

Further Investigations into the Effects of Temperature on a 975 nm Tapered Laser Bar Using Convolution to Ascertain the Dominant Effect of Temperature on a Laser Bar

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Abstract Temperature continues to be an issue in the reliability of high power laser diodes. Any effort, therefore, made to understand the dynamics of temperature on the performance of laser diodes is important. This is because it serves as a catalyst for the generation of nonradiative recombination centers, which ultimately kills laser diodes. In this paper, the convolution of simulation results was done to compare it with experimental results, which revealed more details that hitherto, could not have been captured by experiments alone. The inability of experiments to capture these details is due to the limited spatial resolution of the charged-coupled device (CCD) camera, which is approximately 30 μm much larger than the thickness of the quantum well active region used in the experiment. The convolution results showed a further smile-shaped profile within the four groups of array emitters, which in the experimental results, were considered as one emitter due to the limited spatial resolution of the CCD camera. The use of convolution to determine more details was investigated, due to the dominant effect of temperature found across the output power distribution of high power semiconductor laser diode bars.

Keywords: *by-emitter, emitter, quantum well, defect, non-radiative recombination, degradation, temperature, thermal crosstalk, spatial resolution, convolution, interpolation, charged-coupled device camera*

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1. Introduction

The demand for improved performance and reliability of high-power laser diodes has led to the growth of the industry over the past decade [1]. Apart from the use of high-power laser diodes to pump solid-state lasers, many other applications such as materials processing, printing, medicine, and entertainment have emerged [1,2]. Temperature is one of the main factors limiting the performance of laser bars. Consequently, further investigations into the effects of temperature on the degradation of laser bars have become imperative. Menzel *et al.* [3] investigated the effect of temperature on facet degradation, where reductions in the performance and lifetime were found to be as a result of nonradiative surface recombination. Xia *et al.* [4], Tomm *et al.* [5], and Bull *et al.* [6] all used a detailed "by-emitter" performance analysis of each emitter to understand the behaviour and degradation of the individual emitters. When emitter

temperatures rise, thermal crosstalk between emitters becomes more significant [7]. This paper therefore, seeks to further investigate the effects of temperature on a 975 nm tapered laser bar using convolution to ascertain the dominant effect of temperature on a laser bar. This is necessary, since using experimental results alone may be inadequate, due to the limited spatial resolution of the CCD camera [8].

2. Materials and Methods

The concept of Barlase showing the communication between emitters is shown in Figure 1, which has already been described elsewhere [8]. It is considered as a monolithic block of multiple emitters connected in parallel with each other with a common voltage connected across them shown in Figure 2. Each emitter is biased with a common voltage, but the emitter currents and powers change depending on the details of the individual emitters and their environment.

