High Power High Brightness 808nm QCW Laser Diode Mini Bars

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Abstract

A new class of high power high brightness 808 nm QCW laser diode mini bars has been developed. With *n*Light's *n*XLT facet passivation technology and improvements in epitaxial structure, mini bars of 3 mm bar width with high efficiency design have tested to over 280 W peak power with peak efficiency over 64% on conduction cooled CS packages, equivalent to output power density near 130 mW/µm. These mini laser bars open up new applications as compact, portable, and low current pump sources.

Liftests have been carried out on conduction cooled CS packages and on QCW stacks. Over 370 million (M) shots lifetest with high efficiency design has been demonstrated on CS so far without failure, and over 80 M shots on QCW stacks with accelerated stress lifetest have also proven high reliability on mini bars with high temperature design. Failure analysis determined that the failure mechanism was related to bulk defects, showing that mini laser bars are not prone to facet failure, which is consistent with the large current pulse test and failure analysis on high power single emitters.

Keywords: mini laser bars, quasi-CW, high-power, high-brightness, high efficiency, reliability

1. Introduction

High power and high reliable 808 nm Quasi-CW (QCW) laser bars and stacks are required for pumping applications of solid state lasers. Although traditional 10mm bars could provide high power and high reliability, the brightness is relatively low, and in particular the injection current is high leading to restrictions on the QCW power supply. For applications with compact, portable, low current, and low cost system level requirements, such as portable range finding applications, are difficult to meet using traditional broad area lasers. Recent developments on single emitters have demonstrated close to 70 W peak power under pulse conditions [1]. With various facet passivation techniques to protect the facet from high optical intensity induced failure [1, 2], bulk defects [3], arising from the crystal growth or device fabrication, become the dominant failure sources. Hence the larger the emitting area, the higher the probability a bulk defect will present. Therefore reduced area is favorable for reliable operations. Mini bar lasers combine the advantages of single emitters with those of more traditional 10 mm bars. Similar to multiple single emitter modules [4], they can be used in series to provide high power at relatively low operating current.

To achieve high power high brightness with reduced bar size, the output power of a laser structure needs to be increased by designing a lower confinement factor and hence a larger vertical mode size effectively reducing the optical power density at the facet [5]. For those QCW operations that often require high temperature (HT), devices with better temperature characteristics are desired. However, for those QCW operations with small pulse width that require high efficiency (HE), devices with better wall plug efficiency are desired. This work explored both approaches.

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Reliability has been one of the most important but challenging attributes of diode lasers. The effects of junction temperature and operating current on the laser diode lifetime are well recognized and are commonly estimated by equation (1), relating the device lifetime LT to junction temperature and injection current, given by:

$$LT \propto LT_0 I^{-m} P^{-n} \exp\left(\frac{E_a}{k_B \cdot T_J}\right) \tag{1}$$

where LT_0 is a device based constant, E_a is the empirical activation energy of the device, T_J is junction temperature, k_B is the Boltzmann constant, I is the drive current with m the current acceleration factor, and P is the output power with n the power acceleration parameter. The lower the junction temperature, and the lower the injection current, the longer the device lifetime will be.

A new class of high power high brightness 808 nm QCW mini laser bars has been developed. There are two design approaches, one with high efficiency (HE) design targeting low pulse width and normal temperature applications, and another with high temperature (HT) design targeting large pulse width and high temperature applications. These designs utilize *n*Light's *n*XLT facet passivation technology to enable high power high brightness output.

2. QCW Mini Laser Bars

2.1 Epitaxy and Fabrication

The epitaxy of the mini laser bars emitting at 808 nm is grown by metal organic chemical vapor deposition (MOCVD). The super-large optical cavity design (SLOC) is used for the HE design, and the device structure composition, thickness and doping optimization are chosen to achieve high output power, high reliability, as well as balancing between efficiency and far-field divergence. For HT design, large optical cavity design (LOC) is used. Mini laser bars were fabricated with 1.5mm cavity length and 80% fill factor with a bar width of 3 mm. *n*Light's *n*XLT facet passivation technology was applied to these mini laser bars to protect the facet, enabling very high output power without catastrophic optical mirror damage (COMD).

