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# Investigating the Effect of Defects through Non- Radiative Recombination Centres in a Single Emitter Laser Bar using a Laser Diode Simulation/Emulation Tool

By Christian Kwaku Amuzuvi & Philip Blewushie
*University of Mines and Technology, Ghana*

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*GJRE-F Classification : FOR Code: 020502*

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# Investigating the Effect of Defects through Non-Radiative Recombination Centres in a Single Emitter Laser Bar using a Laser Diode Simulation/Emulation Tool

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## I. INTRODUCTION

High power semiconductor laser diodes have occupied the minds of researchers in the last decade due to their emerging widespread usage in the fields of medicine, industry and in consumer products like laser printers and others [1-2].

The effectiveness of *Barlase* has already been demonstrated using hypothetical laser bars and published elsewhere [3]. In this paper however, *Barlase* is being used to simulate/emulate degradation processes using a hypothetical single emitter high power laser bar considering defects through non-radiative recombination centres. This paper gives a further impetus to the by-emitter degradation analysis technique developed over recent years [4-8].

This tool is also an addition to the by-emitter analysis technique where the effects of certain factors that affect the degradation of laser emitters/bars can be investigated. The objective of this study is to investigate and analyse the effect of the existence of defects through non-radiative recombination centres in a single emitter laser bar.

## II. MATERIALS AND METHODS

The standard test structure selected is one employed in the experimental work in a task published elsewhere [9]. This structure was selected bearing in mind the fact that an attempt will be made to further emulate the degradation of bars made from "the same epitaxial" structure with similar dimensions. The structure used was the 975 nm narrow-angle ($<1^o$) 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 heatsink temperature of 300 K and a trap density in the QW of $2\times10^{15}$ cm$^{-3}$ [10]. All of the simulations in this paper use this structure and the results are referenced to this 'standard' structure. Figure 1 shows the laser structure.

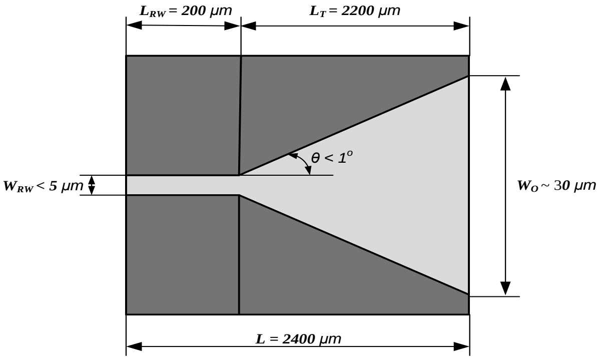

*Figure 1 (a) :* Hypothetical standard 975 nm tapered laser structure

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*Author α : University of Mines and Technology, Department of Electrical and Electronic Engineering, Tarkwa, Ghana.*
*e-mails: ckamuzuvi2000@yahoo.com, ckamuzuvi@umat.edu.gh*
*Author σ: Photonic and Radio Frequency Engineering Group (PRFEG), Electrical Systems and Optics Research Division, Faculty of Engineering, University of Nottingham, Nottingham, NG7 2RD, United Kingdom.*

Simulations were performed considering the effect of introducing defects through non-radiative recombination centres introduced into the quantum well of the single emitter bar. The data obtained from these single emitter simulations were performed in the constant current mode of operation [9].

## III. RESULTS

To investigate the effect of defects, simulations were performed with different levels of non-radiative recombination in the QW. Simulations were carried out for QW trap densities, $N_t$, of 2, 4, 10, 20 and 100 times the standard value, $N_t = 2\times10^{15}\text{cm}^{-3}$.

Figure 2 shows the power-current characteristics and the evolution of the maximum QW temperature with bias current for each of the trap densities investigated. The P-I curves for the different trap densities show how an increase in trap density increases the threshold current and reduces the output power. Figure 2 also shows how the maximum QW temperature increases with trap density and current.

