High Power, Reliable 808 nm Laser Bars for QCW and CW Applications

[a]Mark Mondry, [a]Michael Fouksman, [a]Hailong Zhou, [a]Jun Li, and [b]Jouko Haapamaa

[a]Coherent Inc., Santa Clara, CA, 95054, USA
[b]Coherent Finland, Kauhakorvenkatu 52, Tampere, 33720, Finland

ABSTRACT

Manufacturers of Nd:YAG lasers continue to demand 808 nm pump sources that deliver ever lower operating costs (measured in $/kW-hour). Responding to this demand, Coherent has developed a new generation of high power, 808 nm laser bars. These lasers are most ideal for high power QCW applications, but also perform very well in CW pumping applications. The key to the improved power for QCW bars is increase in catastrophic optical damage (COD) threshold. Through a combination of advances in epitaxial structure design and coating technology after aging COD limit for new generation of bars has been increased by 40%. This allowed us to achieve reliable QCW operation at 270W of peak power. Life test results shows that lifetime of these bars at these conditions exceed 2e9 shots. We also developed similar structure optimized for CW operations. When mounted on micro-channel water cooled packages CW bars operate reliably at an output power of 150 W. Highest power conversion efficiency (PCE) for CW bars was more then 55% with typical PCE value >50%.

Keywords: high power laser diode arrays, COD, aluminum-free, 808 nm

INTRODUCTION

There is a continual drive to increase the output powers of 808 nm laser diode bars and arrays for solid state pumping applications. While initial device performance is relatively a quick achievement to demonstrate, the reliability and reproducibility of new device designs and material structures is not, typically requiring years before sufficient data can be gathered to confirm the typical reliability of a new device design. In this paper, we will present a relatively simple epi design that enables us to extend our established epitaxial technology and device fabrication techniques to higher powers. Because of the similarity of materials and processes, e.g. no new facet passivation, etc., we are able to retain a high confidence that the reproducibility will be similar to our previous device design.

Coherent pioneered the use of molecular beam epitaxy (MBE) for Aluminum-free Active Area (AAA™) high reliability 808 nm pump diodes for the several inherent advantages it offers. This technology enables the realization of InGaAsP quantum well and waveguides that exhibit excellent intrinsic reliability due to an absence of Al-containing alloys in the critical active area. With millions of device-hours in life testing, as the example data in Figure 1 below shows, the intrinsic reliability of AAA™ technology has been well established with a Mean-Time-To-Failure (MTTF) > 38k hours.

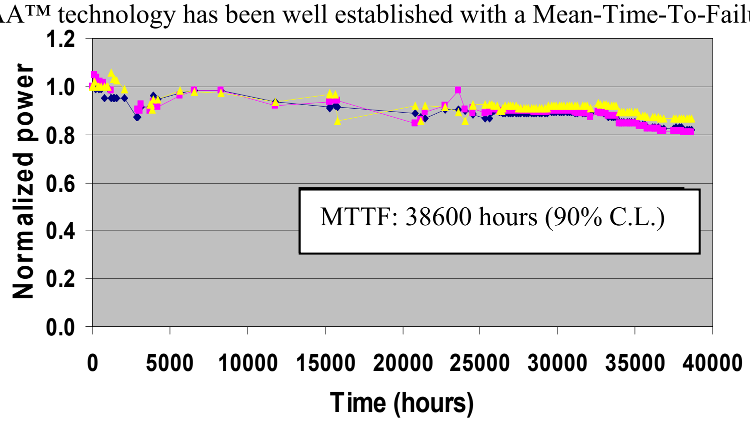

Figure 1: 90% FF 0.6 mm cavity on conductively cooled package tested with 200 µsec pulses @ 25% duty cycle at 80 Amps Constant Current (80 W) at 25° C.

High-Power Diode Laser Technology and Applications IV, edited by
Mark S. Zediker, Proc. of SPIE Vol. 6104, 610408, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.659907

In an addition to this intrinsic reliability, MBE grown AAA™ 808 nm devices display excellent power conversion efficiencies, typically >50%, and superior high temperature performance as shown in Figure 2 below for 16 bar "G-stacks". Even at 60° C, the efficiency of the bars is over >50% as well also shown to the right in Figure 2.

