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Quasi-CW Laser Diode Bar Life Tests

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ABSTRACT

NASA's Goddard Space Flight Center is developing technology for satellite-based, high peak power, LIDAR transmitters requiring 3-5 years of reliable operation. Semi-conductor laser diodes provide high efficiency pumping of solid state lasers with the promise of long-lived, reliable operation. 100-watt quasi-CW laser diode bars have been baselined for the next generation laser altimeters. Multi-billion shot lifetimes are required. The authors have monitored the performance of several diodes for billions of shots and investigated operational modes for improving diode lifetime.

Keywords: laser diode bar, lifetest

1. MOTIVATION

NASA's Goddard Space Flight Center (GSFC) is developing technology for satellite-based, high peak power, LIDAR transmitters. The Geoscience Laser Altimeter System (GLAS) is scheduled to launch in 2001 and requires a 40 Hz, 110 mJ, 4 ns, Nd:YAG laser transmitter to run continuously for 5 years in space.¹ The most efficient optical pump sources for such a laser are semiconductor quasi-CW (QCW) laser diode arrays. However, the reliability of these diodes is in question. Laser diode bars are the only known source of degradation limiting the long-term survivability of the laser.^{2,3} The multi-billion shot performance of 100 W peak power QCW laser diode bars is investigated along with operational modes for improving diode lifetime.

2. MULTI-BILLION SHOT PERFORMANCE TESTS

A dedicated laser diode performance station was established on an optical bench within a secure, white room laboratory. The output power from each diode was collected in an integrating sphere fitted with a calibrated power meter. Dedicated drivers (SDL 928) powered each laser diode with constant current. This research utilized only laser diodes produced by SDL, Inc. At the time, they were the only laser diode manufacturer of 100 W QCW diode bars advertising billion shot operation before end-of-life (EOL - defined as 20% degrade). All the laser diodes tested were packaged by the vendor in their standard water-cooled assemblies (SDL 3255-C). This allowed maximum pulse repetition rate operation for accelerated life tests. A NESLAB CFT-33 chiller supplied temperature controlled water circulation. While operating 24 hours/day, a computer running LabView autonomously monitored instruments measuring the optical power, pulse count, diode drive current, diode temperature, and ambient temperature and humidity. An interlock circuit, attached to each diode power supply, disabled the drive current if the diode temperature rose above a set-point; protecting the diode from chiller failure or thermal runaway.

The performance of nine diodes operated for billions of shots is illustrated in Figure and Table 1. Diodes U350 and U920 show less frequent sampling because they were used in separate accelerated tests while pumping a laser crystal.^{2,3}

