PERFORMANCE OF PHOTODIGM'S DBR SEMICONDUCTOR LASERS FOR PICOSECOND AND NANOSECOND PULSING APPLICATIONS

By Jason O'Daniel, Ph.D.

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1. Introduction

Photodigm's DBR semiconductor laser diode provides excellent spectral stability and high power for pulsed applications. These lasers are capable of producing pulses as short as a few 10's of picoseconds. Photodigm's DBR laser diodes are an excellence choice as seed sources for short pulse fiber amplifier systems, as these laser diodes provide spectrally-clean, high-speed pulses. Photodigm has three different DBR laser structures that operate with a single spatial mode that are referenced in this document. These three basic structures are illustrated in Figure 1.1. The data presented in this document is experimentally obtained measurements from driving Photodigm DBR laser diodes under pulsed conditions ranging from several 10's of picoseconds to 50 ns.

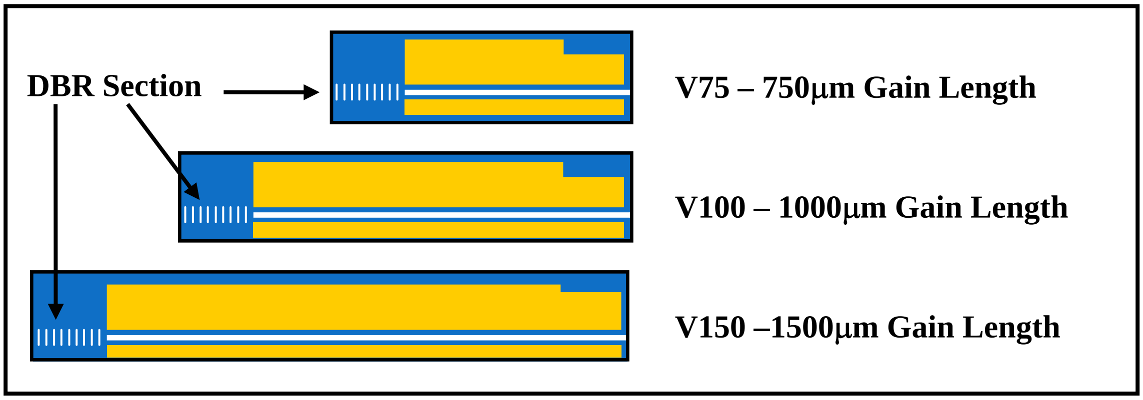
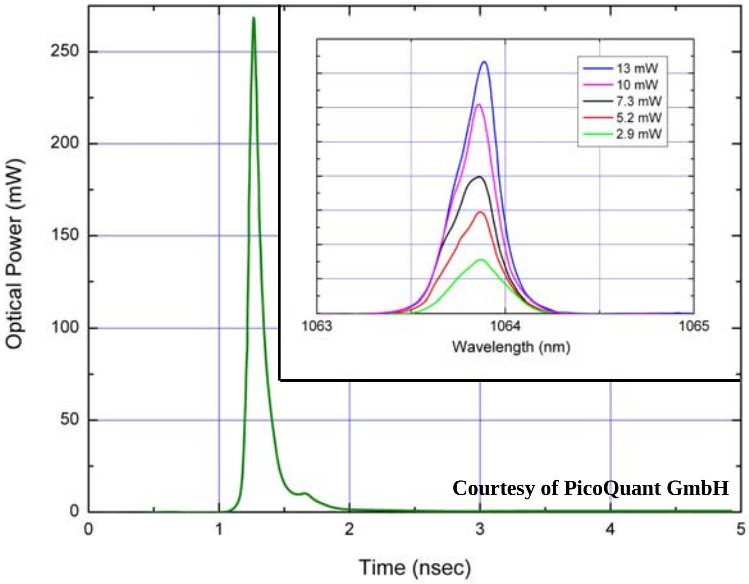


Figure 1.1. Photodigm single spatial mode DBR laser structures basics

2. Pulse Measurements for Pulse Widths below 300 ps

Very short pulses, on the order of 10's of picoseconds can be obtained from semiconductors through the process of gain-switching. Gain-switching occurs as a large number of carriers are initially pumped into the active region of the laser. Once the laser is pumped above threshold, there is a surge of stimulated emission depleting the carriers faster than they can be injected. This surge of photons is a gain-switching spike. If the flow of injected carriers is cut off before the laser can recover from the carrier depletion, a very short pulse can be obtained. Figure 2.1 shows a gain-switch pulse obtained from a Photodigm V100 1064 nm DBR laser.