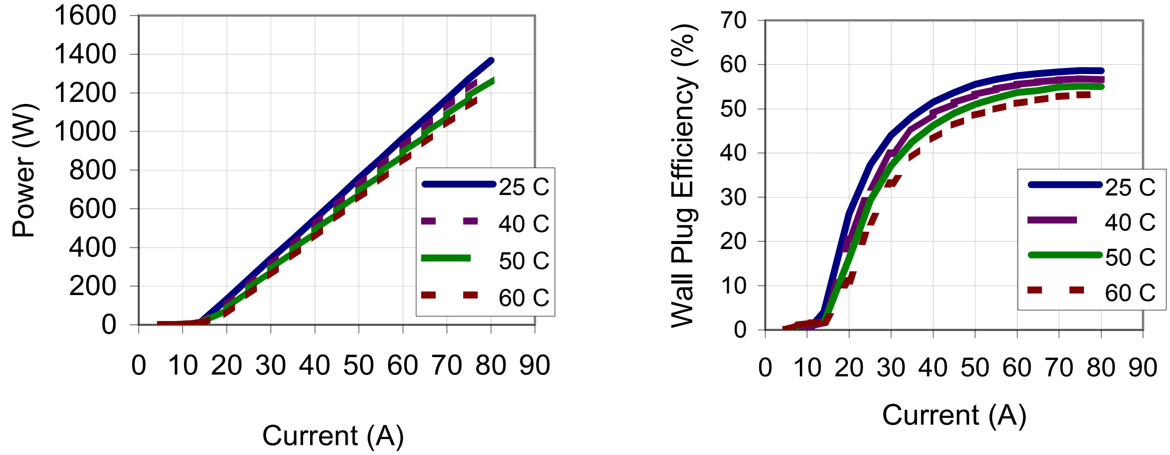

Figure 2: Conductive-cooled 16 bar "G-stack" tested with 250 μsec pulses @ 0.5% duty cycle

The desire of solid state laser integrators for higher output powers and/or lower dollars per watt ($/W) have posed a challenge to high power laser diode manufacturers of how to change the design of their devices to achieve higher output powers and still have confidence in the new device structure's real world reliability and reproducibility. We have taken an approach which enables to achieve higher output powers at 808 nm and retain the high reliability and reputation of our previous generation AAA™ structure by a relatively simple scaling of our device structure.

NEW EPITAXIAL DESIGN APPROACH

If we define a device's operating power in terms of a "linear power density" (LPD), such that

$$\mathrm{LPD} = \frac{P_{op}}{\text{width of active area}}$$

where the "width of active area" is the total width of the active area, e.g. a typical 40 watt 30% fill factor (FF) bar would be 40 watts divided by the product of 19 emitters of 150 μm each, or 14 mW/μm. We have observed limited reliability (MTTF <10 khrs.) at 808 nm for our traditional design AAA™ structure when the LPD> 20 mW/μm. This limitation posed the challenge of how to the reliable operating power density while maintaining the high confidence of product consistency.

The answer to this challenge was found by applying a vertical scaling of our traditional epi structure design. As shown below in Fig. 3 (a), our traditional epi structure has a waveguide design such that it supports only the fundamental

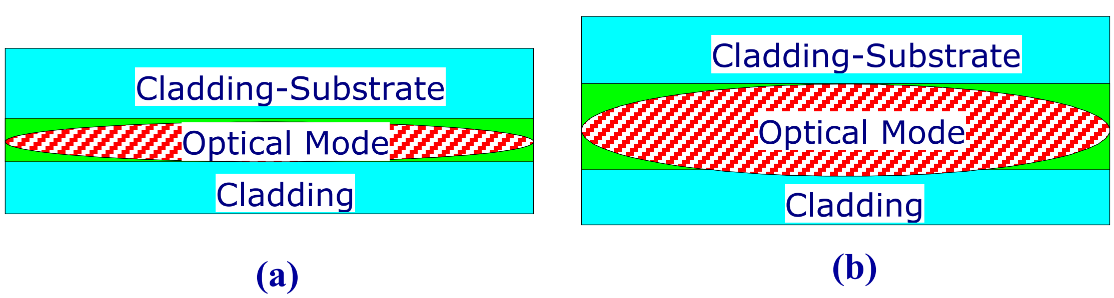

Figure 3: (a) Traditional waveguide designed to support a single transverse mode (b) "Extended Power" design increases the waveguide thickness and expands the optical mode

optical mode, i.e. single transverse mode. In our new "Extended Power" (EP) design, as shown schematically in Figure 3(b), the waveguide thickness has been increased such that it actually can support higher order modes. However, the epitaxial structure has been optimized to only allow the fundamental mode to lase.

