Vixar Application Note

Operation of VCSELs Under Pulsed Conditions

Increasing VCSEL Output Power

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1.0 Introduction

This application note will discuss how the optical output power from a Vertical Cavity Surfaced Emitting Laser (VCSEL) can be increased beyond the output power under continuous wave (CW) conditions, when driven under pulsed current conditions. To understand the increase in optical output we must discuss the thermal characteristics of VCSELs. Some guidelines regarding the how the increased peak pulsed power is affected by pulsed width and duty cycle will be provided.

2.0 Background

A typical Light vs. Current (LI) curve for a VCSEL is illustrated in Figure 1. As the current is increased above the laser threshold current (Ith), the output power of a VCSEL will generally increase in a linear fashion and we can measure a slope efficiency (mW/mA) over some operating region, for example from 2 mA to 4 mA of the LI response of Figure 1. However as the current is increased further the output power reaches a peak or maximum (Pmax) at a current that is defined as Imax. As the current is increased further, beyond Imax, the LI curve rolls over. This is rollover phenomena is caused by internal junction heating and is known as “Thermal Rollover”. Thus thermal management is very important for VCSELs and t realize optical output powers beyond Pmax we must consider the thermal characteristics of VCSELs. VCSELs exhibit high levels of current density and thus high levels of thermal flux density within their small-diameter thin active-junction regions

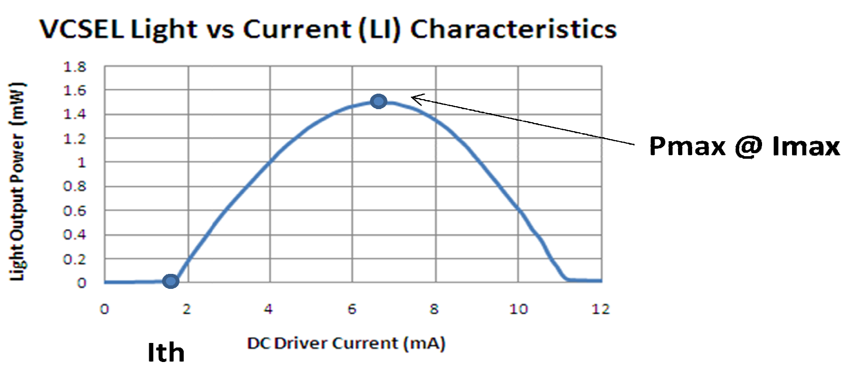


Figure 1: Example of Light vs. Current (LI) Curve for a VCSEL

3.0 VCSEL LIV Characteristics over Temperature

Of course, the thermal rollover characteristics of a VCSEL will be dependent on the operating temperature. An example of the LIV curves for a 670 nm Single Mode (SM) VCSEL over temperature is illustrated in Figure 2. It can be seen that as the temperature is increased that threshold currents increase and that Pmax & Imax decrease.

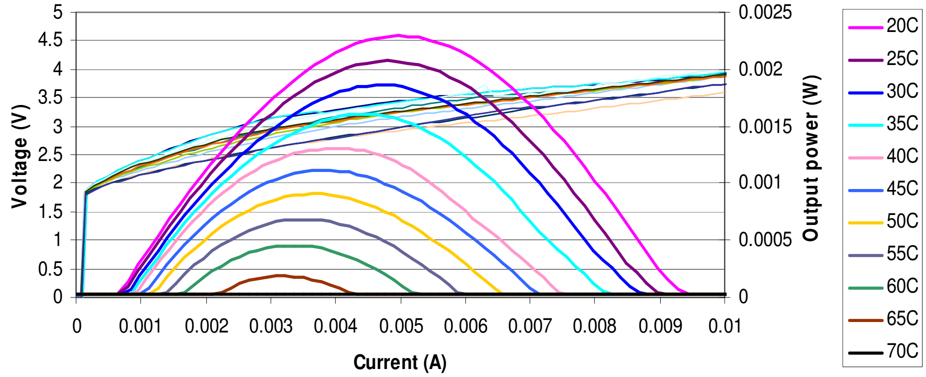


Figure 2: Light Output and Voltage versus Current (LIV) Over Temperature for a 670 nm SM VCSEL

4.0 Increased Optical Power under Pulsed Driver Conditions

The thermal heating of the junction can be reduced by application of short current pulses at reduced duty cycle. The reduced junction heating results in significantly increased optical output power. An example of the peak pulsed power characteristics for a 670 nm VCSEL over temperature is provided in Figure 3 for pulsed conditions of 50 ns at 1% duty cycle. Notice that the LI curve for the same device under DC or CW operation at 20C is superimposed (Blue Curve). For DC operation Pmax is about 2 mW at Imax = 7 mA. When driven under short-pulse low duty-cycle conditions the pulsed thermal roll over point is not reached up to currents of 28 mA, except at the highest temperatures of 100C or 120C.