Mini laser bars have been bonded on various packages depending on their intended applications. Commonly the mini laser bars were soldered p-side down on a thermal expansion matched CuW insert using an AuSn hard soldering technique, and then assembled to a standard Cu CS base. The mini laser bars were also bonded on micro-channel coolers (MCC) package. A very compact mount package with mini bars AuSn soldered on both sides in a clamshell format was successfully developed for portable range finding applications. Mini bars were also stacked together into QCW stack format. Since under short pulse width (PW) QCW operation the junction temperature rise is relatively small, the device performances of the MCC package and QM mount package are almost identical to that of the conductively cooled CS package. Hence we will only present data on CS package.

2.2 Device Performance

2.2.1 LIV

The characterization of mini laser bars was performed on 808 nm devices with 3 mm bar width, 1.5mm cavity length and 80% fill factor. The measurements were performed using a Direct Energy Inc. QCW power supply with a maximum peak current of 125A. The test conditions are 25 °C, 300 µs pulse width and 0.3% duty cycle (DC). Figure 1 shows a typical LIV characteristic comparison between HT design and HE design. The output powers are almost identical. Due to lower voltage and hence lower waste heat, the peak efficiency is improved to ~ 64% for HE design, about 5% higher than the 59% peak efficiency obtained on HT materials. The "noisy" efficiency data is due to experimental noise.

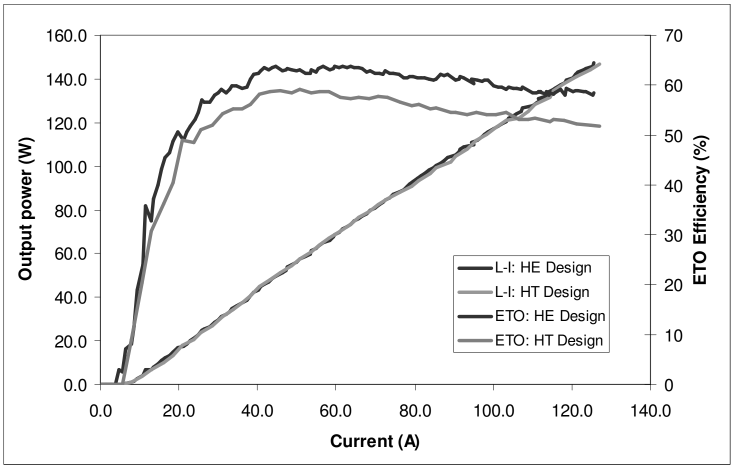

Fig.1 Comparison of HT design vs HE design on output power and ETO efficiency vs injection current. Due to lower voltage, the peak efficiency of HE design is about 64%, 5% higher than that of HT design.

2.2.2 COD Test

COD test were carried out to test the catastrophic optical mirror damage (COMD) level. Figure 2 shows a comparative COD test results up to 300 A, which is the limit of the Cutting Edge Optronics' eDrive power supply. For the HT design, devices experienced catastrophic failure after reaching peak power of 266 W, equivalent to facet power density of 120 mW/µm. For HE design mini laser bars, devices would repeatedly reach peak power of 284 W without failure. This peak power is equivalent to a facet power density of 129 mW/µm, with each emitter delivering near 26 W. Failure analysis on failed parts reveals that bulk defects rather than facet failures are the root cause. Figure 3 shows a sample after etching revealing that the COD originated from bulk defects, and then catastrophically ran away in directions towards either the front or rear facet. Due to *n*XLT facet passivation technology, the facet is still intact. Bulk defects have been found to be crystal defects, or device fabrication defects.