Courtesy of PicoQuant GmbH

Figure 2.1. Photodigm DBR laser gain-switched pulse with a pulse width of 98 ps; the inset shows the optical spectrum at several different average power levels under gain-switching operation at 40 MHz

Under these short pulse conditions, the device is spectrally stable as can be seen in the inset of Figure 2.1. For gain-switching applications, the device length is not an issue in terms of spectral stability. Longer devices, such as the V100 and V150, will yield a higher usable peak power than the shorter V75 devices. A gain-switched pulse can be easily obtained with a modulated drive current by slowly increasing the current level until the gain-switch spike occurs. If the current is increased too far, the laser will start to emit photons past the gain-switch spike. The pulse widths of these gain-switched spikes using this drive method are typically in the range of 200-300 ps and the peak power is typically low. A great deal of electrical engineering is required to achieve high-power gain-switched pulses, and even more must go into achieving pulses of less than 100 ps. Photodigm's DBR lasers are very well suited for achieving these types of pulses in that the DBR sections have a small amount of saturable absorption that can be increased by operating the devices at higher temperatures (40-50°C). This saturable absorption causes the device to jump on abruptly during operation increasing the rise time of the pulse appreciably.

3. Pulse Measurements Ranging from 4 ns to 50 ns

The devices presented here are from Photodigm V75 DBR lots processed with Photodigm's new grating structure (this new grating structure was integrated into the manufacturing process in June 2009). This new grating structure ensures excellent mode selection during pulsed operation for windows of operation that are extremely large in size, in terms of both peak current and temperature.

3.1. Electrical Setup

The Photodigm V75 DBR semiconductor lasers were mounted on C-Mounts and pulsed using an Avtech Electrosystems AVO-6D-B Laser Diode Pulser. The lasers were driven at pulse widths ranging from 4 ns to 50 ns at a repetition frequency of 20 kHz, which is the driver's maximum frequency. The electrical pulses were not ideal due to a small amount of ringing present in the pulses as shown in Figure 3.1.

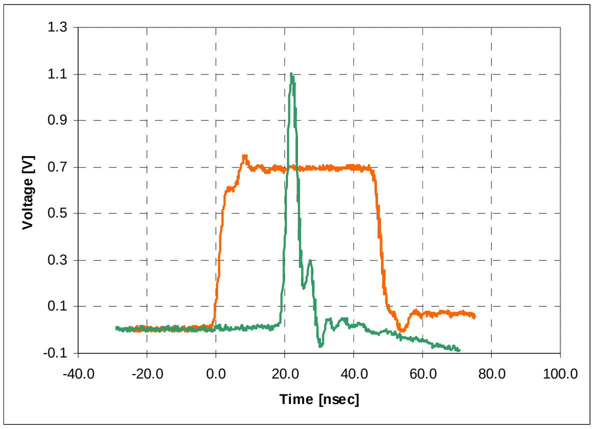


Figure 3.1. 4 ns and 50 ns electrical pulse from Avtech monitor

3.2. Optical Setup

The laser light from the DBR laser was collimated with an aspheric lens and coupled into an unbalanced Michelson interferometer as shown in Figure 3.2; unbalanced meaning that the arm lengths are slightly different to provide a slight time-of-flight delay for light in one arm with respect to the other arm. The delay allows for two different portions of the pulse to interfere with one another. As the source wavelength changes, the intensity of the interference will change accordingly, thus providing a wavelength sensitive monitor. The light at the interferometer output was coupled into a single mode HI-1060 optical fiber with FC/APC connectors and analyzed using an Agilent Infinium DCA 86100A Wide-Bandwidth Oscilloscope. This oscilloscope is equipped with an 86105A 20GHz optical/electrical module. The oscilloscope was used in eye diagram mode to capture a very high number of pulses to get a statistical overview of the distribution of the laser modes. An example of an interferogram for a non-ideal device is shown in Figure 3.3 as an example. This example illustrates both inconsistent mode selection from pulse to pulse, as well as a mode hop during the pulse.