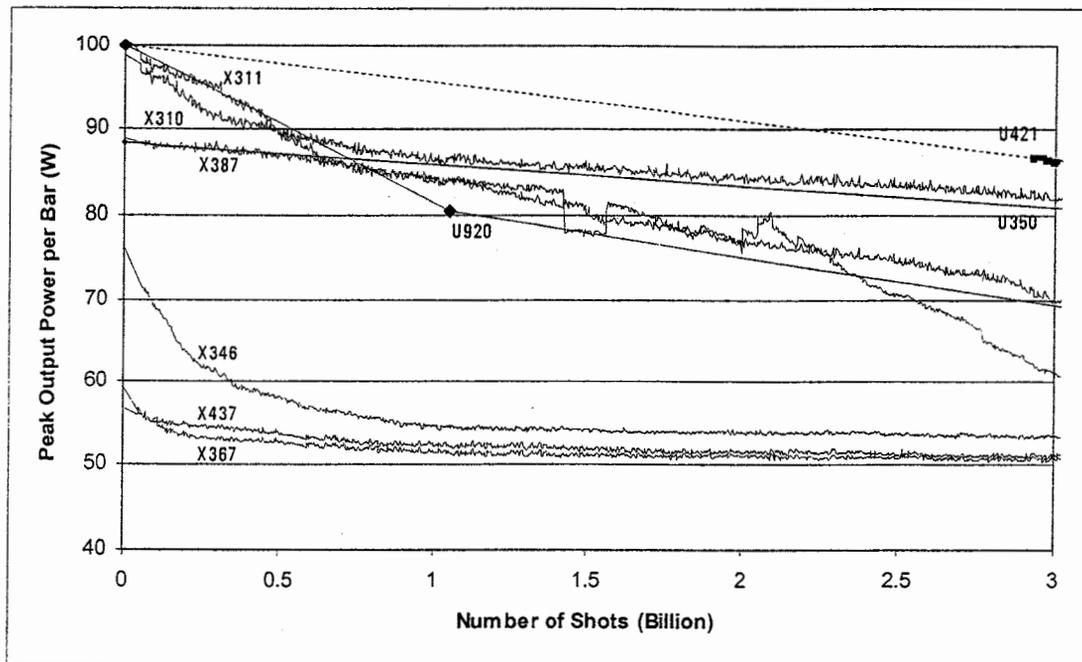


Figure 1. - Output power degradation of 9 laser diode bars over multi-billion shots.

| Serial Number | # bars / package | Duty Cycle (%) | Optical Power De-Rate (%) | Temp (°C) | Total # Shots (10 ⁹) | Total Degrade (%) | EOL (10 ⁹) |
|---------------|------------------|----------------|---------------------------|-----------|----------------------------------|-------------------|------------------------|
| U421 | 3 | 4 | 0 | 25 | 5 | 23 | 5 |
| U350 | 1 | 10 | 10 | 24 | 7 | 20 | 7 |
| U920 | 1 | 10 | 0 | 24 | 15 | 45 | 1 |
| X310 | 1 | 4 | 0 | 30 | 3 | 17.2 | - |
| X311 | 1 | 4 | 0 | 20 | 3 | 31.7 | 1.5 |
| X387 | 1 | 4 | 12 | 30 | 3 | 32.8 | 2.47 |
| X346 | 1 | 4 | 25 | 20 | 3 | 31.5 | 0.33 |
| X437 | 1 | 4 | 40 | 30 | 3 | 10.7 | - |
| X367 | 1 | 4 | 40 | 20 | 3 | 14.3 | - |

Table 1. - Operating conditions and results of billion shot performance tests of SDL-3255 laser diode bars. End-of-life (EOL) is defined as the 20% degrade point.

3. INVESTIGATION OF RELIABILITY PARAMETERS

In addition to monitoring laser diode performance for billions of shots, we investigated operational modes for improving lifetime. The tests performed on the "X---" Series diodes at GSFC (Figure and Table 1) were designed to observe effects of de-rated power and decreased heatsink temperature. In this test, six one-bar stacks in water-cooled packages (SDL 3255-C1)

were run in pairs at constant current. Two diodes were run at 93 amps, two at 109 amps, and two at 121 amps. One of each of these diode pairs was run at a heatsink temperature of 20° C; the other at 30° C. Each diode pair (same current) was powered with a single current driver while each diode triplet (same temperature) was cooled with a single water chiller. For each of the diode pairs running at the same current, the more efficient diode was run at the warmer temperature, so the optical powers would be closer and power de-rate more comparable.

In tests performed at SDL, Inc. (sponsored by NASA/GSFC, GLAS Project) four, 6-bar stacks (SDL 3252-H6) were operated for billions of shots: one stack at 100 W peak optical power, one at 80W and two at 60 W.⁴ This test was designed to isolate the effect of de-rating the peak optical power of the laser diode arrays from facet temperature effects. This was accomplished by increasing the duty cycle of arrays with lower peak optical power so that all the arrays operated at the same average optical power and thus the same facet temperature (30° C). (See Figure and Table 2.) In this test, the diode drive currents were periodically adjusted to keep the peak optical output power constant.