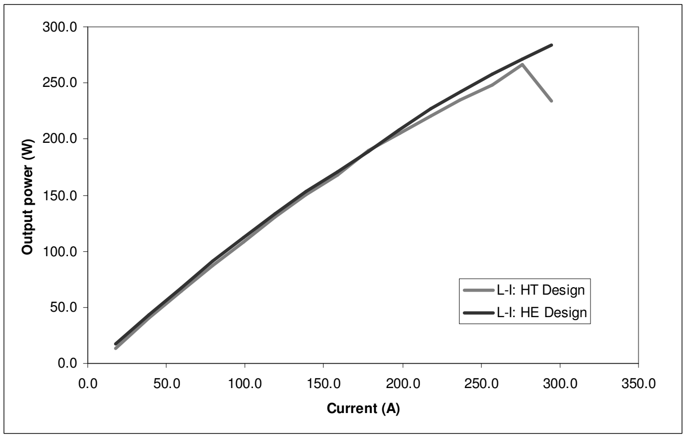

Fig.2 COD test comparison of HT design vs HE design under 300 µs pulse width, 0.3% DC, 10 °C. 266 W peak power with failure was observed for HT design, while for HE design 284 W peak power without failure was tested which was limit by power supply, equivalent to 130 mW/µm .

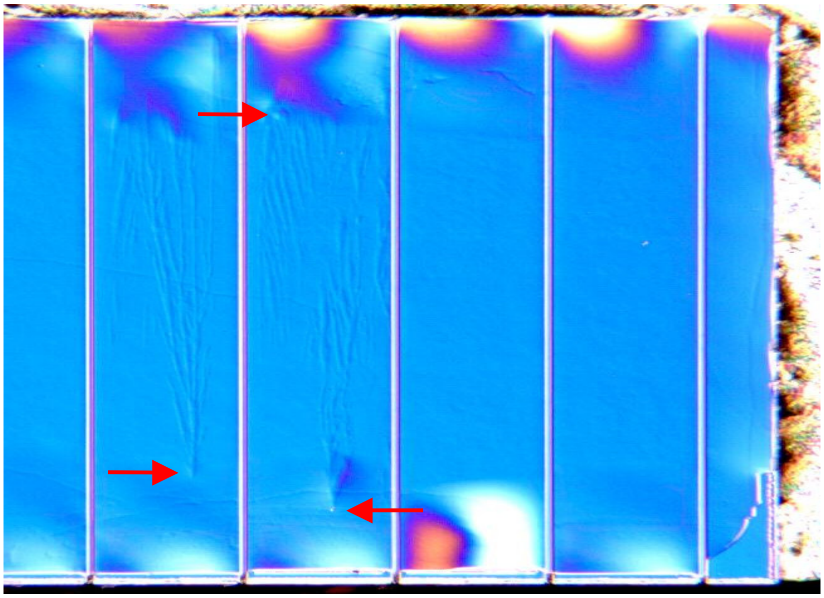

Fig.3 A failed part after etching revealing failed emitters. Originated from bulk defects, they could catastrophically run away towards the rear or front facet with multi COD lines.

COMD level is best illustrated by the pulse test data on single emitters as it is easier to generate the peak current levels required . Figure 4 shows COMD test comparison between HT design and HE design with single emitters under 3 µs pulse width at 10 °C. HE design single emitter demonstrated close to 70W COMD level, equivalent to 340 mW/µm. *n*Light's *n*XLT facet passivation technology along with HE design has made such a high COMD level possible.