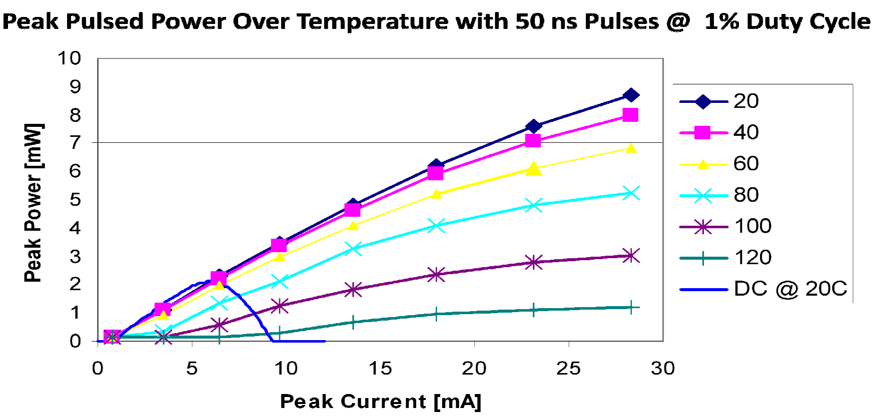


Figure 3: Peak Pulsed Power Characteristics Over Temperature for a 670 nm SM VCSEL

It should be noted that the peak pulsed power of Figure 3 was measured by using an average power meter, recording the time averaged power, and dividing the average power by the duty cycle to arrive at the peak power.

Figure 4 depicts the actual pulsed optical power captured on an oscilloscope using a 350 MHz O/E converter at various pulsed currents. The pulses are 250 ns wide at 1% duty cycle with the different pulses stored in memory and overlaid at various drive current levels. When the optical pulses remain relatively square, calculating the peak power from the average power divided by the duty cycle is quite accurate.

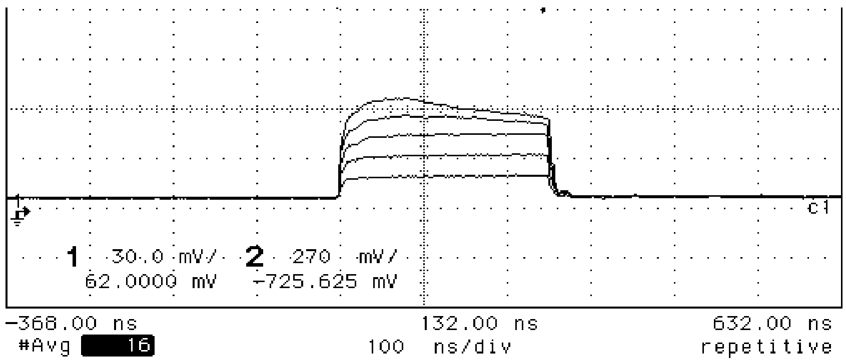
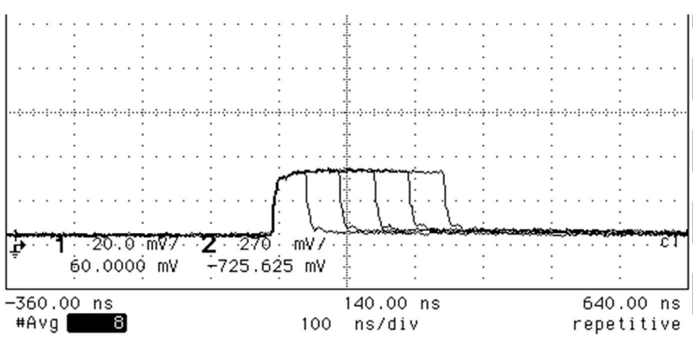


