Evaluation of the Radiation Hardness of GaSb-based Laser Diodes for Space Applications

Ignacio Esquivias, José-Manuel G. Tijero, Juan Barbero, Demetrio López, Marc Fischer, Karl Roessner, and Johannes Koeth

Abstract—**We present an evaluation of the effects of proton and gamma irradiation on the performance of GaSb-based 2.1 µm laser diodes lasers for space applications. The study is focused on the effects of radiation on the Power-Current, Current-Voltage and Wavelength-Current-Temperature characteristics of the lasers. No significant radiation damage has been found.**

Index Terms— **Laser diodes, GaSb-based materials, radiation effects, mid-infrared lasers.**

I. Introduction

LASER diodes are increasingly used for space applications, either to pump solid state lasers, in photonic payloads, or as sources for LIDAR or spectrometric applications. In space applications reliability issues are a primary concern and among them, radiation hardness is one of the most distinctive with respect to terrestrial applications.

A good deal of effort has been devoted to study specifically the effect of radiation on the performance of the most common visible and near infrared emitting GaAs- and InP-based diode lasers [1-5, and references herein]. Johnston and Miyahira [1] studied the effect of proton radiation on different types of low power commercial laser diodes with emission wavelengths between 660 and 1550 nm. They found a linear increase of the threshold current with proton fluence as well as a small reduction of the slope efficiency. They interpreted the degradation as arising from an increased non-radiative recombination rate and observed more clearly the radiation effect when they measured the devices below threshold.

Troupakia et al. [2] performed a detailed test plan for 808 nm high power laser bars including vibration test, proton and gamma irradiation. They concluded that the evaluated devices are robust enough to survive the vibration and radiation stresses of most space flight missions.

However, as far as we know, the radiation effects on GaSb-based laser diodes have not been previously investigated. These devices, emitting in the middle infrared between 2 and 3 µm are of a great interest for spectroscopy applications. The degradation of GaSb p-n junctions after irradiation has been analyzed in [6], in the frame of their application in multiple-junction solar cells. An increase of the non-radiative recombination after radiation was observed, and the degradation rates for GaSb and GaAs junctions were found to be similar in the order of magnitude.

In this work we present results on the radiation hardness of mid infrared emitting GaSb-based diode lasers for space applications. The work has been performed in the framework of the European Space Agency (ESA) Invitation to Tender AO/1-5618/08/NL/CP), with the aim of evaluating the future use of these devices in on-board spectrometric applications. The general results of the evaluation were presented in [7].

II. Laser Devices, Characterization, and Radiation Conditions

A. Laser Devices

The analyzed devices were 2100 nm emitting Distributed Feedback (DFB) GaSb-based laser diodes. The laser structures were grown on GaSb substrates by Molecular Beam Epitaxy (MBE). The active region consisted of several type I InGaAsSb quantum wells separated by AlGaAsSb barriers. The confinement and cladding layers were also different AlGaAsSb alloys. The structures were processed into narrow ridge laser diodes, and the DFB structure was realized by depositing a metal grating on both sides of the ridge. More details on the epilayer structure and processing technology for similar devices can be found in [8, 9].

The laser chips were mounted onto heat-spreaders and fiber-packaged in hermetic butterfly mounts, including an integrated thermo-electrical controller, monitor photodiode and a temperature sensing element. The laser output was coupled to a SMF-28 single mode fiber.

B. Laser Characterization

The Optical Power-Current (P-I) characteristics were measured out of the fiber using a Thorlab laser driver and a

Manuscript received April 29, 2011. This work was supported by the ESA under ITT AO/1-5618/08/NL/CP "Screening and Pre-evaluation of Shortwave Infrared Laser Diode for Space Application".

Ignacio Esquivias and José-Manuel G. Tijero are with Universidad Politécnica de Madrid, ETSI Telecomunicación, Ciudad Universitaria, 28040 Madrid (Spain), (phone: +34913367339; fax: +34913367319; e-mail: esquivia@ tfo.upm.es).

Juan Barbero and Demetrio López are with Alter Technology Group Spain, Majada 3, 28760 Tres Cantos (Spain).

Marc Fischer, Karl Roessner, and Johannes Koeth are with nanoplus GmbH, Nanosystems and Technologies, Oberer Kirschberg 4, D-97218 Gerbrunn (Germany).