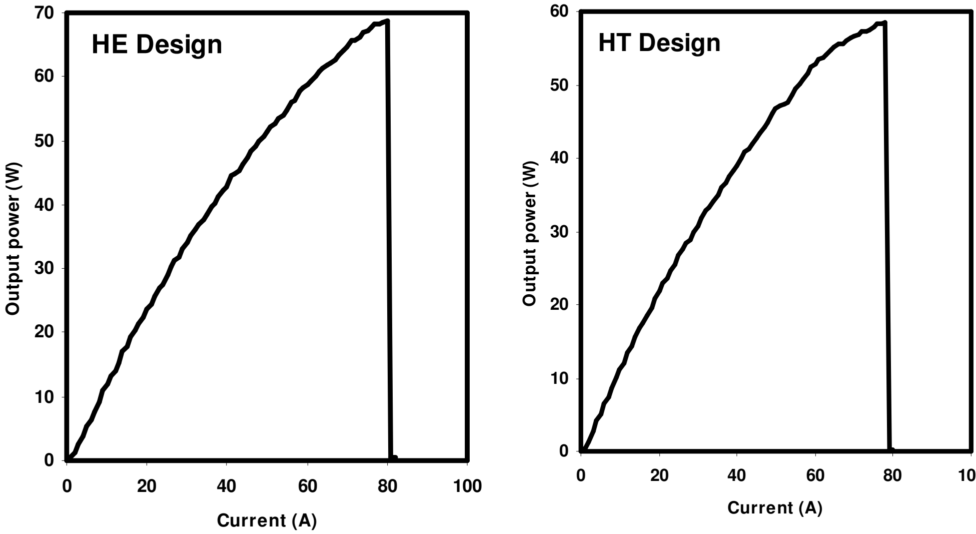

Fig.4 COD test comparison of HT design vs HE design on single emitters. Test condition is 3 µs pulse width and 10 °C. HE design could reach near 70 W COMD level.

2.2.3 Temperature Performance

In order to achieve high output power, SLOC structure is used to increase the vertical mode size, hence the carrier confinement is reduced and the temperature performance will be inadvertently affected. Therefore for high temperature and high duty cycle (DC) applications, a HT design rather than the HE design is more suitable. Figure 5 shows a HT design mini laser bar tested at 70 °C, 80 °C, and 90 °C under 25% DC. The monitoring temperature in the CS mount temperature sensing well yields 81 °C, 91 °C and 102 °C, respectively. The diode performs well at such a high temperature and large 25% duty cycle.

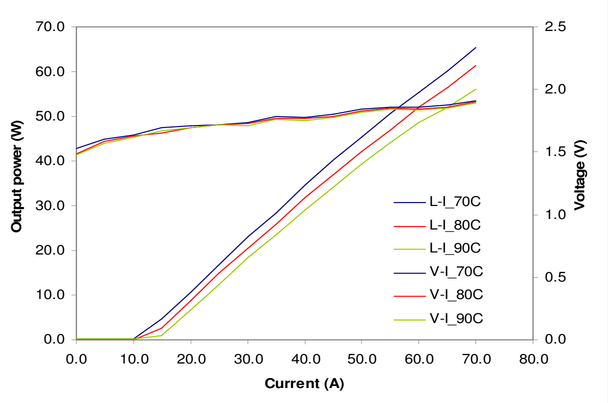

Fig.5 HT design mini laser bars LIV vs temperatures at 70 °C, 80 °C, and 90 °C. The pulse condition is 25% DC.

As mentioned above, junction temperature is of great importance for lifetime [6]. The lower the junction temperature the longer the lifetime is. We studied the junction temperature as a function of pulse width (PW) under fixed duty cycle (DC) and under fixed frequency, as shown in Figure 7 and Figure 8, respectively. Under both conditions, at low pulse width, the junction temperature is at least 6 °C lower for the HE design in comparison to that of the HT design. As pulse width increases, the junction temperature increases for both the HT and the HE design. Near 1 ms pulse width, the junction temperature increases are accelerated. Above 4 ms pulse width, the junction temperature is higher for the HE than the HT design under both fixed DC or fixed frequency. This is attributed to its better temperature performance of the HT design. Therefore, for QCW operation with large pulse width, the HT design is more suitable, however, at low pulse width, the HE design is more desirable due to its lower junction temperature.