The benefits of the EP design are:

(1) No new processing – minimizes fabrication complexity and new failure mechanisms
(2) Increases Catastrophic Optical Damage (COD) Limit
(3) Lower Cavity Photon Density
(4) Extends the Reliable Operating Power Limit of our AAA™ technology

Evidence of the increased COD limit can be seen below in Figure 4 where 60 mm wide 1.5 mm long single stripe emitters have been burned-in for 200 hours and tested to COD failure. The data points represent the maximum power reached prior to COD failure. As can be seen, the EP design results in up to 40% improvement in the COD power limit.

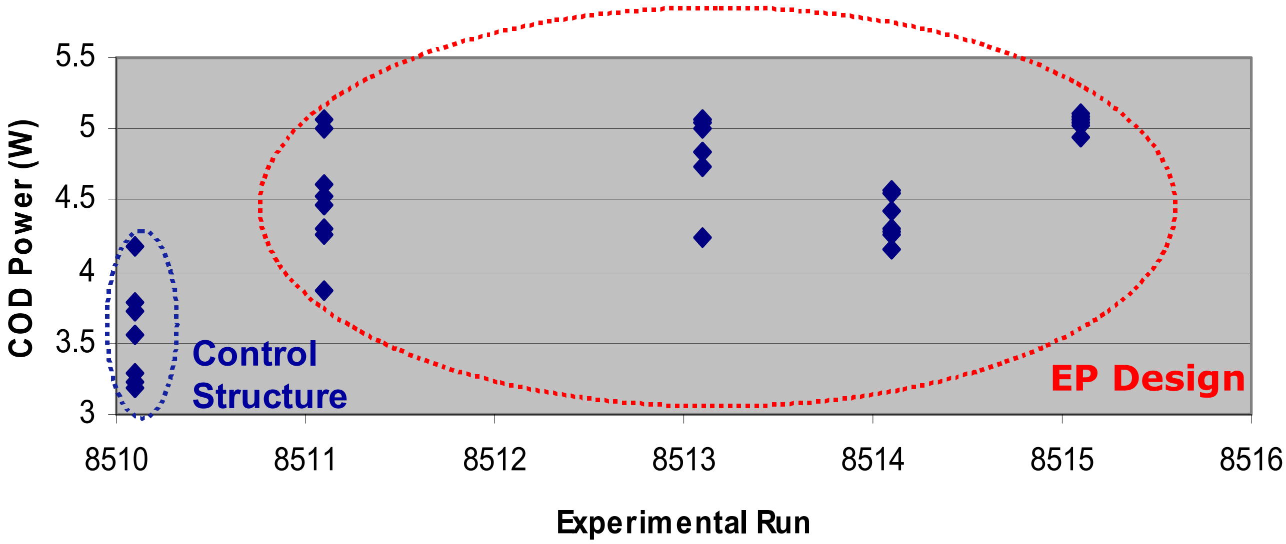

Figure 4: Measured COD power limits of 60 um wide 1.5 mm long single emitter devices of traditional and EP epi designs

The translation of this higher COD power limit into an enhancement of long term device reliability is exhibited in the comparative life test shown in Figures 5 (a) and (b) below. In Figures 5 (a), 60 um wide 1.5 mm long single emitters