Hamamatsu InGaAs photodetector. The calibration of the optical power was performed using a Newport thermopile as power detector. The subthreshold Current-Voltage characteristics (I-V) were measured using a Keithley SMU-237 source. The lasing wavelength, as a function of current and temperature, was determined using a Bristol 721A wavelength meter.

20 devices were characterized and submitted to a detailed test plan [7], which in addition to radiation tests included mechanical, thermal cycles and lifetime tests. The most relevant electro-optical laser parameters are summarized in table I. It should be noted that the power delivered by the laser chip was much higher than the ex-fiber measured power due to the coupling losses, estimated to be ~ 50%.

TABLE I
SUMMARY OF TYPICAL VALUES OF MAIN LASER PARAMETERS

Parameter	Typical Value	Unit
Threshold current, I_{th}	20	mA
Slope efficiency, η_{slope}	0.16	W/A
Max Optical Power, P_{max}	10	mW
Emission wavelength at P_{max}	2096	nm
Side Mode Suppression Ratio, SMSR	> 35	dB
Temperature dependence of the emission wavelength, $d\lambda/dT$	0.20	nm/K
Current dependence of the emission wavelength, $d\lambda/dI$	0.025	nm/mA

C. Radiation Conditions

Three samples were exposed to a Total Ionization Dose (gamma radiation) up to 100 krad in four different steps at a dose of 550 rad/h using a cobalt-60 source in the facilities of Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT, Madrid, Spain). Three samples (one of them previously gamma irradiated) were exposed to Displacement Damage (DD) with proton radiation up to $2\cdot10^{10}$ protons$\cdot$cm^{-2} in three steps at 60 MeV and proton flux of 10^7 protons$\cdot$cm^{-2}s^{-1}, in the facilities of the Catholic University of Louvain (UCL, Louvein la Neuve, Belgium). During the gamma-ray and proton irradation processes the sample temperature was 25 ºC and the devices were short circuited. The radiation conditions were selected as representative for a typical LEO (low earth orbit) satellite in a three year mission.

The P-I and wavelength characteristics were measured after each radiation step, while the subthreshold I-V characteristics were measured initially and at the end of the test plan for each device. Two non-irradiated samples were used as reference.

III. RESULTS AND DISCUSSION

Fig. 1 shows examples of the evolution of the P-I characteristics for gamma (Fig. 1a) and proton (Fig. 1b) irradiated samples at the different radiation steps. The absence of radiation damage can be clearly inferred from the stable threshold current and slope efficiency. The wavelength tuning characteristics remained also unchanged after the radiation test, as it is shown in Fig. 2.

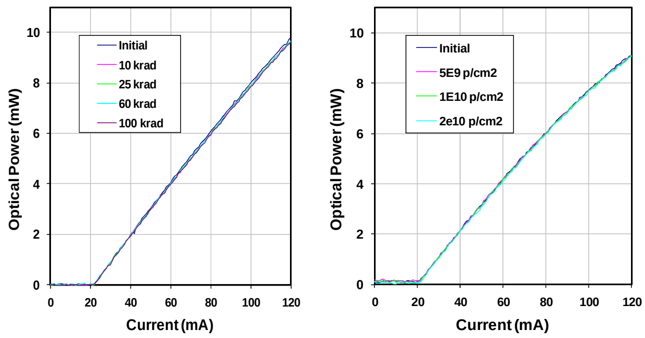

Fig. 1. Optical Power-Current characteristics of lasers exposed to gamma radiation (a) and proton radiation (b) during the different test steps

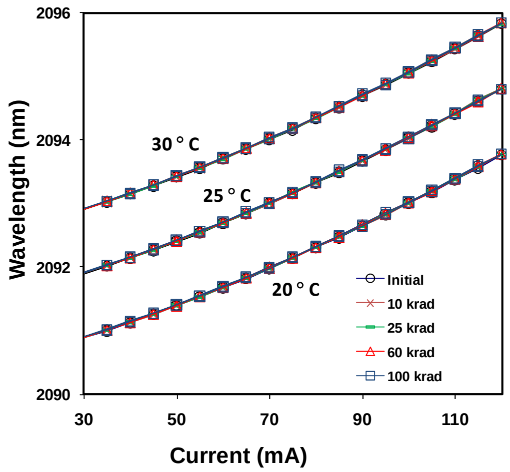

Fig. 2. Emission wavelength as a function of current at three different temperatures for a lasers exposed to gamma radiation during the different test steps.