Figure 4: Peak Pulsed Power Characteristics Over Temperature for a 670 nm VCSEL

5.0 Effect of Pulse Width & Duty Cycle on Peak Pulsed Power

For short pulse widths (below 250 ns) and low duty cycle (below 5%), it can be shown that the Peak Pulsed Power is essentially independent of either the pulse width or the duty cycle. Figure 5 depicts the actual pulsed optical power captured over a range of pulse widths from 50 ns to 250 ns for a 670 nm Single Mode (SM) VCSEL. Various pulse widths were captured into the scope's memory and over laid. The data table has the scope memory # (M1 … M4) and the live scope trace, along with the pulse width (Tw) and duty cycle. It can be seen that the peak pulsed power or height of these optical pulses are essentially constant over this operating region.

Optical Pulses Received by a Fiber Coupled O/E Converter @ 25C

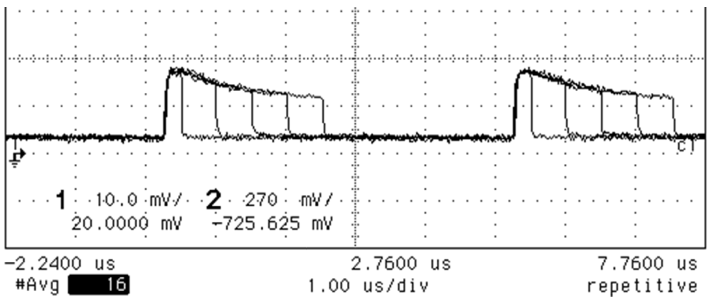


Mem #	Tw (ns)	Duty (%)
M1	50	1%
M2	100	2%
M3	150	3%
M4	200	4%
Live	250	5%

Figure 5: Peak Pulsed Power Characteristics vs. Pulse Width and Duty Cycle Over Temperature for a 670 nm SM VCSEL

However, as the pulse width is increased, the optical pulses will start to exhibit a droop within each pulse due to intra-pulse heating. Figure 6 illustrates the intra-pulse droop as the pulse widths and duty cycle are both increased. If the peak power were measured using the average power meter, corrected for the duty cycle, then the peak power would be the time averaged peak power across the pulse.

Pulse Width and Duty Cycle Variation @ 5 us Period @ 50C



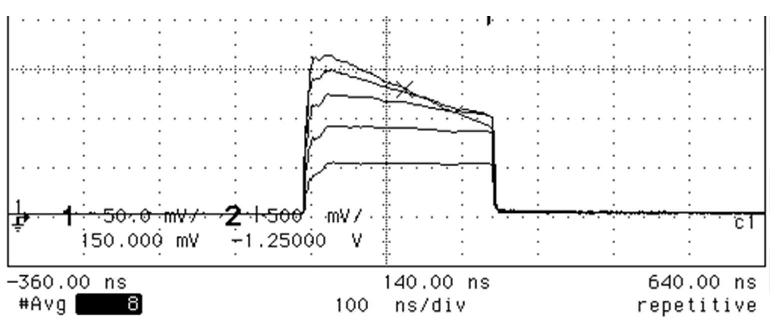
Mem #	Duty (%)	Tw (ns)
M1	5%	250
M2	15%	750
M3	25%	1250
M4	35%	1750
Live	45%	2250

Figure 6: Peak Pulsed Power Droop Characteristics as Pulse Width and Duty Cycle are Increased

6.0 Effect of High Pulse Drive Currents

Similar to the droop observed for longer pulse widths and higher duty cycles, droop in the optical pulse can occur for high drive currents. Figure 7 illustrate this effect where the optical pulse droops for pulsed currents of 18.8 and 22 mA.

Optical Pulse Characteristics vs Driver Current; PW = 250 ns, DC = 5%



Mem #	Ipp (mApp)
Live	22.0
M4	18.8
M3	12.5
M2	9.4
M1	4.7

Figure 7: Peak Pulsed Power Characteristics vs. Pulsed Drive Current for a 670 nm SM VCSEL

7.0 Variation of Pulse Width at Fixed Duty Cycle

We now understand how the pulsed optical signal behaves when driven to high pulsed currents, long pulse widths (1 us or higher), and high duty cycles (approaching 50%) and are aware of the optical droop due to intra-pulse heating. , Let's examine the pulsed power curves under a fixed duty cycle of 10% when the pulse width is increased from 100 ns to 750 ns as illustrated in Figure 8. Keep in mind that the average optical power meter is performing a time average over the pulse width and that some droop could be present for higher pulse widths and higher currents.