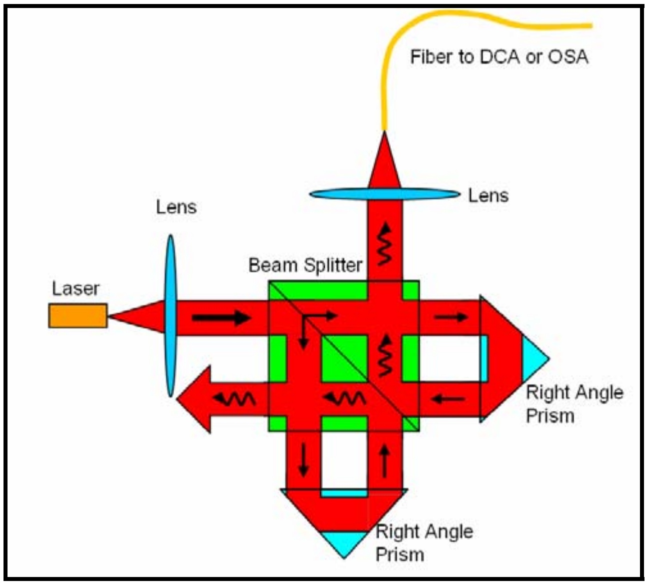


Figure 3.2. Unbalanced Michelson Interferometer for monitoring spectral behavior during pulsed operation

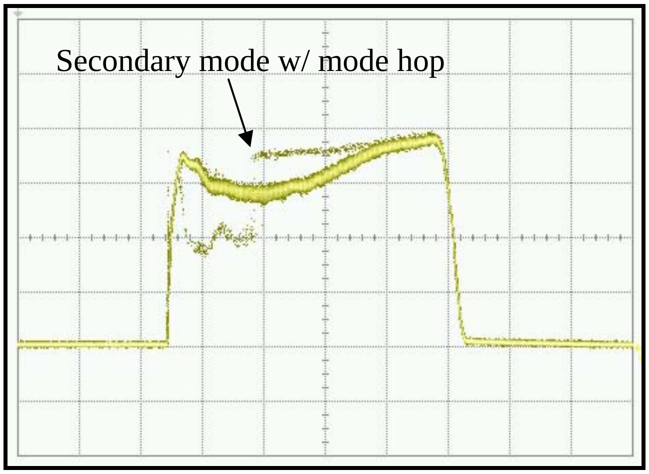


Figure 3.3. Non-ideal device showing a secondary mode being selected with a low probability; further, this secondary mode has a very apparent mode hop.

Figure 3.4 is the optical pulse measured with one arm of the interferometer blocked for a variety of pulse widths. The roundedness near the rising and falling edges comes from the rise and fall times associated with the laser diode driver used. The gain-switching spike on the rising edge of the pulse is inherent to semiconductor lasers; however, this spike can be virtually eliminated through pre-biasing the laser to just below threshold. The ringing from the electrical pulse is very apparent in the optical pulses longer than 8 ns.