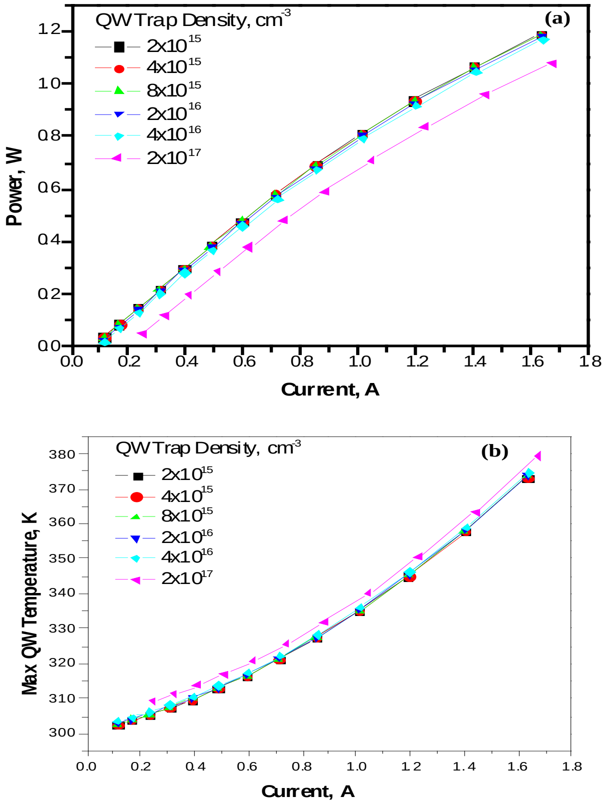


*Figure 2 :* (a) Power-current characteristics and (b) the maximum temperature in the QW as a function of current for simulations with different QW trap densities

Figures 3 and 4 shows the equivalent power-voltage/current-voltage characteristics and the evolution of the maximum QW temperature with bias current for each of the trap densities investigated.

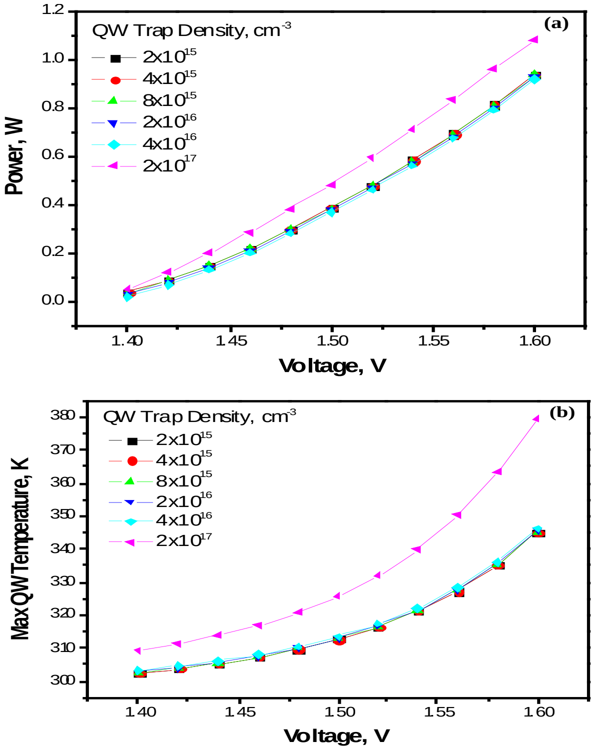


*Figure 3 :* (a) Power-voltage characteristics and (b) the maximum temperature in the QW as a function of voltage for simulations with different QW trap densities

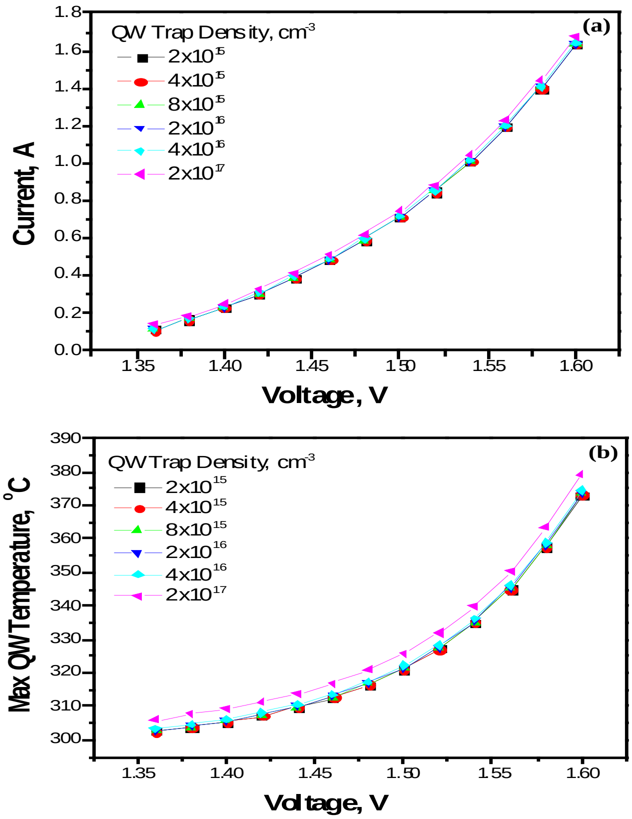


*Figure 4 :* (a) Current-voltage characteristics and (b) The maximum temperature in the QW as a function of voltage for simulations with different QW trap densities