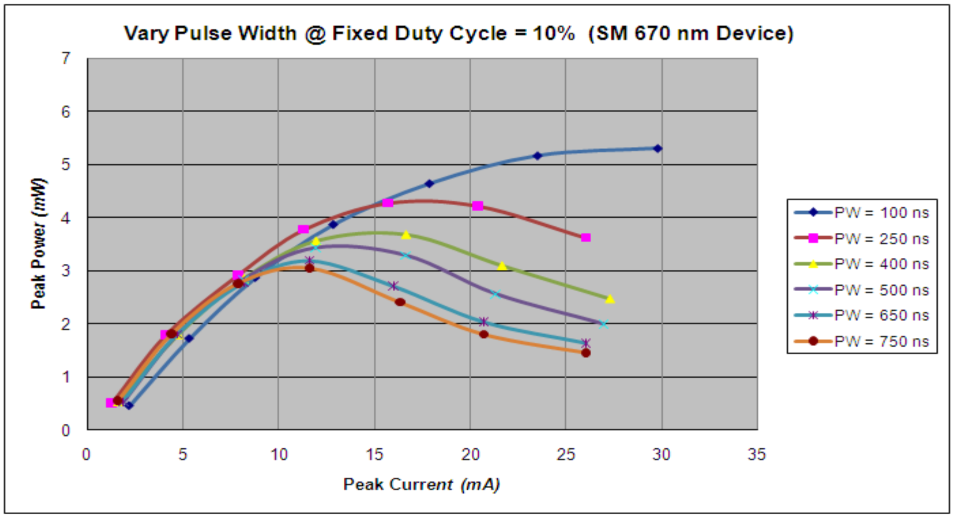


Figure 8: Peak Pulsed Power Characteristics vs. Pulse Width @ 10% Duty Cycle for a 670 nm SM VCSEL

8.0 Variation of Duty Cycle at Fixed Pulse Width

We can also examine the pulsed power characteristics for a fixed pulse width of 500 ns when the duty cycle is varied from 5% to 50% as illustrated in Figure 9.

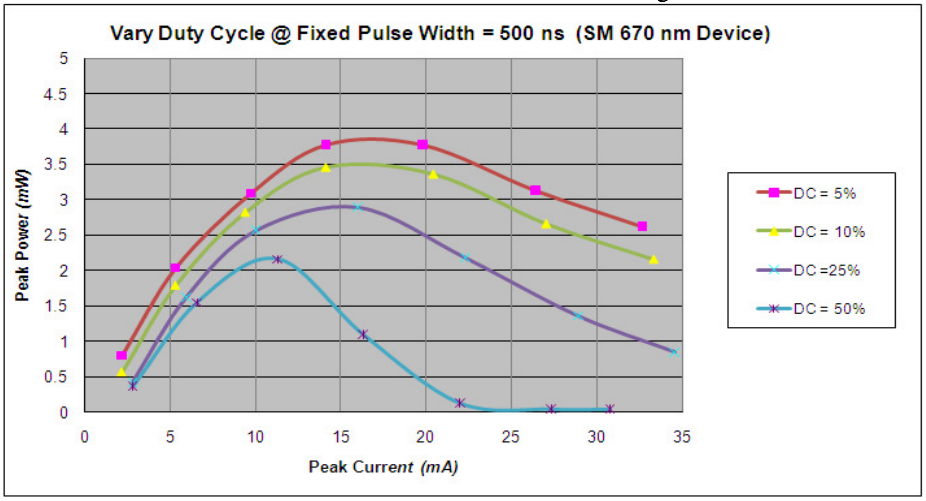


Figure 9: Peak Pulsed Power Characteristics vs. Pulse Width @ 10% Duty Cycle for a 670 nm SM VCSEL