The subthreshold I-V characteristics have been previously used as a sensitive tool to detect radiation damage [3-5]. The sensitivity of the subthreshold measurements is due to the relative contribution of the different recombination mechanisms at different bias conditions. Shockley-Read-Hall recombination, caused by defects in the semiconductor, is usually predominant at low current levels while spontaneous and Auger recombinations are the main recombination paths at current levels close to threshold. Since the radiation damage is due to the creation of defects in the crystalline structure, it should be more clearly observed at low injection levels. For this reason we measured the I-V curve down to very low current levels (0.1 μA). The I-V characteristics were analyzed using an equivalent electric circuit for the laser devices consisting in a resistance (R_S) in series with the parallel combination of a p-n junction diode and a shunt or leakage resistance (R_L). The I-V characteristics of such circuit are given by the following analytical expression:

$$I = I_0\left(\exp\left(\frac{q}{mkT}(V - IR_S)\right) - 1\right) + {(V - IR_S)}/{R_L} \qquad (1)$$

where m is the diode ideality factor, k the Boltzmann constant, T the absolute temperature, q the electron charge, and I_o the saturation current. Fig. 3 shows, as an example, the measured initial I-V characteristic of a laser, compared with the results of a fitting of (1) to the experiments. The black line corresponds to the I-V characteristic of the leakage resistance (R_L = 35 kΩ in this example), showing that at very low current levels the leakage resistance is the predominant current path. The red line in Fig. 3 corresponds to the exponential I-V characteristic of an ideal p-n junction with m = 2 and $I_0 = 4.5 \cdot 10^{-8}$ A, and the difference with the total I-V of the device is due to the series resistance R_S = 4.5 Ω. The value of the initial electrical parameters m, I_0 and R_S were very similar in all devices, while R_L ranged between 3 and 100 kΩ.

The initial and final I-V characteristics of some samples subjected to irradiation, as well as one of the reference samples, are shown as examples in Fig. 4. As it can be observed, in some samples there is a change of the current at low voltage, which corresponds to maximum changes in R_L of around 50%. However, these changes are not present in all irradiated samples, and they are also observed in the reference samples, so they are not correlated with radiation effects. At voltages higher than 0.3 V, corresponding to the p-n junction I-V exponential characteristics, the changes are negligible in all samples. In fact, the changes of the junction parameters I_0 and m were within experimental error. In consequence, we consider that there is no measurable radiation damage in the tested samples.

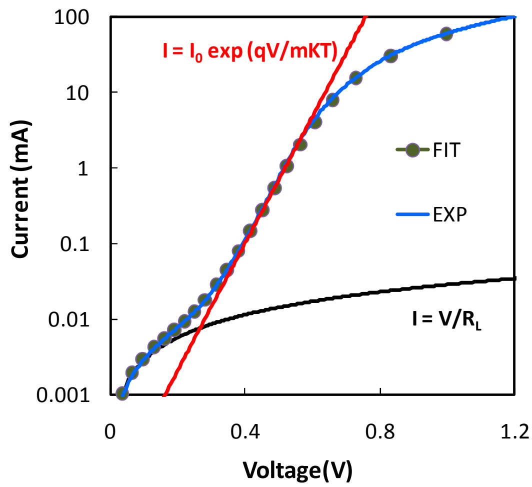

Fig. 3. Experimental (EXP, blue line) and calculated (FIT, grey circles) subthreshold Current-Voltage characteristics for one of the lasers. The black and red lines correspond to the calculated I-V characteristics of the leakage resistance and of the ideal p-n junction, respectively.

