Research Article
Describing a Laser Diode Emulation Tool Using Single Emitter Simulation Results

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Abstract: This study describes and explores the use of a laser diode simulation tool at the single emitter level of operation and how they can be degraded. A test of the simulation tool is implemented to complement the by-emitter degradation analysis of high power laser diodes. The simulation tool is called *Speclase*, designed for the simulation of single emitters. Tests were performed using a 975 nm narrow-angle (<1º) tapered laser structure from Alcatel Thales III-V Lab with front and rear facet reflectivities of 3 and 90%, respectively. The tool worked for both the constant current and power modes of operation. Simulation results were obtained for both constant QW trap density, based on the maximum QW temperature and variable QW trap density generation due to local heating. Single emitter degradation results are obtained using the Arrhenius equation to compare the rate of degradation between the constant and variable QW trap densities.

Keywords: By-emitter degradation, degradation, emulation tool, heat sink, quantum well, trap density

INTRODUCTION

Rapid progress has been made over the past decade in the development of high-power laser bars due to high demands placed on the reliability and durability of such devices. There has also been a widespread demand Steele (2008) and use of such devices leading to the requirement of high output powers. Some traditional applications of laser diodes include pumping solid-state lasers, material processing, printing, medicine and entertainment. Laser bars consist of a linear array of emitters on a common substrate, which are connected in parallel. Emitter degradation is in known to be faster in a bar than identical emitters. Packaging-induced strain and self heating are known to play a role in the increase degradation rate of laser bars. An attempt to understand this further led to the development of the by-emitter degradation analysis technique over recent years Xia *et al.* (2002), Tomm *et al.* (2002), Bull *et al.* (2005), Lim *et al.* (2005) and Bream *et al.* (2006). This tool is a further addition to the by-emitter analysis where the effects of certain factors that affect the degradation of laser emitters/bars can be investigated. This study describes and explores the use of *Speclase* to simulate lasers at the single emitter level of operation and degrade them. The first section of this study discusses briefly the description of the emulation tool and the method used in achieving convergence of the simulation. In the second section, 3 tests were considered including the degradation/aging to demonstrate that a lot can be learnt using the tool. The third section concludes the paper.

DESCRIPTION OF THE EMULATION TOOL

The simulation tool used in this study, *Speclase*, was based on UNott's 2.5D spectral laser model, the full details of which have been published elsewhere Lim *et al.* (2009) and Lim *et al.* (2007). For this study, Speclase was modified to pause at the end of each Fox-Li iteration Agrawal (1984) to update the bias voltage calculated by a Lab View control interface. *Speclase* uses Newton's method to achieve convergence of a simulation to a given voltage, current or output power. This method is also used in the Lab VIEW control interface to control the simulation voltage for each round trip in order to converge upon the desired current (or power).

Speclase uses Newton's method to achieve convergence of a simulation to a given voltage or bias current. This method was used in the emulation tool to control the simulation voltage for each Fox-Li iteration Agrawal (1984) in order to converge upon the desired current (or power).

The laser simulator can investigate the influences of various device parameters in order to enhance beam quality and optimise the brightness of semiconductor lasers. Some of the device parameters that can be

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examined and their effects investigated are the packaging induced strain, introduction of defects, heat sink temperature, absorption of the mirror, reflectivity of the mirror, altering the thermal resistivity of the substrate, the thermal conductivity of the solder and others. The focus of this study is to test the validity of the simulation tool.

TESTING THE EMULATION TOOL

To confirm the correct operation of the control interface, a number of tests were carried out on a standard test laser structure. The laser structure used was the 975 nm narrow-angle (<1°) tapered laser from Alcatel Thales III-V Lab. The total length was 2.4 mm, consisting of a 200 μm ridge waveguide and a 2200 μm tapered amplifier. The front and rear facet reflectivities were 3 and 90%, respectively. The 'standard' simulation of this structure assumes a heat sink temperature of 300 K and a trap density in the QW of 2×10^{15} cm^{-3}. All of the simulations use this structure and the results are referenced to this 'standard' structure. Three tests were conducted as follows:

Test 1: Single emitter simulations were performed using the Lab View control interface using the constant current mode of operation to check if there was agreement with results obtained by running *Speclase* alone. Exact agreement was found between these tests indicating that the control interface was working correctly.