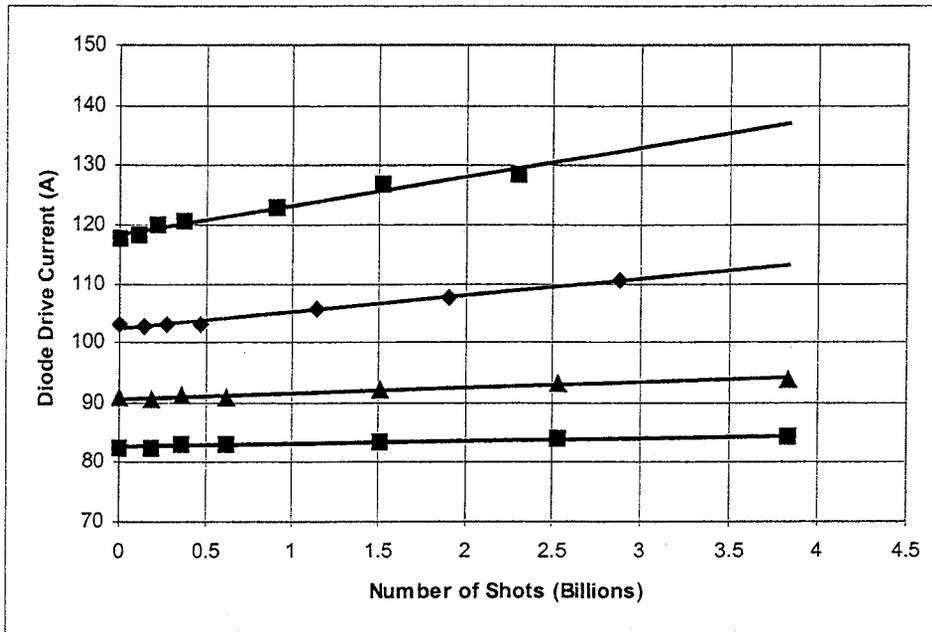


Figure 2. SDL performance test of 3252-H6 100 W QCW laser diode bars at constant optical power. The heatsink and diode junction temperatures are held constant.

| Serial Number | # bars / package | Duty Cycle (%) | Optical Power De-Rate (%) | Temp (°C) | Total # Shots (10 ⁹) | Total Degrade (%) | SDL's Predicted EOL (10 ⁹) |
|---------------|------------------|----------------|---------------------------|-----------|----------------------------------|-------------------|--|
| X392 | 6 | 9 | 0 | 20 | 2.3 | 9.4 | 4.9 |
| X389 | 6 | 11.2 | 20 | 20 | 2.8 | 7.3 | 7.9 |
| X390 | 6 | 15 | 40 | 20 | 3.8 | 3.5 | 22 |
| X391 | 6 | 15 | 40 | 20 | 3.8 | 2.2 | 35 |

Table 2. Operating conditions and results of billion shot performance Tests of SDL 3252-H6 laser diode arrays.

Both the GSFC and SDL tests demonstrate an advantage in long-term performance from de-rating optical power. From our admittedly small statistical sample, if you draw a straight line through the data, then an increase of 3.5 billion shots in laser diode life is realized for every 10% in optical peak power de-rating. There was no significant improvement in diode performance for the units which were operated at a 10° cooler temperature; 20° versus 30°. In general, the diode electrical-to-optical efficiency is a better predictor for long term performance. The more electrically efficient diodes degraded slower than less efficient diodes, under similar operating conditions.

The emission wavelength and number of active emitters, for the GSFC "X---" series diodes, were also recorded over billions of shots. At 500 million shot intervals, the laser diode wavelengths were measured using an integrating sphere fiber coupled to a Hewlett Packard 70951A optical spectrum analyzer. Figure 3 illustrates the change in the peak emission wavelength of the laser diodes over billions of shots.