9.0 Dependence on Device Design

Most of the data presented so far, was taken from Vixar's Single Mode (SM) VCSELs that exhibit peak pulsed power levels between 4 mW and 8 mW, depending on the pulse conditions . However, significantly more pulsed power (20 mW) can be delivered from Vixar's Multi-Mode (MM) VCSELs as illustrated in Figure 10. Again, these pulsed power curves were taken over a range of temperatures (similar to Figure 3). However, two different VCSEL aperture sizes, denoted MSC-3 and MCS-4, are included, as well as multiple devices for each aperture size. You can see that the larger aperture MSC-4 exhibits the highest pulse power at 25C and about the same amount of power at 50C as the MCS-3 device does at 25C. When the temperature is increased to 75C, both of these devices essentially produce the same pulsed power, with MCS-4 only showing a slight advantage.

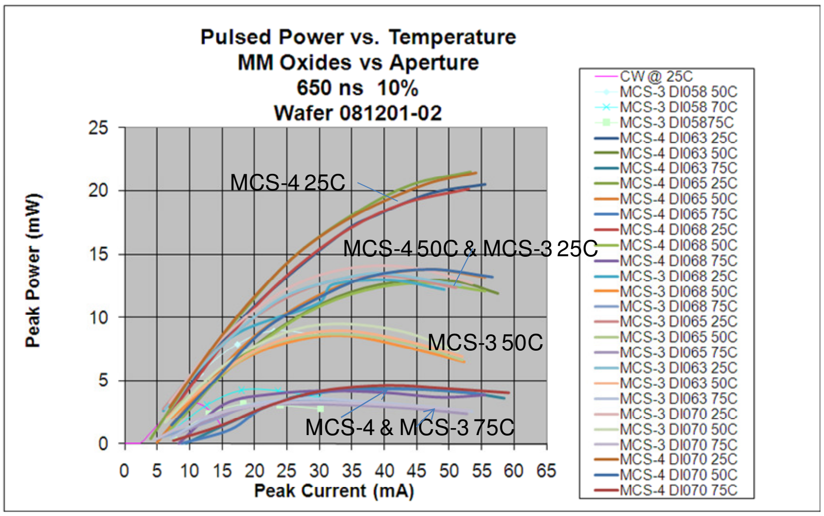


Figure 10: Peak Pulsed Power Characteristics for Vixar's MM VCSELs over Temperature for 2 Different Aperture Sizes

The pulsed characteristics for a SM device at 500 ns & 10% duty cycle are provided in Figure 11.

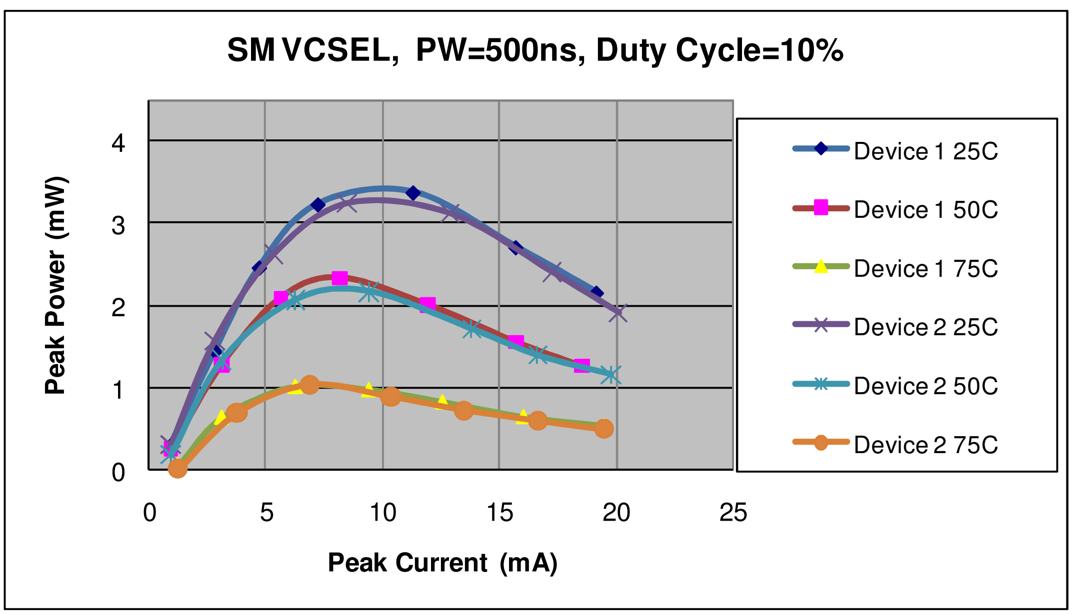


Figure 11: Peak Pulsed Power Characteristics for Vixar's SM VCSEL over Temperature at 500 ns & 10%