Test 2: Further single emitter tests were also performed to test the constant power mode of operation. In order to do this, the output power from a constant current mode simulation was used as the target power for a constant power mode simulation to check that it indeed converged to the current of the first simulation. The results of this are given in Table 1. It is interesting to note, however, that significantly more round trips were needed to achieve convergence in the constant power mode simulation.

Test 3: Single emitter tests were conducted using *Speclase* with a constant QW trap density, based on the maximum QW temperature. The degradation level observed in these tests indicated an overestimation in the degradation rate because it is not physically reasonable to have a constant QW trap density based on the maximum QW temperature. *Speclase* therefore needed to be modified in order to accurately represent local degradation processes (e.g., trap generation due to local heating). The modification of the model to accept a local trap density distribution makes it possible for the generation of a trap density distribution which evolves as a function of the temperature distribution.

Table 1: Data obtained from single emitter simulations performed in constant current and power modes

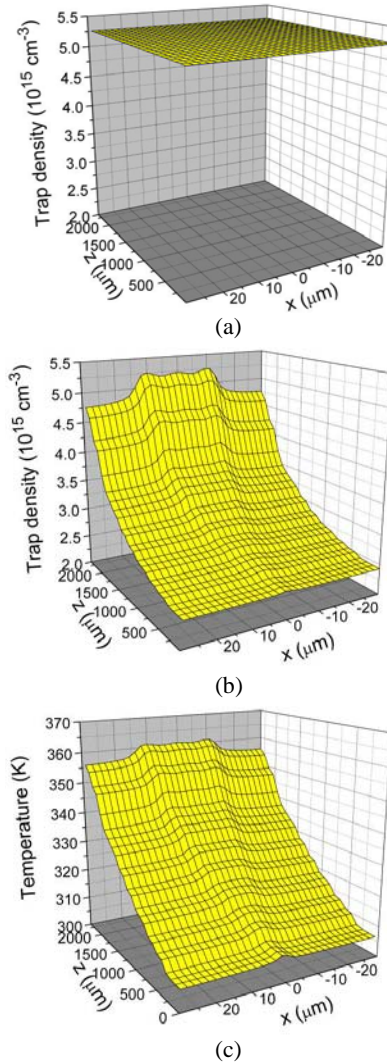|	Constant current mode	Constant power mode
Start voltage (V)	2.000	1.000
Target current (A)	2.000	NA
Target power (W)	NA	1.065
Number of round trips	11	19
Converged voltage (V)	1.66137	1.66130
Converged current (A)	1.00002	0.99993
Converged power (W)	1.06532	1.06506

Fig. 1: 3D plots of (a) uniform trap density, (b) local trap density and (c) QW temperature profile

Figure 1a and b shows the uniform and local trap density profiles. Single emitter simulations were performed with a uniform trap density distribution as shown in Fig. 1a and for a local trap density distribution (Fig. 1b). A more realistic trap distribution was attained, as seen in the 3D plots of Fig. 1. These simulations were done to appreciate the effect of local increase in QW temperature profile even in single emitters. Figure 1b shows a more physically reasonable

trap density profile with respect to the local QW temperature profile (Fig. 1c). Studies were carried out to do some comparisons using a constant QW trap density and spatially variable QW trap density aging models.

The degradation/aging model of lasers has often been described using the Arrhenius equation Casey and Panish (1978), Fukuda (1991) and Hausler *et al.* (2008). The Arrhenius equation will therefore be used in the aging process and 2 models will be implemented to update the trap density and temperature as follows:

- Constant QW trap density based on maximum QW temperature:

$$\Delta N_t(x, z) = A \exp(-E_a / kT_{QW\_Max})t_{aging} \qquad (1)$$

- Spatially variable QW trap density based on QW temperature distribution:

$$\Delta N_t(x, z) = A \exp(-E_a / kT_{QW}(x, z))t_{aging} \qquad (2)$$

where,
ΔN_t = Change in trap density
A = Pre-Arrhenius constant
E_a = Activation energy
k = Boltzman constant
t_{aging} = Aging time
T_{QW} = Quantum well temperature