The threshold current and slope efficiency have been extracted from the P-I curves in Figure 2 and plotted as a function of trap density in Figure 5. For moderate trap densities ($N_t$ up to $2\times10^{16}$ cm$^{-3}$), the threshold current increases by around 10-15%. At much higher trap densities ($N_t$ up to $2\times10^{17}$ cm$^{-3}$), the threshold current can more than double. Similarly, at moderate trap densities, the decrease in slope efficiency is less than 1%, but at higher trap densities this reduction can be as large as 5%.

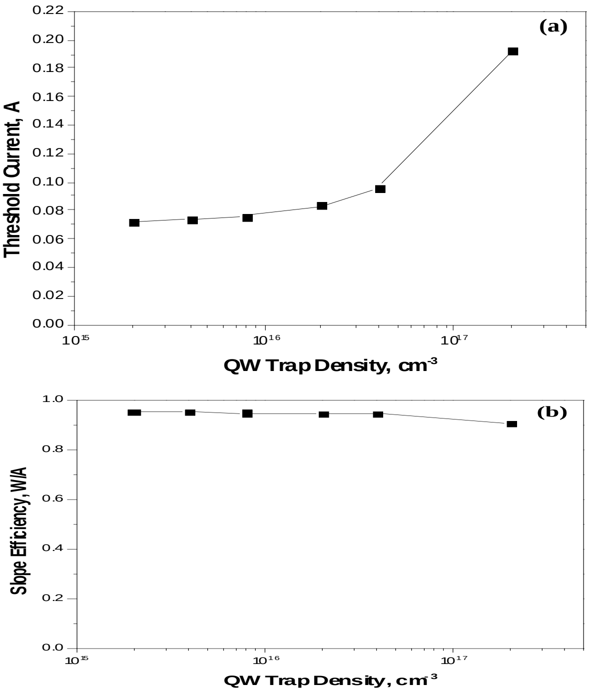
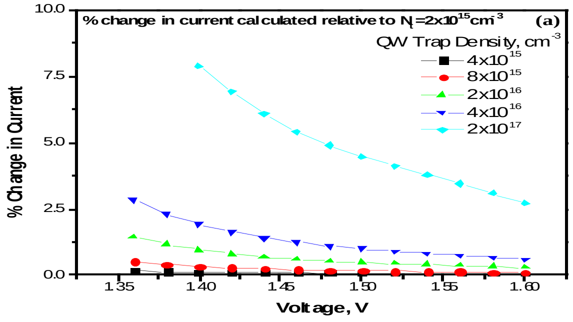


*Figure 5 :* (a) Dependence of threshold current and (b) Efficiency (right) on QW trap density

To see the differences in the simulations, the percentage change (relative to the case with $N_t$ = $2\times10^{15}$cm$^{-3}$) in both bias current and output power are shown in Figure 6. These results are plotted for different bias voltages, as the bias voltage is common to all emitters in the laser bar. The percentage change in current for a given voltage is smaller than the percentage change in output power at the same voltage. This may help to explain why simulations converged faster for the constant current mode than for the constant power mode.



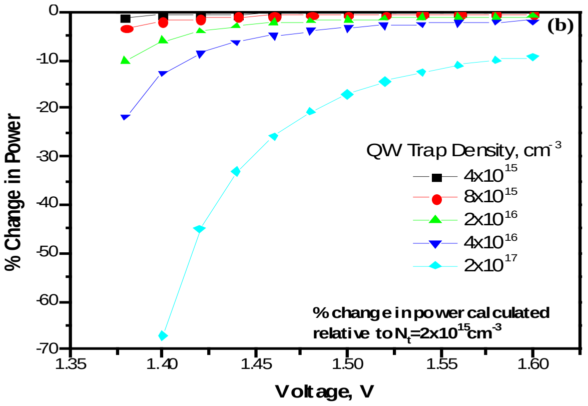
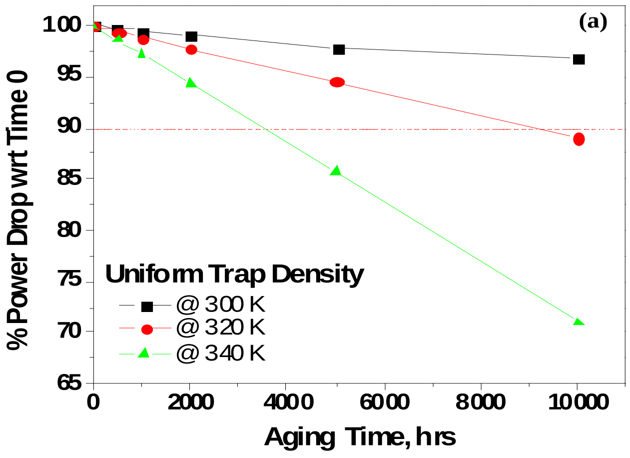