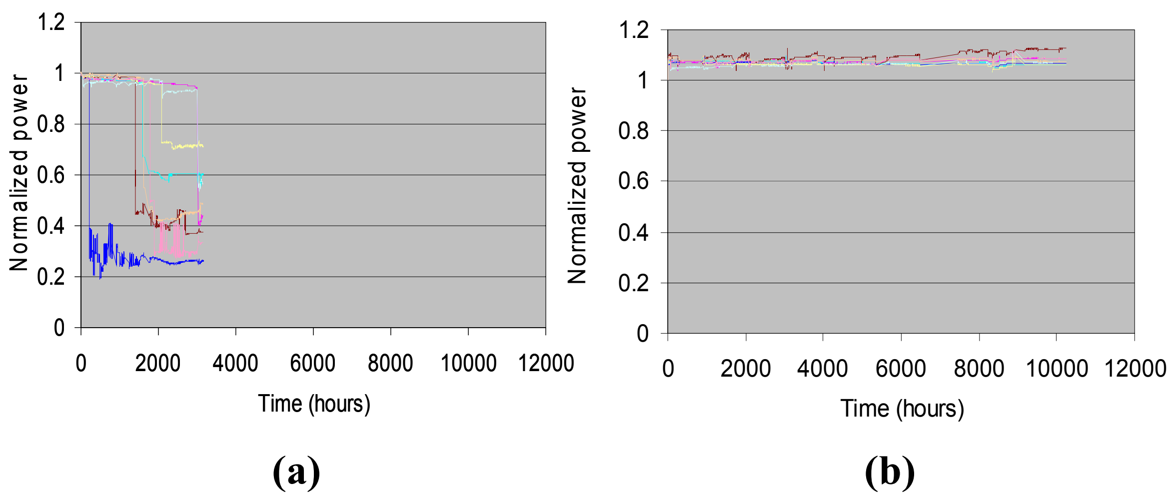

Figure 5: (a) Life test of traditional epi design single emitters (b) Life test of EP design single emitters

were fabricated from our traditional epi design and burned-in for 200 hours prior to being life tested at 1.8 Watts (30 mW/µm) at 40° C. As can be seen in the plot of Figure 5 (a), all the devices died by 3000 hours with a MTTF of 1700 hours. However, for single emitter devices of the same geometry fabricated from the EP design, all ten devices exhibited minimal degradation out beyond 10k hours under the same life test conditions.

"EXTENDED POWER" BAR DEVICE RESULTS

The EP epi design has been successfully applied to bar arrays as well. Shown below in Figure 6, 30% FF 1.5 mm cavity length bars on conductively cooled package (CCP) exhibit 53% power conversion efficiency (PCE) at an operating power of 60W CW at 25° C. Extrapolated life test data also at 60 W (20 mW/µm) indicates a MTTF > 15k hours (90% confidence level) for this same device geometry.

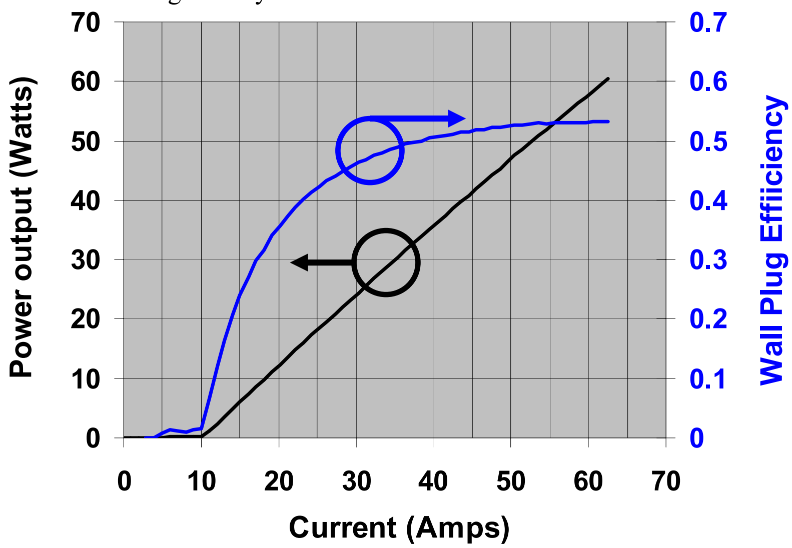

Figure 6: EP design 30% FF 1.5 mm cavity bar on CCP at 25° C

The intrinsic potential CW performance of the EP design can be observed in Figure 7 where a 75% 1 mm cavity length EP design bar has been mounted on a Micro-Channel Cooler Package (MCCP). Because a MCCP has a much greater cooling power relative to a CCP, greater power outputs and efficiencies can be achieved. As can be seen in Figure 7, a peak power > 200 W is attained with a peak PCE of 56% at 150 W at an operating temperature of 20° C