10.0 Temperature and Pulse Width Dependence

The temperature dependence for the MM MCS-3 device is provided in Figure 12 at 5% duty cycle for pulse widths of 250 and 500 ns. Notice that at 25C, that the 250 ns curve is essentially the same as for the 500 ns curve. However, at higher temperatures the 250 ns curves are higher than for the 500 ns curves. This illustrates the complexity of the thermal dynamics within the VCSEL structure.

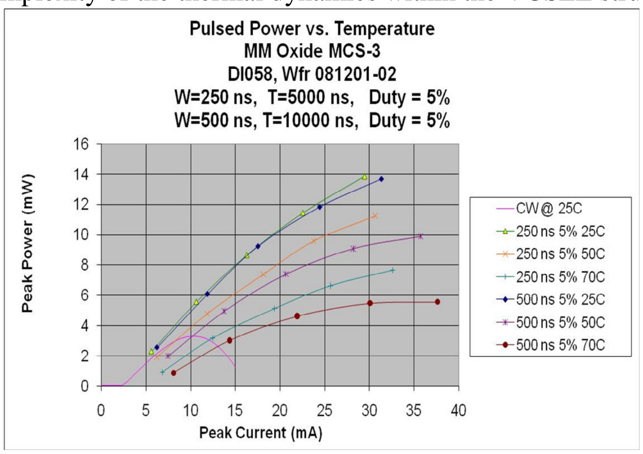


Figure 12: Peak Pulsed Power for Vixar's MCS-3 MM VCSEL over Temperature for 2 Different Pulse Widths

11.0 Stressed Pulse Testing

All of the previous pulsed power data was taken when driven with purely periodic signals. Some applications, for example laser printers, could require short isolated pulses or bursts of pulses with long periods without any pulses. Figure 13 illustrated an example of such stressful pulse streams with four 2 ns pulses in a 10101010 pattern, followed by 246 ns of off time, followed by a single 2 ns pulse. The smaller image on the right is a zoomed in view of the 4 pulses. These pulses were created using a pulsed pattern generator (PPG) and recorded using a high-speed (3 GHz) O/E receiver. A commercial laser driver IC was used to drive the VCSEL. The VCSEL was coupled to a multi-mode optical fiber that routed the optical signal to the O/E receiver. Vixar has measured such pulses with off times up to 1 µs. To achieve such stressful pulses the driver electronics must be fully DC coupled at the differential input and the VCSEL must be fully DC coupled to the driver output. The VCSEL must be driven hard below threshold to prevent any issues with off state bounce. Notice that the pulsed output levels for the 4 pulses are essentially the same as the level for the single pulse.

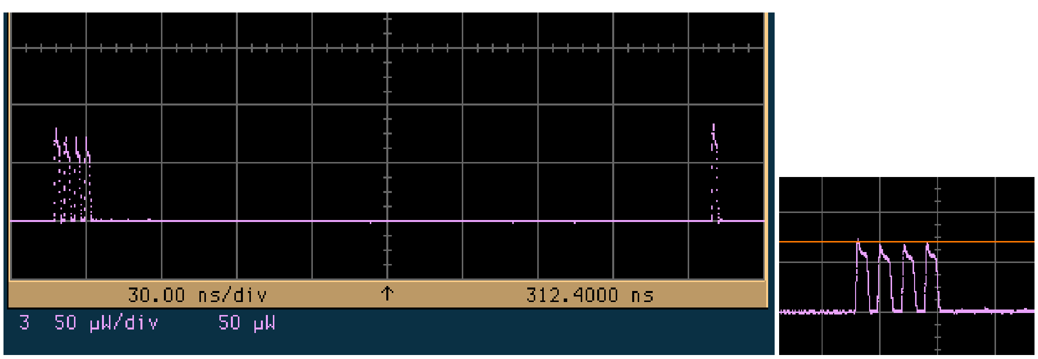


Figure 13: Illustration of Stressed Pulses Testing

12.0 Modulation at 1 Gb/s

Using the test set as described in the previous section, a 1 Gb/s optical signal was recorded using a random test pattern and the 4th order Bessel Thompson filter needed for optical transmitter standards compliance testing. The optical eye diagram is provided in Figure 14 (1 ns Pulse Width). Since the bandwidth of Vixar's devices are around 5 GHz, a clean, open, low jitter eye was observed with very little effort. Vixar has performed such testing with our devices and a variety of commercial laser driver ICs.