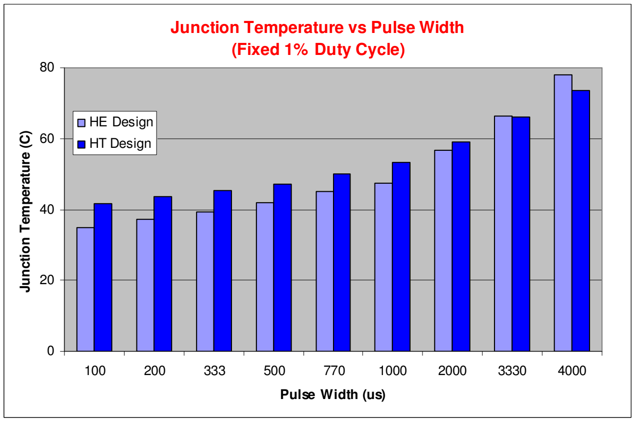

Fig.7 Junction temperature as a function of pulse width under fixed 1% DC for both HE and HT design. Both increase as pulse width increases.

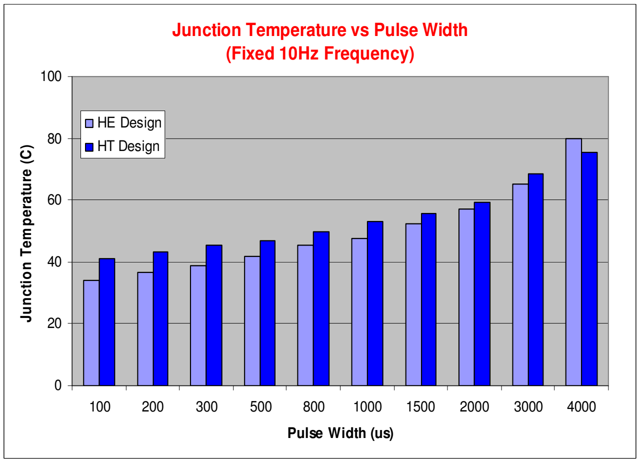

Fig.8 Junction temperature as a function of pulse width under fixed 10Hz frequency for both HE design and HT design. Both increase as pulse width increases.

2.2.4 Near-Field Uniformity

Uniform near-field (NF) of all emitters is very desirable for uniform pumping of solid state crystals to avoid any localized heating. Also, large optical intensity spike in NF could cause a localized hot spot within the laser cavity making the laser much more prone to potential catastrophic failure. Such optical intensity spikes in the optical path of a bulk defect would greatly lower the COD level, reducing the reliability of these devices. Therefore a careful design and processing optimization is necessary to achieve uniform NF.

We studied the NF behavior under QCW conditions from low current up to 200 A. At low current close to threshold NF is not very uniform due to the difference in turn-on current for each emitter. As current increases, NF becomes more uniform. Figure 9 shows QCW near field (NF) scan of a 3 mm mini bar under 200 A at 300 µs pulse width, 0.3% DC, 25 °C. The NF is uniform for all emitters without any edge effect.

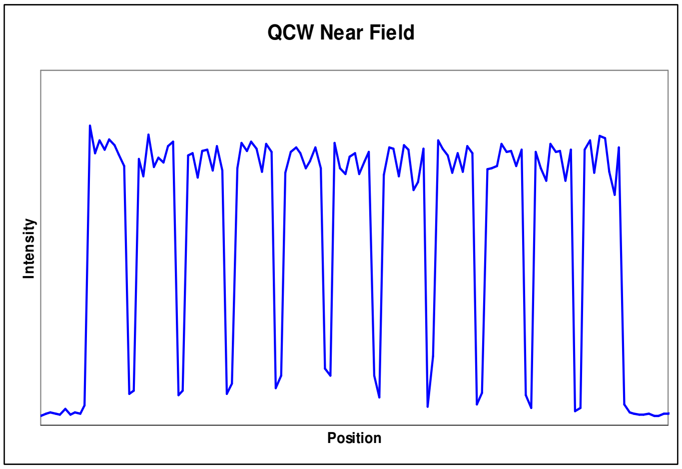

Fig.9 QCW NF scan of 3 mm mini laser bars. The test condition is 300 µs, 0.3% DC, 200 A. The NF is uniform for all emitters.