*Figure 6 :* (a) Percentage change in current and (b) Power in simulations at different QW trap densities relative to the standard QW trap density of $2\times10^{15}$cm$^{-3}$

In Figure 6, at a voltage of 1.50 V (this is around the probable operating point of this device, i.e. the device is lasing well above the threshold, but has not reached the thermal roll-over point), the current increases by up to 1% for moderate trap densities with up to a 4% reduction in power. For higher trap densities, the current increase is of the order of 5% with the power reduction reaching nearly 20%. *Barlase* was enhanced to allow for a spatially variable trap density distribution and hence a more realistic trap density distribution was attained [9].

The trap density distribution, generated as a function of QW temperature distribution in this case allows for a more realistic and accurate simulation of the degradation behaviour (Figure 7b), which the earlier case (Figure 7a) had overestimated. The increased degradation rate observed at higher temperatures in Figure 7a was as expected. The degradation rate is slower with the local trap model (Figure 7b) with a device surviving 10,000 hrs of aging at both 300 K and 320 K. However, a device losses more than 10% power after ~7,000 hrs at 340 K.



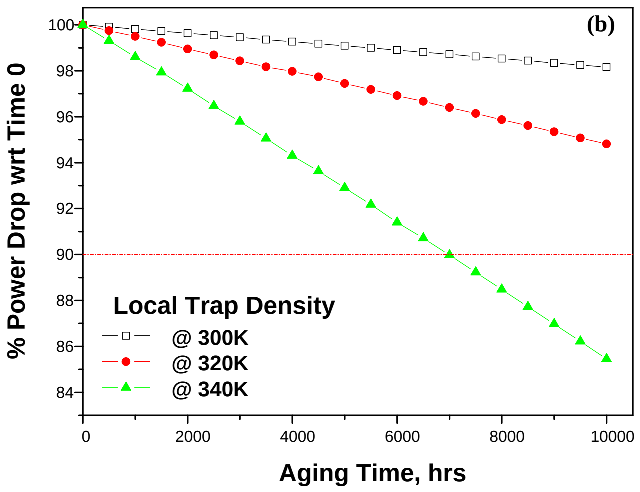


*Figure 7 :* Graphs of (a) Emitter power and (b) % Power drop against aging time

## IV. DISCUSSION

The principal factors that affect laser degradation are defects (both point defects and line defects), temperature, packaging-induced strain, and inhomogeneous heatsinking (e.g. solder voids, solder flow, etc.). To understand how each of these factors affects the operation and degradation of a laser, a number of simulations were performed using a single emitter bar. In this paper, the investigation was done considering the effect of the introduction of defects through non-radiative recombination centres independently. The simulations were performed for a constant bias voltage, as this is the common factor between individual emitters once they are part of a laser bar. In all cases, simulations were attempted at voltages ranging from 1.32 V to 1.60 V at intervals of 0.02 V. Majority of these simulations converged within 10 – 15 round trips.

## V. CONCLUSION

We have shown in this paper that, even simulations of single emitters can provide a great deal of insight into how emitters will operate in the context of a laser bar. However, it is important to consider their operation with respect to a fixed bias voltage and not with respect to a fixed bias current. The factor investigated here (i.e., defect density through non-radiative recombination) can affect the operation of an emitter. That notwithstanding, it is high levels of defects can play a significant role in the degradation of emitters. It is known that low levels of defects and packaging-induced strain have low effects on laser degradation, but these are nonetheless important when combined with all other factors that can affect laser degradation. The limitation of this study is that the research work is ongoing and more work needs to be done to improve upon the simulation tool to include a global thermal solver.

## VI. ACKNOWLEDGEMENT

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