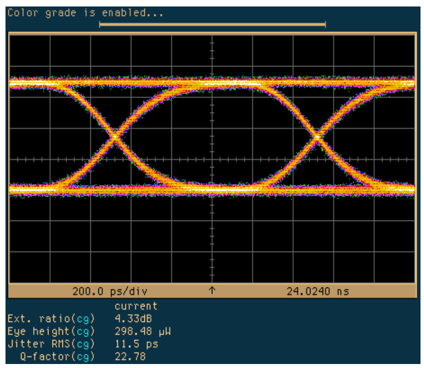


Figure 14: Compliance Filtered Optical Transmitter Eye Diagram at 1 Gb/s

13.0 Preliminary Pulsed Reliability Data

Vixar has accumulated 5.3 million device-hrs of constant current (CW) reliability test data over the past 3 years. However, in order to fully understand device reliability when driven under pulsed conditions, a pulsed reliability test was started November 2009. Driver boards were designed and built to pulse each laser with 500 ns pulses at 12.5% duty cycle. Four boards are under test at 3 temperatures and under 3 different pulsed current levels in a matrix fashion, as typical for reliability testing. This allows for calculation of acceleration factors. A total of 192 devices are currently on test. Figure 15 provides the test data for one of these boards, Board #1, which is running at 50C and has accumulated 9538 hrs. This board has 2 different devices and 3 different pulsed drive currents. At each reliability readout point, the board is pulled from the oven and the CW LIV characteristics are measured. Thus, this data represents the maximum output power under CW testing as a function of time under pulsed conditions. The pulsed reliability testing is still running.

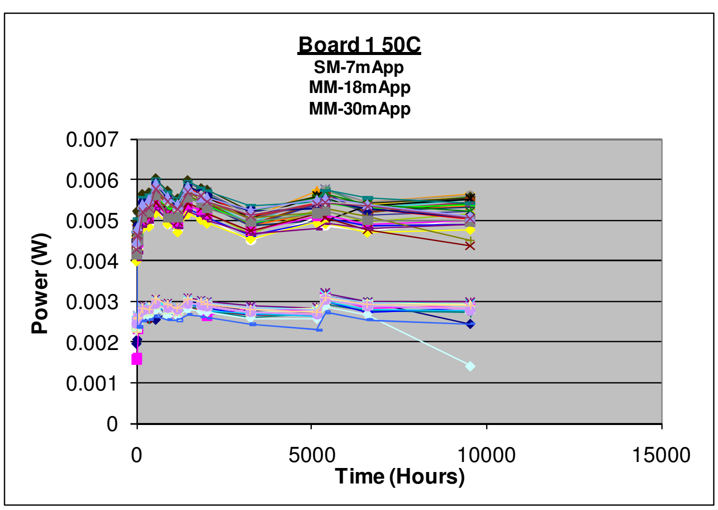


Figure 15: Pulsed Power Reliability Data

14.0 Summary

Extensive VCSEL pulsed-power data has been presented over a range of various pulsed conditions. Since the pulsed power output of a VCSEL is limited by thermal heating of the junction, it is dependent on many factors. These factors include pulse width, pulse duty cycle, temperature, peak pulsed current, and device type. This application note serves as a guide that can be used to help estimate the level of peak pulsed power could be obtained under a given set of pulse conditions. Vixar has automated our pulsed power testing capability and can help you optimize device selection, operating temperature range, and operating current range for your pulsed application. Vixar's engineers have many years of experience in VCSEL development and operation for high-speed fiber communication and can help customers develop solutions for the VCSEL drive electronics. Vixar has initiated a pulsed reliability study to insure that high reliability is maintained for your applications. Please contact Vixar if you would like to discuss this application note or should require some pulsed data at your specific operating conditions.