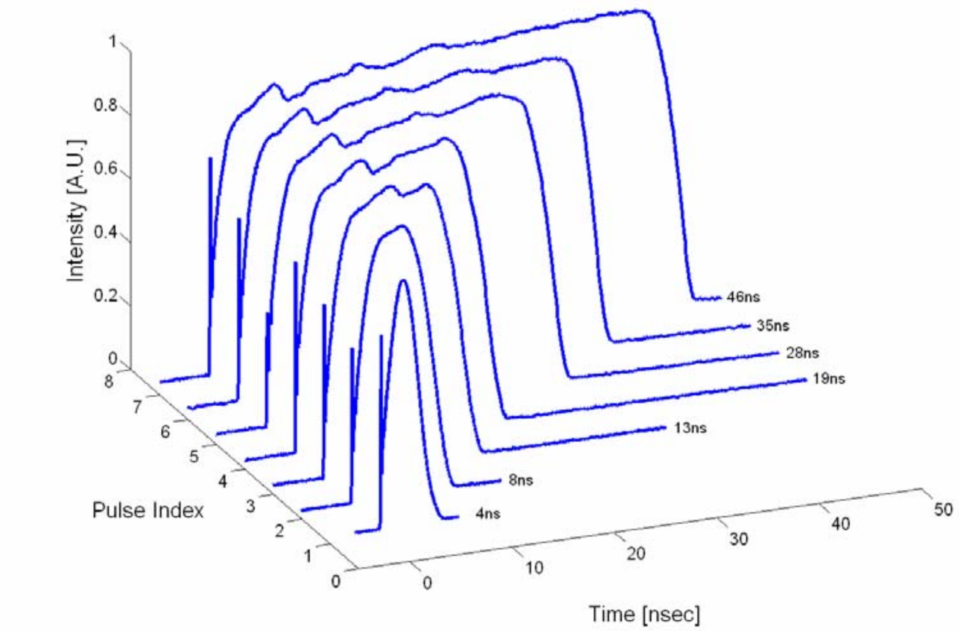


Figure 3.4. Optical pulse traces through the unbalanced interferometer with one arm blocked with various pulse widths

The same optical setup was also used to record the optical spectrum during pulsed operation. This was accomplished by blocking one arm of the interferometer and moving the fiber end to an Ando AQ6317 Optical Spectrum Analyzers (OSA) to record the optical spectrum. The resolution setting on this OSA was set to the minimum of 10pm.

3.3. Measurement Results for 976 nm V75 DBR Lasers

The measurements presented here were taken from a typical Photodigm 976 nm V75 DBR laser diode. At a peak current level of 560 mA (~425 mW) the interferogram shows no sign of a secondary mode or any competition between modes for temperatures ranging from 15ºC to 60ºC; a few samples at different temperatures of the interferograms at this peak current level are shown in Figure 3.5. In Figure 3.5, it is worth noting again that these interferograms are wavelength dependent traces; the amplitude of the interferogram has no absolute relation to the actual peak power of the pulse (i.e. the reduction in interferogram amplitude as temperature increases in this series is purely coincidental). The range in temperature could be larger, but temperatures outside of the 15ºC to 60ºC range were not investigated. Figure 3.6 shows the spectrum as measured by the OSA for this device at 560 mA (~425 mW peak power) at 20ºC and 35ºC.

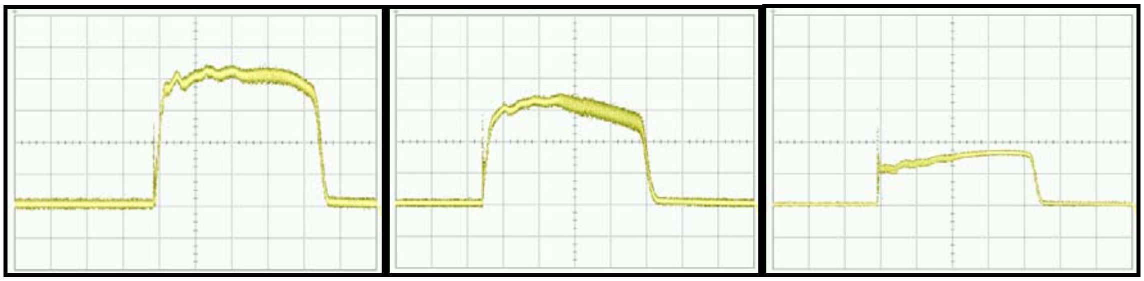


Figure 3.5. 976 nm V75 DBR Laser unbalanced interferogram showing consistent mode selection from pulse to pulse at 50 ns with a 560 mA peak current at 20°C (left), 35°C (center), and 60°C (right) (x-axis 10 ns/div, y-axis A.U.)