3. Lifetest

3.1 CS Mount Parts Lifetest

Lifetest has been carried out on 3 mm wide mini laser bars mounted on conductively cooled CS mounts. Lifetest conditions are 300 µs, 1.5% DC, 145 A, about 170 W. Figure 10 shows 5 parts at various stages of lifetest, and up to 370 M shots without failure. The power degradations are about 4% and 11% for those two with 370 M shots, about 3% and 0.3% degradation for another two parts after 150 M shots, and 2.5% degradation for one part after 75 M shots. None of the lifetest devices show emitter drop-off. Approaches are underway to address the slow degradation.

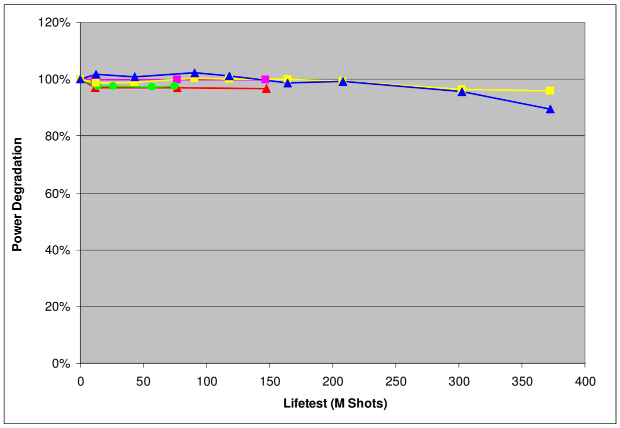

Fig.10 Power degradation vs lifetest duration. The lifetest condition is 300 µs, 1.5% DC, 145 A, which is equivalent to about 170 W. Very stable output power up to 370 M shots is obtained.

3.2 QCW Stack Lifetest

HT mini laser bars have been built into a 3-bar QCW stacks, and stress lifetest has been carried out. Figure 11 shows the stress lifetest results. For lifetest current up to 145 A under 200 µs, 20 Hz, 0.4% DC, near 6% power degradation was observed up to 80 M shots. Operating current at 100 A corresponds to 126 W per mini bar, while operating current at 145 A corresponds to 160 W per mini bar.

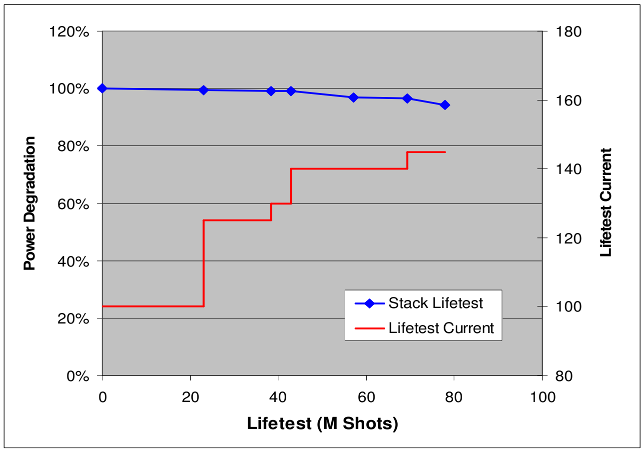

Fig.11 Normalized operating power vs lifetest duration. The lifetest condition is 200 µs, 0.4% DC. The current is stepped up to 145 A.

4. Conclusions

A new class of high power high brightness mini laser bars has been developed. For short pulse width and normal temperature application, the HE design is more desirable. For applications with large pulse width and at elevated temperature, the HT design is more suitable. HE mini bars demonstrated near 64% peak power conversion efficiency. Over 280 W output power has been demonstrated which is limited by power supply, and up to 370 M shots lifetest without failure has also been carried out. HT mini bars were built into QCW stacks and demonstrated good stress lifetest results. These mini bars enable a new class of compact, portable and high brightness pump source.

Acknowledgements

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