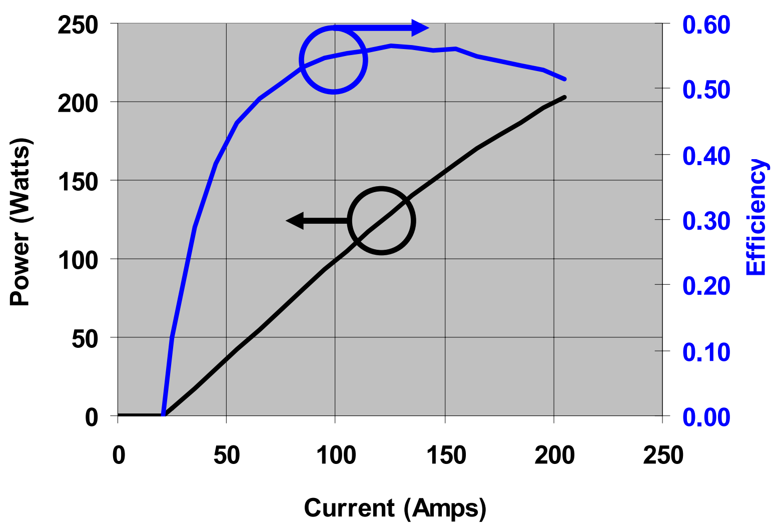

Figure 7: EP design 75% FF 1.0 mm cavity length tested CW on MCCP at 20° C

The increased COD limit of the EP design makes it well suited for Quasi-CW (QCW) applications as well. Shown in Figure 8, a EP design 90% FF 1 mm bar is tested on a CCP to a maximum power of 225 W QCW, 200us pulse @ 100Hz at 20° C. In contrast, our traditional epi design would COD limit at approximately 180 W under similar conditions.

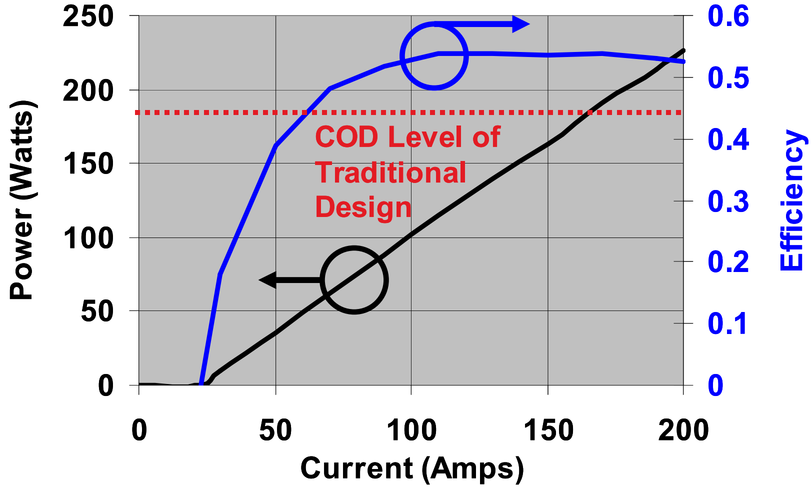

Figure 8: EP design 90% FF 1.0 mm cavity length tested on CCP, 200us pulse @ 100Hz at 20° C

The long-term reliability of this QCW EP bar is exhibited in the life test data shown below in Figure 9. Due to test equipment limitations, 0.5 cm wide bars ("half bars") of 90% FF 1.0 mm EP design epi were packaged and initially tested to a power level equivalent to 170 W QCW for a standard 1 cm bar. Minimal degradation was observed for 1100 hours or 1.6e9 shots at this 170 W/cm level. The life test power was then increased to 200 W/cm where minimal degradation was observed for an additional 1.3e9 shots. The estimated MTTF for this bar at 200 W/cm is 3.6e9 shots (90% confidence level).