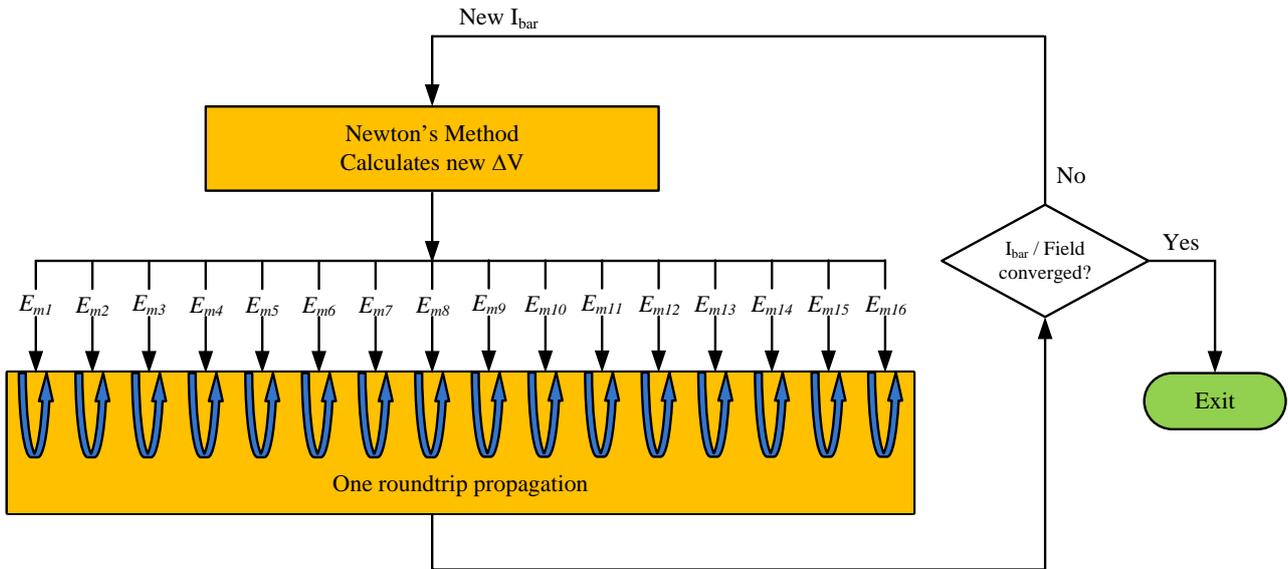


Figure 1. Flow chart showing the communication between emitters in Barlase for the sixteen emitter 975 nm tapered laser bar

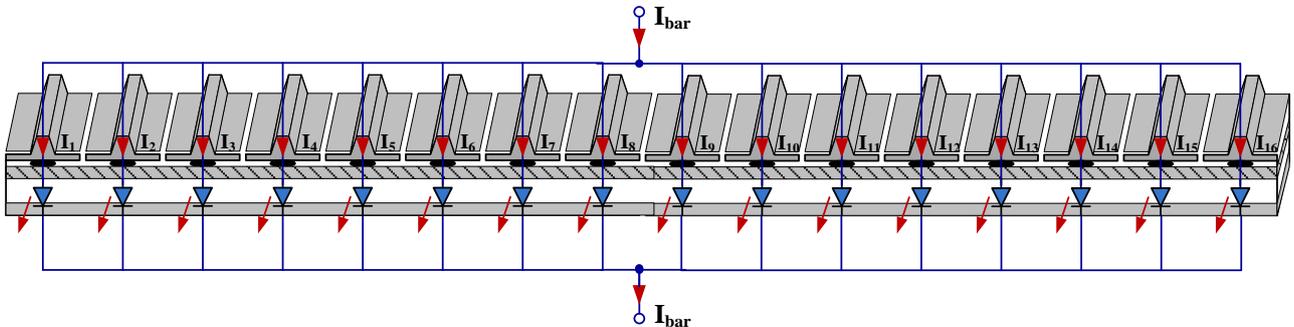


Figure 2. The representation of the sixteen emitter 975 nm tapered laser bar

A hypothetical 8-emitter 975 nm tapered laser bar was used to test for the correctness of the interpolated result, prior to the analysis of the real 16-emitter 975 nm tapered laser bar in Figure 2. Figure 3 shows the graphs of the original and interpolated simulated results, which indicate the successful implementation of the interpolation. The interpolated result phase is needed in order to transform the original simulated result from its non-uniform mesh to a uniform mesh, which is a necessary requirement for the convolution to be performed.

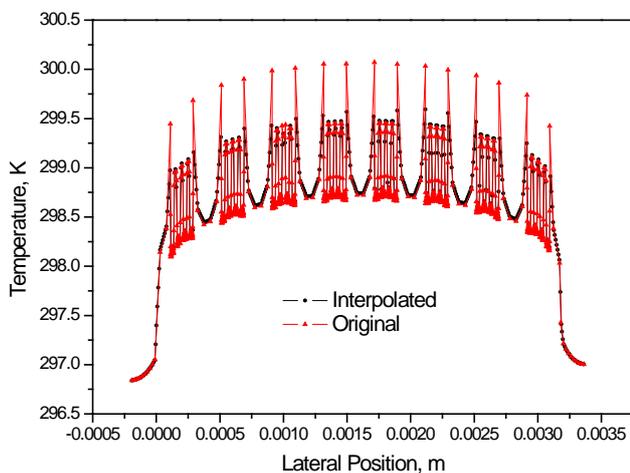


Figure 3. A hypothetical 8-emitter 975 nm tapered laser bar to test the correctness of the interpolated result

3. Results and Discussion

As the thermal camera has a limited spatial resolution, which is much larger than the active region of the laser and because the substrate is transparent to infrared light, the measured temperature underestimated the active region temperature by a factor A . This means that the actual temperature, T_{real} , is calculated from $T_{real} - T_{ref} = A(T_{measured} - T_{ref})$, where $T_{measured}$ is the measured temperature and T_{ref} is the heatsink temperature. Measurements of the emission wavelength shift and measurements at elevated temperatures give $A \sim 1.4$ [7]. Theoretical work, where simulated temperature profiles are convolved with the spatial response function of the thermal camera give a value of $A \sim 1.1$, but this did not consider the transparency of the substrate to infrared emission.