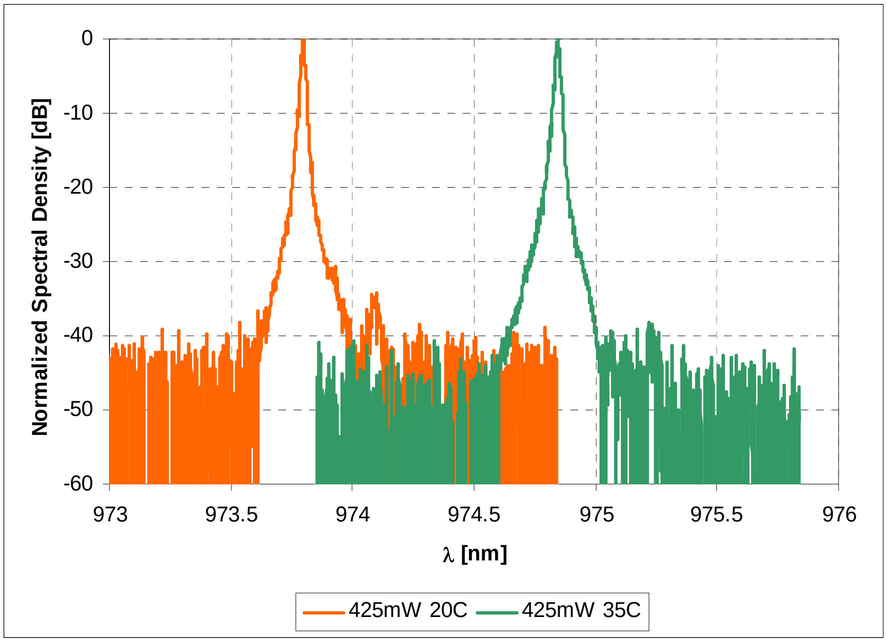


Figure 3.6. 976 nm V75 DBR Laser optical spectrums in dB scale

For this device, the pulse remains stable until near 880 mA for a 50 ns pulse at 20°C (~660 mW) at which point the interferogram becomes irregular. At this current, the optical pulse from a single arm of the interferometer is irregular, as seen in Figure 3.7. Presently, it is unclear exactly what is causing this optical pulse breakdown at this high power level. This optical pulse breakdown is some sort of induced modulation that is accompanied by significant spectral broadening, but the devices typically retain a single spectral mode as measured by an OSA. The precise point at which this pulse breakdown phenomenon occurs is device dependent.

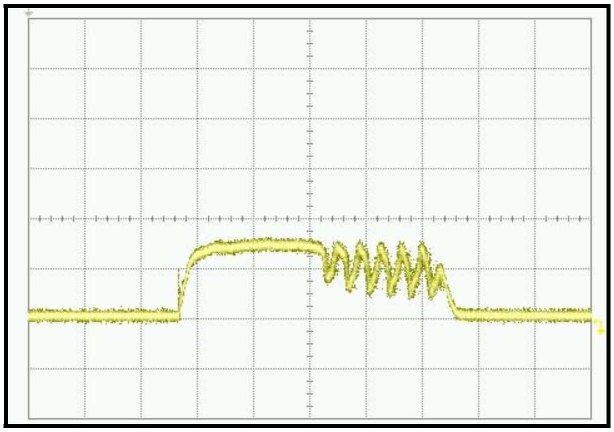


Figure 3.7. Optical pulse illustrating pulse breakdown for a 976nm V75 DBR Laser at 50 ns with a 880 mA peak current and a temperature of 20°C (x-axis 10 ns/div, y-axis A.U.)

Below the current level of 880 mA, the device maintains excellent mode selection as seen in Figure 3.8. The interferogram shown in Figure 3.8 was taken at a peak current of 760 mA (~570 mW); the small steps in the pulse correspond to the ringing of the electrical pulse. The interferogram becomes very wavy right before the onset of the optical pulse breakdown seen in Figure 3.7, and the spectrum as measured by the OSA becomes broader as seen in Figure 3.9. The broadening of the spectrum for increasing current levels can clearly be seen in Figure 3.9.