Case study 1 (single emitter)-uniform QW trap density: The first case study made to investigate the comparisons for single emitters uses an aging model where the QW trap density is kept constant. The aging was emulated at a constant current of 1.5 A, for aging times up to 10,000 h. The parameter being varied is the heat sink temperature at: 300, 320 and 340 K, respectively. The emitter power dropped as a function of aging time for different heat sink temperatures of 300, 320 and 340 K. In Fig. 2, power loss occurs with both increased aging time and temperature, as expected.

The percentage power loss was calculated and plotted with respect to an unaged emitter. There is a 10% power loss after ~3,500 h at 340 K and after ~9,000 h at 320 K, which is more than the acceptable threshold (10% power loss). This quick rate of degradation can be attributed to the aging model used, which overestimates the rate of degradation.

Case study 2 (single emitter)-local QW trap density: The second case study was to investigate the degradation of the same single emitter using an aging model where the QW trap density depends on the local QW temperature. The aging was emulated for a
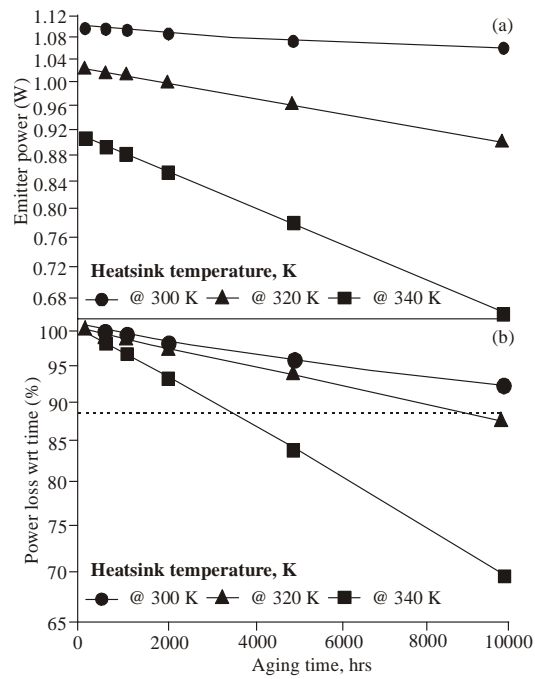

Fig. 2: Graphs with uniform trap density for (a) emitter power versus aging time and (b) % power loss with respect to the unaged emitter
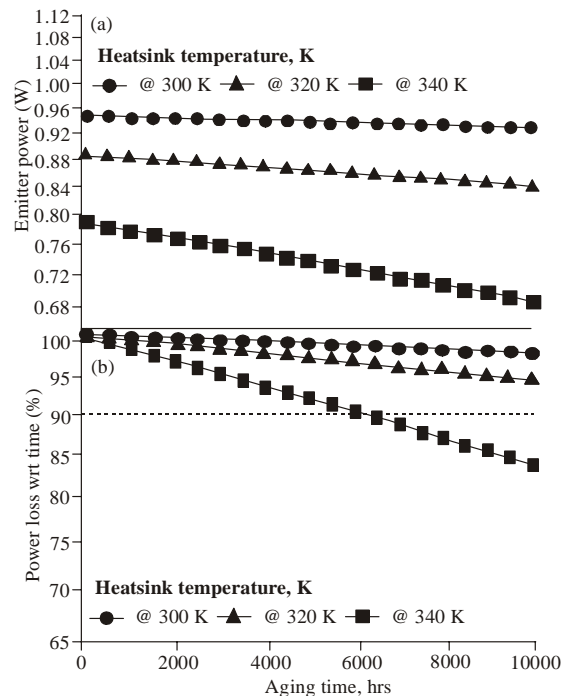

Fig. 3: Graphs with local trap density for (a) emitter power versus aging time and (b) % power loss with respect to the unaged emitter

constant current of 1.5 A, with aging times up to 10,000 h. The parameter being varied is the heat sink temperature at: 300, 320 and 340 K, respectively.