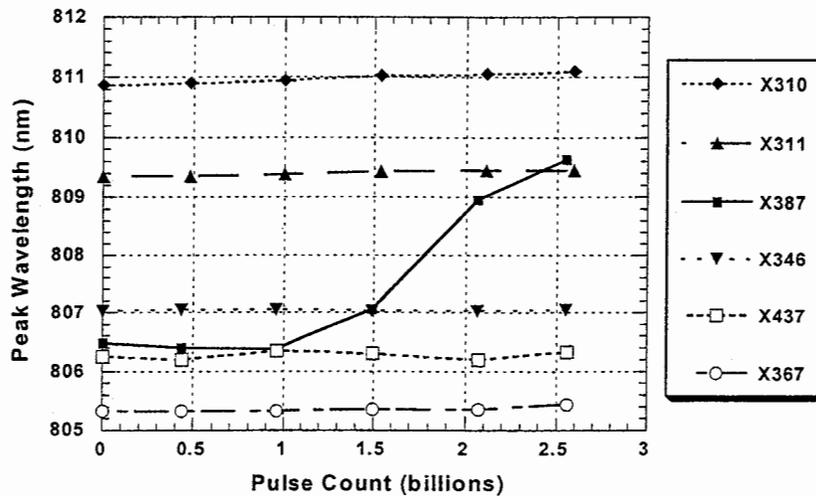


Figure 3. – Peak emission wavelength of laser diode bars recorded over billions of shots.

It is reasonable to assume that as the laser diode degrades, a growing fraction of the electrical drive power, which is no longer converted and emitted as optical power, will be absorbed by the diode, thereby generating additional heat. Heating the diode package shifts the peak emission wavelength by 0.3 nm/° C. In Table 3, the diode optical power degrade (ΔP), calculated temperature rise (ΔT), and finally calculated wavelength shift ($\Delta\lambda$) are compared to the measured wavelength shift.

| Diode | Output ΔP (W) | Calculated ΔT (C) | Calculated $\Delta\lambda$ (nm) | Measured $\Delta\lambda$ (nm) |
|-------|-----------------------|---------------------------|---------------------------------|-------------------------------|
| X310 | 15.52 | 0.50 | 0.15 | 0.23 |
| X311 | 26.98 | 0.86 | 0.26 | 0.1 |
| X387 | 18.36 | 0.59 | 0.18 | 3.15 |
| X346 | 22.59 | 0.72 | 0.22 | 0.02 |
| X367 | 7.9 | 0.25 | 0.08 | 0.1 |
| X437 | 4.93 | 0.16 | 0.05 | 0.08 |

Table 3. – Comparison of calculated and measured diode peak emission wavelength shift after 2.5 billion shots.

Interestingly, there is little correlation between the calculated and measured peak wavelength shifts. For diodes with low percent degrade (X310, X367, and X437) there is a constant factor of ~ 1.5 between the calculated and measured shifts. In contrast, the high percent degrade diodes have no apparent interdependence. This may be an indication of dissimilar diode degradation mechanisms. This behavior requires further analysis.

The diode facets were imaged using a zoom lens and beam profiler. A sample of the recorded images is shown in Figure 4. Degradation in the number of emitters was tracked over the life of the test.

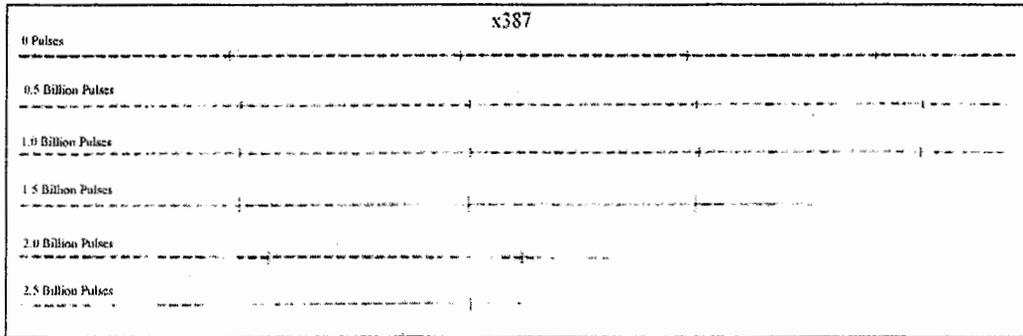


Figure 4. – Close-up images of laser diode X387 emission taken at 500 million shot intervals. A complete diode bar consists of 79 emitters. Erosion of the number of emitters is evident.