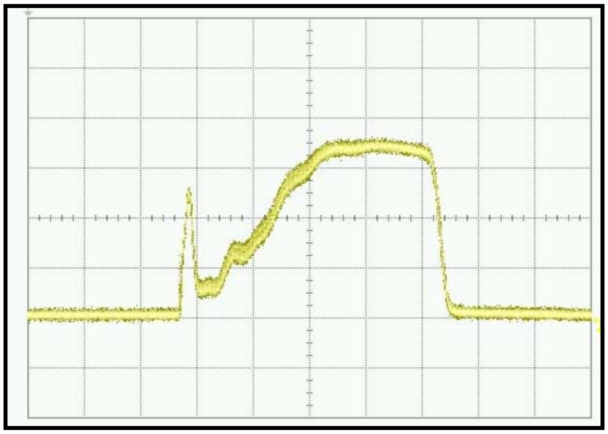


Figure 3.8. 976 nm V75 DBR Laser interferogram for 760 mA peak current at 20°C (x-axis 10 ns/div, y-axis A.U.)

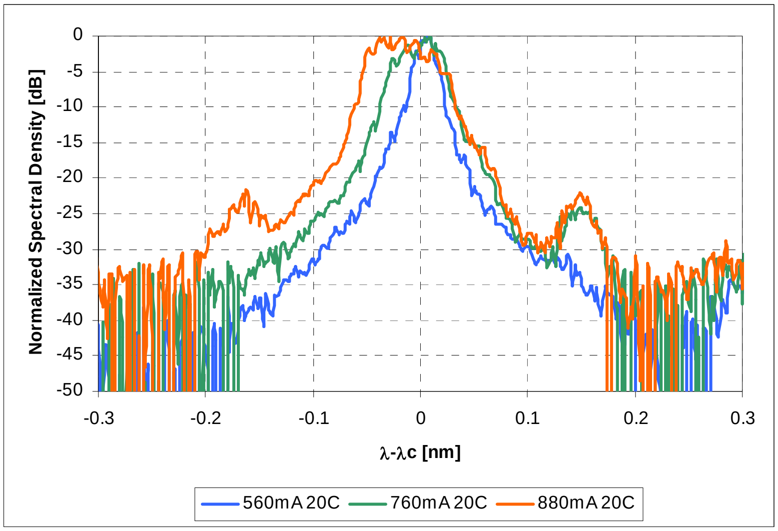


Figure 3.9. 976 nm V75 DBR Laser optical spectrum for various drive current levels

The point at which the pulse breakdown occurs is pulse width dependent. The breakdown typically starts at the falling edge of the pulse and works it way toward the beginning of the pulse as the peak current is increased further. Therefore, shorter pulse widths often times have a higher usable peak current or peak power than longer pulse widths. This is evident in the interferogram for the 976 nm V75 DBR Laser shown in Figure 3.10; for this 4 ns pulse width, the peak current is extended to just below 1000 mA (or approximately 730 mW peak power).

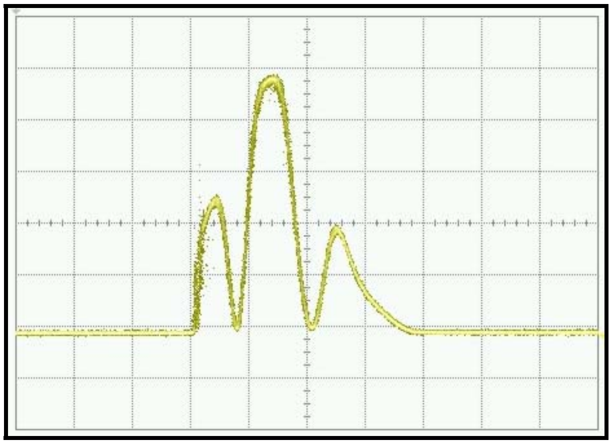


Figure 3.10. 976 nm V75 DBR Laser interferogram for 4 ns pulse with 970 mA peak current at 35°C (x-axis 2 ns/div, y-axis A.U.)