A further investigation of the temperature measurement was carried out using simulation results of the 975 nm tapered bars by convolution. The convolution routine consists of two parts. The first part interpolates the temperature profile generated by Barlase (which is on a non-uniform mesh) onto a uniform mesh. This is done by the *griddata.m* [9] function in Matlab. Once the temperature is on a uniform mesh, a 2D convolution is performed using Matlab's *conv2.m* function. The *conv2.m* function only operates on a uniform mesh, hence the

interpolation step using the *griddata.m* function used. Figure 4 shows the graphs for the thermal data for the original (simulation), interpolation, convolution and experimental results being compared. The experimental results were taken at a T_{ref} of 25°C and that of the original, interpolation, and convolution at a T_{ref} of 20°C, hence the temperature difference between them.

Analysing the details of the simulation and the experimental data reveals that, low spatial resolution of the camera has some effect on the accuracy of the measured results as seen in the comparison done between them. There is a change of ~ 0.35 K between the convoluted data from two peaks at $\sim 3000 \mu\text{m}$.

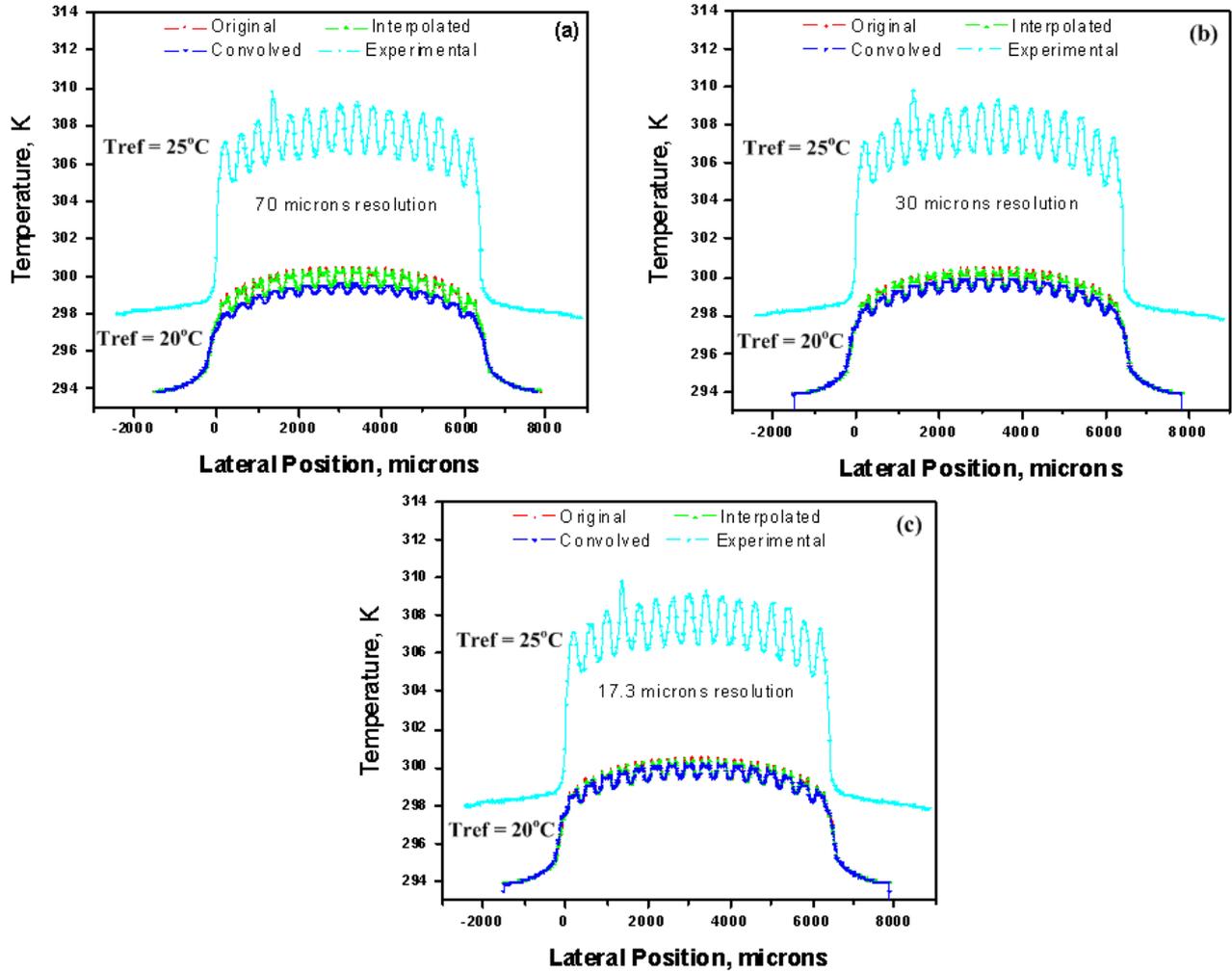


Figure 4. The graphs for the thermal data for the original, interpolation, convolution and experimental results; (a) for a spatial resolution of 70 microns, (b) 30 microns and (c) 17.3 microns being compared

Figure 5 also shows a further investigation made on portions of the graphs of Figure 4, on the central emitters (8, 9 and 10) [10] at different spatial resolutions for the CCD camera (17.3, 30 and 70 microns) for the thermal data for the simulation, interpolation and convolution results being compared. It reveals some disparities, Δx_1 and Δx_2 , when the spatial resolution of the CCD camera is varied. This goes to buttress the point that, the spatial resolution of the CCD camera can affect the accuracy of the experimental results.

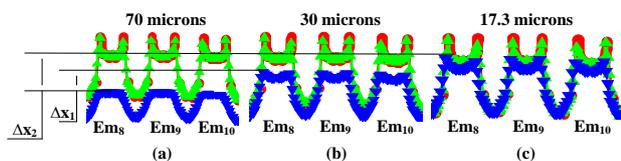


Figure 5. Portions of the graphs for the thermal data for the simulation, interpolation and convolution results for central emitters (8, 9 and 10) magnified for; (a) when the spatial resolution is 70 microns, (b) 30 microns and (c) 17.3 microns being compared