In Fig. 3, power loss occurs with both increased aging time and temperature, as expected. However, the rate of degradation is slower than in case study 1 (power loss during aging). The lower degradation rate is due to the introduction of the local trap density in the model. Devices will survive the targeted 10,000 h time at both 300 and 320 K. However, at 340 K, a 10% power loss occurs at ~7,000 h.

CONCLUSION

This study has demonstrated how UNott's state-of-the-art simulation tool, can be used to simulate single emitters/bars and age them using a simple aging model based on the Arrhenius equation under a range of operation conditions. Simulations were performed on single emitters to test the tool at constant voltage operation of the laser. The results obtained show that the simulation of single emitters can provide useful insight into how individual emitters will operate in the context of a laser bar. Nevertheless, the actual impact on the performance of emitters in a bar is more complex, due to current competition and thermal cross talk.

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REFERENCES

Agrawal, G.P., 1984. Fast-Fourier-transform based beam-propagation model for stripe-geometry semiconductor-lasers-inclusion of axial effects. J. Appl. Phys., 56: 3100-3109.

Bream, P.J., J.J. Lim, S. Bull, A.V. Andrianov, S. Sujecki and E.C. Larkins, 2006. The impact of nonequilibrium gain in a spectral laser diode model. Opt. Quantum Electron., 38(12-14): 1019-1027.

Bull, S., J.W. Tomm, M. Oudart, J. Nagle, C. Scholz, K. Boucke, I. Harrison and E.C. Larkins, 2005. By-emitter degradation analysis of high-power laser bars. J. Appl. Phys., 98: 063101.

Casey, H.C. and M.B. Panish, 1978. Heterostructure Lasers: Fundamental Principles. Academic Press, San Diego, pp: 272, ISBN: 012163101X.

Fukuda, M., 1991. Reliability and Degradation of Semiconductor Lasers and Leds. Artech House, Boston, pp: 343, ISBN: 0890064652.

Hausler, K., U. Zeimer, B. Sumpf, G. Erbert and G. Trankle, 2008. Degradation model analysis of laser diodes. J. Mater. Sci-Mater. Electron., 19: 160-164.

Lim, J.J., T.M. Benson and E.C. Larkins, 2005. Design of wide-emitter single-mode laser diodes. IEEE J. Quantum Electron., 41(4): 506-516.

Lim, J.J., R. MacKenzie, S. Sujecki, M. Sadeghi, S.M. Wang, Y.Q. Wei, J.S. Gustavsson, A. Larsson, P. Melanen, P. Sipila, P. Uusimaa, A.A. George, P.M. Smowton and E.C. Larkins, 2007. Simulation of double quantum well GaInNAs laser diodes. IET Optoelectron, 1(6): 260-265.

Lim, J.J., S. Sujecki, L. Lang, Z.C. Zhang, D. Paboeuf, G. Pauliat, G. Lucas-Leclin, P. Georges, R.C.I. MacKenzie, P. Bream, S. Bull, K.H. Hasler, B. Sumpf, H. Wenzel, G. Erbert, B. Thestrup, P.M. Petersen, N. Michel, M. Krakowski and E.C. Larkins, 2009. Design and simulation of next-generation high-power, high-brightness laser diodes. IEEE J. Sel. Top. Quantum Electron., 15(3): 993-1008.

Steele, R., 2008. Laser Focus World. Retrieved from: http://online.qmags.com/LFW1108/ Default. aspx? sessionID = 81697E67BEC59096E4AA81FC2 &cid = 798041&eid = 10916.

Tomm, J.W., A. Gerhardt, T. Elsaesser, D. Lorenzen and P. Hennig, 2002. Simultaneous quantification of strain and defects in high-power diode laser devices. Appl. Phys. Lett., 81(17): 3269-3271.

Xia, R., E.C. Larkins, I. Harrison, S.R.A. Dods, A.V. Andrianov, J. Morgan and J.P. Landesman, 2002. Mounting-induced strain threshold for the degradation of high-power AlGaAs laser bars. IEEE Photon. Technol. Lett., 14(7): 893-895.