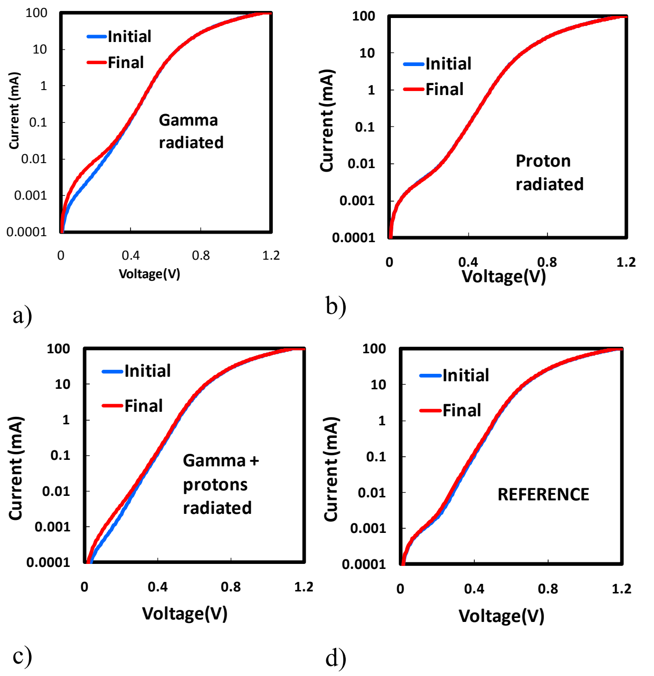

Fig. 4. Subthreshold Current-Voltage characteristics of lasers exposed to gamma radiation (a), proton radiation (b), gamma and proton radiation (c), and reference sample (d)

IV. Conclusions

GaSb-based DFB laser diodes emitting in the 2.1 µm wavelength range and integrated in a Butterfly package with an output power of around 10mW were evaluated in terms of radiation hardness for applications in a space environment.

Radiation related degradation was not observed up to 100 krad of gamma radiation and up to $2 \cdot 10^{10}$ protons·cm^{-2} at 60 keV. The results indicate that mid-infrared lasers based on GaSb are suitable candidates for space applications.

Acknowledgment

This work has been founded by the European Space Agency under contract AO/1-5618/08/NL/CP.

References

[1] A. H. Johnston and T. F. Miyahira , "Radiation Degradation Mechanisms in Laser Diodes", IEEE Trans. Nuclear Sci., vol. 51, no. 6, pp. 3564-3571, 2004

[2] E. Troupakia, A. A. Vasilyev, N. B. Kashem, G. R. Allan, M. A. Stephen; "Space qualification and environmental testing of quasicontinuous wave laser diode arrays"; J. Appl. Physics, 100, 063109, 2006.

[3] S. C. Lee, Y. F. Zhao, R. D. Schrimpf, M. A. Neifeld and K. F. Galloway; "Comparison of Lifetime and Threshold Current Damage Factors for Multi-Quantum-Well (MQW) GaAs/GaAlAs Laser Diodes Irradiated at Different Proton Energies", IEEE Trans. Nuclear Sci., vol. 46, no. 6, pp. 1797-1803, 1999.

[4] H. Ohyama et al.; "Impact of neutron irradiation on optical performance of InGaAsP laser diodes", Thin Solid Films, vol. 364, pp 259-263, 2000.

[5] M. Boutillier et al.; "First Evaluation of Proton Irradiation Effects on InAs/InP Quantum Dash Laser Diodes Emitting at 1.55 µm", IEEE Trans. Nuclear Sci., vol. 55, no. , pp. 2243-2247, 2008.

[6] V. M. Andreev, V. V. Evstropov, V. S. Kalinovski, V. M. Lantratov, and V. P. Khvostikov, "The Effect of Damaging Radiation (p, e, γ) on Photovoltaic and Tunneling GaAs and GaSb p–n Junctions", Semiconductors, vol. 41, no. 6, pp. 732–736, 2007.

[7] J. Barbero, D. López, I. Esquivias, J.M.G. Tijero, M. Fischer, K. Roessner, J. Koeth, M. Zahir, "Evaluation of 2.1µm DFB lasers for space applications", International Conference on Space Optics ICSO 2010, 4 - 8 October 2010, Rhodes, Greece.

[8] T. Bleuel, M. Müller, A., Forchel, "2-µm GaInSb-AlGaAsSb distributed-feedback lasers", IEEE Photonics Technol. Lett., vol. 13 (6), pp. 553-555, 2001.

[9] M. Hümmer, K. Rößner, A. Benkert, A. Forchel; "GaInAsSb-AlGaAsSb Distributed Feedback Lasers Emitting Near 2.4 µm"; IEEE Photonics Technol. Lett., vol. 16 (2), pp. 380-382, 2004.