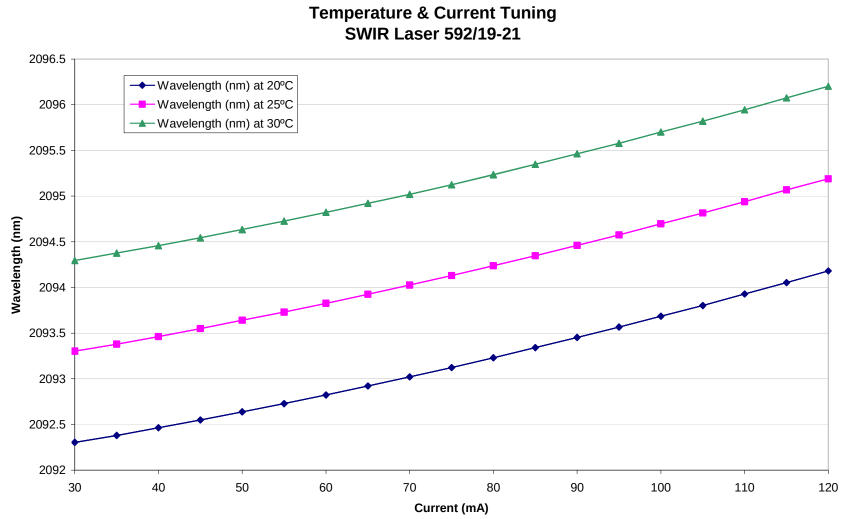

Figure 2. SWIR Laser temperature and current tunability

B. Ambient Temperature dependence.

Fig. 3 shows the variation of the wavelength of the laser with a fixed TEC controlled temperature of the laser diode of 20ºC when the external ambient temperature is changed between -20ºC and +70ºC. As expected, the actual temperature of the laser diode and the one measured with the control thermistor are not exactly the same. This effect, based on the internal temperature gradient that will be always present in a package, needs to be taken into account when controlling the laser chip temperature for future improvements towards high wavelength precision measurements

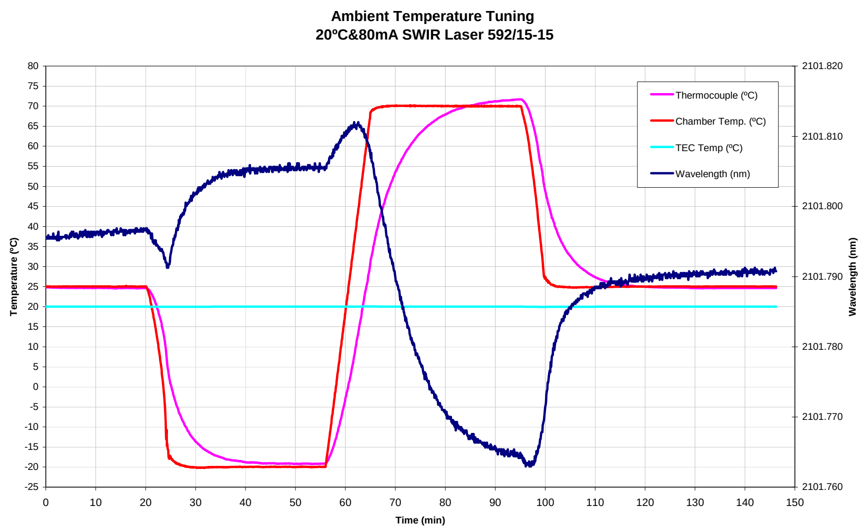

Figure 3. SWIR wavelength variation (dark blue line; right axis) with ambient temperature cycling for a laser diode TEC controlled temperature of 20ºC (light blue line). The red line is the actual chamber temperature and the purple line is the laser package temperature measured with an additional thermocouple.

C. Linewidth measurements

The emission linewidth of the lasers has been measured using a heterodyne technique with two SWIR lasers of similar emission wavelength. This technique [2, 3] combines the output of two different lasers onto a photodiode. One of the sources is tuned by means of current and temperature to match the lasing wavelength of the other source, through monitoring in an Optical Spectrum Analyzer or wavelength meter (the Bristol 721 in this case). The beating of the two optical fields produces a Power Spectral Density (PSD) at an electrical frequency given by the frequency difference of the two optical signals and containing information of the combined linewidth of the two sources. The variation of the wavelength induced by the thermal and current instabilities (although very low) lead to an unstable beating peak when measured in a spectrum analyzer. An active averaging method was developed to get optimum results. The combined linewidth obtained for the two lasers operating at maximum power was 0.54 MHz which corresponds to 0.27 MHz (0.008pm) for each laser. These values are extremely small and they should be confirmed by other methods.

V. MAIN RESULTS

The main results obtained when comparing the results before and after each environmental test are summarized in the following paragraphs:

- Mechanical Subgroup Test results: The samples have supported without degradation the mechanical tests (vibration and SRS shocks).
- Radiation Subgroup Test result: Neither gamma nor proton radiation has affected the lasers.
- Endurance Test results: Several samples are supporting the strong life test conditions without any degradation showing that the technology has the capability to survive the life test requirements, although a better uniformity of the lot manufacturing, if possible, is desirable. Additionally, an early failure and degradation for some of the devices were observed as will be presented in the talk.
- Thermal Subgroup Test results: Analyzed samples showed degradation during thermal cycling affecting output power and tuning characteristics of the devices, but the underlying reason of this behavior is presently not understood and currently investigated further.
- Construction analysis: The Residual Gas Analysis (RGA) showed a certain amount of internal humidity in the package. This can clearly have an impact on device reliability and could also be the underlying reason for the different behavior during endurance testing.

VI. CONCLUSIONS

DFB laser diodes based on a laser structure in the AlGaInAsSb/GaSb material system emitting in the 2.1µm wavelength range and integrated in a Butterfly package with an output power of around 10mW ex-fiber are investigated for the first time for applications in a space environment and measurement results of the corresponding test plan (mechanical, thermal, radiation and endurance) are presented.
The required accuracy to control the wavelength is directly coupled with the accuracy of the laser current and of the laser diode temperature. If high accuracy of the wavelength control is needed, then the dependence of the wavelength with ambient temperature that will be always present, even with laser diode temperature control, should be taken into account. No radiation related degradation has been observed. A problem related to thermal cycling is indicated by the results obtained till now; further investigations of this effect (including DPA) are currently being performed. The endurance test results obtained till now (this test continues) shows different behavior for different samples, but seems to show that there are no fundamental reasons that could prevent the use of this technology for space applications.

REFERENCES

[1] T. Bleuel, M. Müller, and A. Forchel, A.; "2-µm GaInSb-AlGaAsSb distributed-feedback lasers", *IEEE Photon. Technol. Lett.* , vol. 13 (6), pp. 553-555, 2001.
[2] D. Derickson, *Fiber Optic Test and Measurement*, Prentice Hall, New Jersey, 1998.
[3] M.O. Van Denveter, P. Spano, S.K. Nielsen, "Comparison of DFB Laser Linewidth Measurement Techniques. Results From Cost 215 Round Robin", *Electron. Lett.*, vol. 26, pp. 2018-2020 1990.