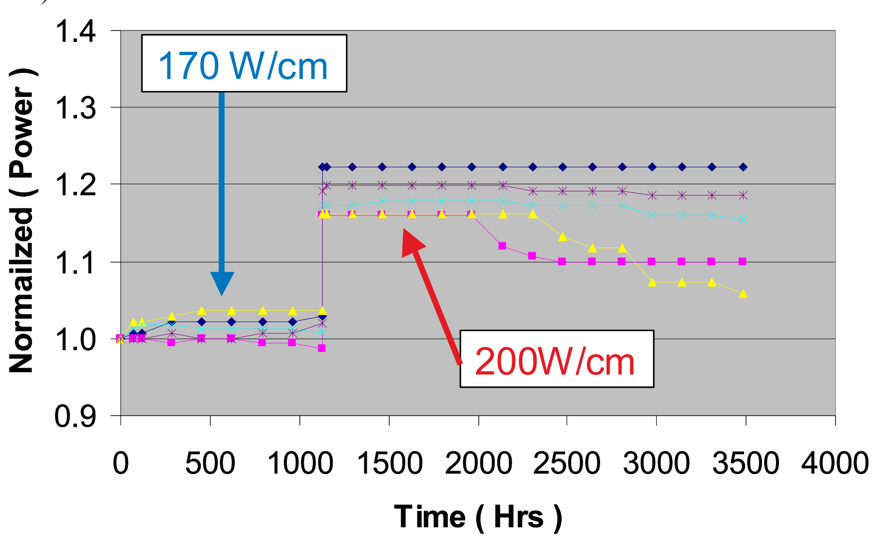

Figure 9: "Half bar" 90% FF 1.0 mm cavity length devices on CCP, 500us pulse @ 400Hz at 25° C

The EP design can be extended to even higher QCW powers by increasing the cavity length to 1.5 mm as shown in Figure 10. Packaged on a CCP, 270 W QCW is achieved using 90% FF 1.5 mm cavity tested with 500us pulses @ 50Hz at 25° C.

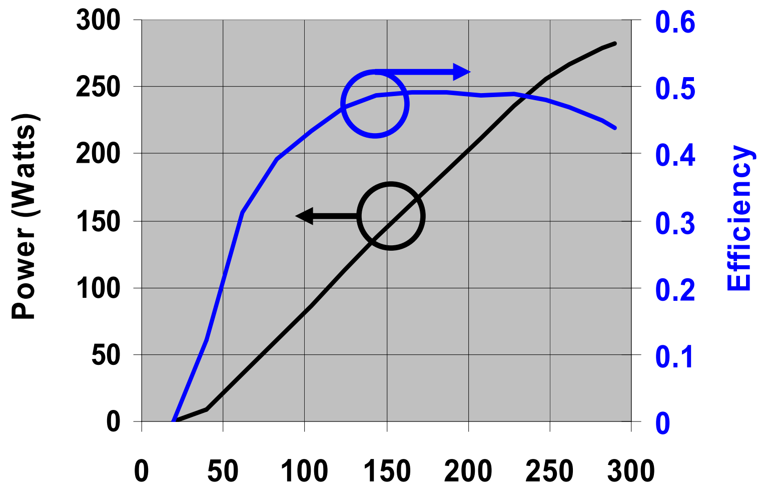

Figure 10: EP design 90% FF 1.5 mm cavity length bar tested on CCP with 500us pulses @ 50Hz at 25° C.

SUMMARY

We have extended the reliable 8XX nm power limit of our AAA™ technology with a new "Extended Power" (EP) epi design. This EP design increases the COD limit by up to 40% relative to our previous 808 nm AAA™ epi design. For a 30% FF bar packaged on a CCP operating at 60 W CW, MTTF >15k hours are indicated. CW Powers up to 200 W have been measured for bars packaged on a MCCP. For QCW operation, 200 W has been achieved with a 90% FF 1 mm cavity length bar on a CCP. An MTTF >3e9 shots is estimated for 200 W QCW operation with 90% FF 1 mm cavity length devices. Powers up to 270 W on a CCP have also been measured for 90% FF 1.5 mm cavity length devices.

ACKNOWLEDGMENTS

The authors would like to acknowledge Patrick Reichert for his contribution of the G-stack device results.