The optical power degradation per diode was compared to the decrease in number of emitters. In Figure 5, the power per diode is divided by the number of active emitters and plotted as a function of number of shots. The ratios were normalized to the initial value. If the diode power degradation was exclusively due to a decrease in the number of active emitters, the traces would stay constant at unity. Values less than one correspond to decreased optical loading per emitter. If the power per emitter decreases as well as the number of emitters, the traces would all slope below unity. Values greater than one correspond to increased optical loading. An extreme example is diode X387. In this case, the percentage of failed emitters is substantially greater than the power degradation. It is proposed that for these failed emitters, the impedance increases, forcing more current through the active emitters. X387 is also the only laser diode tested to show events with stepped increase in optical power. (See Figure 1.) After the diode's power increases, the degradation rate increases. This supports the theory that more current is flowing through the active emitters. This increase in the current elevates the temperature and therefore the emission wavelength. This is clearly shown for diode X387 in Figure 3.

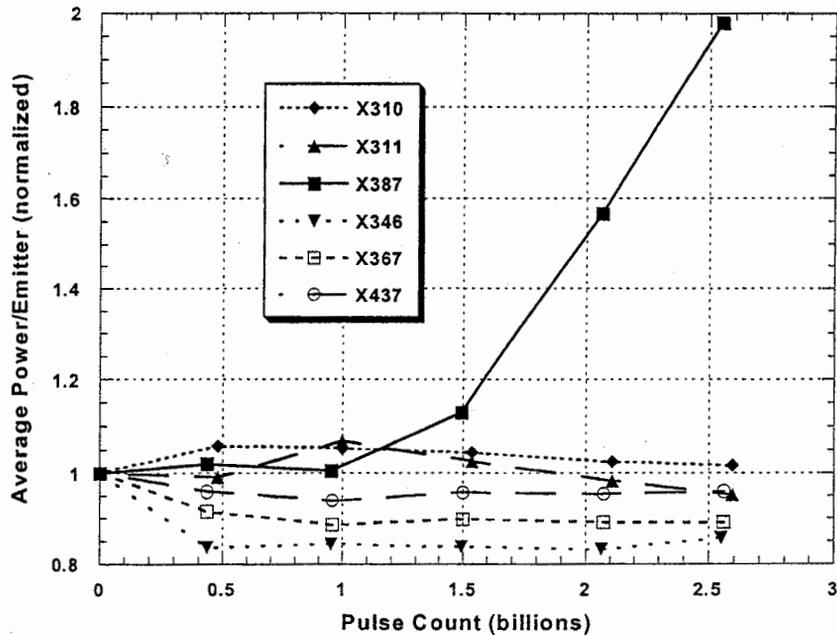


Figure 5. – Average power per emitter of SDL 3255 laser diode bars.

4. CONCLUSIONS

The multi-billion shot performance of QCW laser diode bars has been recorded. De-rating the optical power has been shown to improve long duration performance. Comparing diodes with a 10° C difference in operational temperature revealed no significant change in performance. Further investigation of degradation mechanisms is required to explain the inconsistent wavelength shifts and emitter power loading.

5. REFERENCES

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DISCUSSION

- Q.** Several years ago, A NASA Nd:YAG system was scheduled to go to Mars and back. There was a problem with the laser altimeter on that probe. It's sometimes called package-induced failure; this problem was discovered around the time of the launch. My question is, when you test these diodes, are you testing them under the conditions in which they will actually be used while in orbit?
- A.** Not exactly, we didn't do the test in a vacuum. In the first power slide that I have shown here, the original data is actually for two of those diodes, for diodes in actually pumping lasers in the situations. Although it's not in vacuum, they were diodes actually being used to pump the lasers. But we didn't try to repeat the space environment in this case.
- Q.** In the case I'm referring to, the laser was actually packaged in an inert environment. It operated well on the bench when it was not packaged, but when it was packaged, it failed in 10^6 rather than 10^9 shots. Do you know of this phenomenon in package-induced failure?
- A.** No, I'm not familiar with it.