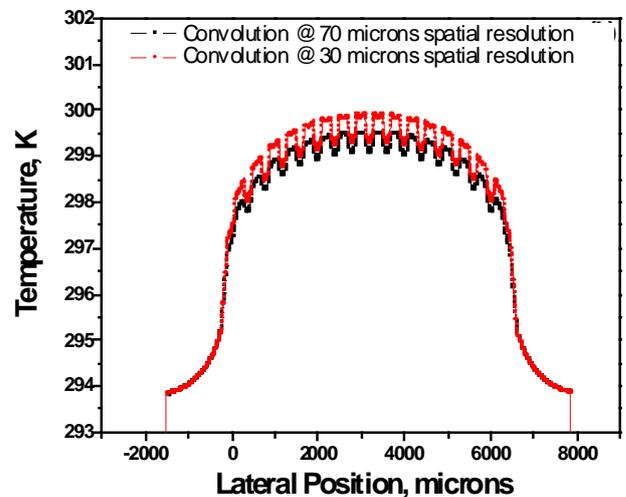


Figure 6. Convolution results for different mic spatial resolutions of 30 and 70 microns compared

Figure 6 shows the convolution results at different spatial resolutions of 30 and 70 microns being compared to further evaluate the effect of poor spatial resolution in the measurement of temperature.

To resolve the peaks, lots of points are needed. The finest spacing in the non-uniform mesh is around 0.5 microns. Therefore, N points in the Matlab file needs to be around $3 \text{ mm}/0.5 \text{ microns} = 6000$ points in the uniform mesh in the x -direction. The computer resources available during this simulation, could handle only 2200 points in the x -direction, which makes the convolution analysis inconclusive. This shortcoming, notwithstanding, the emulation tool Barlase, has demonstrated its versatility in addressing numerous challenges high power laser diodes may have, in the bid of understanding and resolving them. This research work is still evolving and promises to reveal many more interesting results in the quest to making laser diodes more reliable and durable.

4. Conclusion

It is established that, more details and understanding can be derived with the increase in computer power to perform such simulations. Investigation of the measured temperature was carried out with the simulation results of the 975 nm tapered bars by convolution. The convolution routine consists of two parts. The temperature profile generated by Barlase, which is on a non-uniform mesh, is first interpolated to transform it onto a uniform mesh to allow, secondly, the profile to be convolved. Theoretical work, where simulated temperature profiles are convolved with the spatial response function of the thermal camera give a value of $A \sim 1.1$, without considering the transparency of the substrate to infrared emission. In a nutshell, more information can be gathered with enhanced

computer power to further investigate the effect of temperature on the reliability of semiconductor high power laser bars.

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