A noticeable trait of the interferogram in Figure 3.10, is that the there are two valleys in the trace. These two valleys indicate that the wavelength is changing quite significantly during the pulse. In order to gauge the chirp or broadening of the spectrum with peak current, the OSA spectrum was recorded for several peak current levels for the 976 nm V75 DBR Laser under test. The width of the optical spectrum was determined at full width half maximum from the OSA spectrum. This width was reduced by the spectral width for CW operation (effectively subtracting away the point spread function of the

OSA). The chirp was then calculated based on this number; while this is not an extremely accurate way to measure the chirp it does give a fairly accurate representation. The chirp values calculated by this method for a 50 ns pulse as a function of peak drive current are shown in Figure 3.11 (left); the slightly higher chirp value at lower currents comes from the Avtech laser driver. The top of the pulse has a slope with a slight increase at low drive currents.

This measurement was also carried out for a fixed current and various pulse widths. The chirp values resulting from these measurments are shown in Figure 3.11 (right). The chirp for the 625 mA peak current versus pulse width shows a trend that is most likely explained by the slow rise and fall times of the laser diode driver for the shorter pulses. Since the instantaneous frequency of the laser is varying over the entire pulse, the measured optical spectrum will be significantly broader. As the pulse starts to have a flat top, the instantaneous frequency will have a more centralized distribution around the frequency corresponding to this steady state area. However, as the pulse becomes longer the instantaneous frequency will begin to change during the flat top of the pulse due to heating effects at these high current levels and longer pulse widths.

If the application requirements are lenient in terms of power or pulse width, this ability to vary the chirp by changing the peak drive current or pulse width can be useful in obtaining the desired chirp for the application.

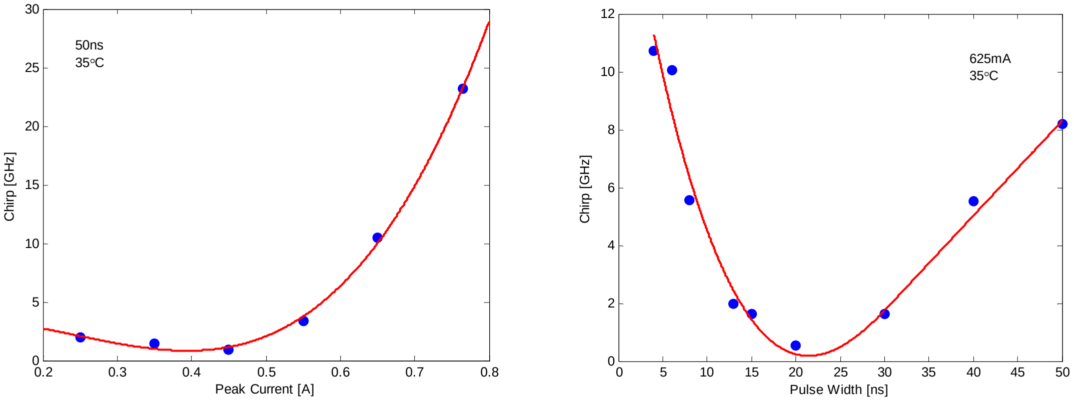


Figure 3.11. Approximate chirp versus peak current for a 50 ns pulse (left), and approximate chirp versus pulse width for a peak current of 625 mA (right).

3.4. Measurement Results for 1064 nm V75 DBR Lasers

The measurements presented here were taken from a typical Photodigm 1064 nm V75 DBR laser diode. For this device, the pulse remains stable until just past 700 mA for a 20 ns pulse at 20°C (~500 mW) at which point the interferogram becomes irregular. At a peak current level of 700 mA (~500 mW) the interferogram shows no sign of a secondary mode or any competition between modes for temperatures ranging from 20°C to 50°C; a few samples at different temperatures of the interferograms at this peak current level are shown in Figure 3.12. The range in temperature could be larger, but temperatures outside of the 20ºC to 50ºC range were not investigated. Figure 3.13 shows the spectrum as measured by the OSA for this device at 700 mA (~500 mW peak power) at 20ºC and 35ºC.

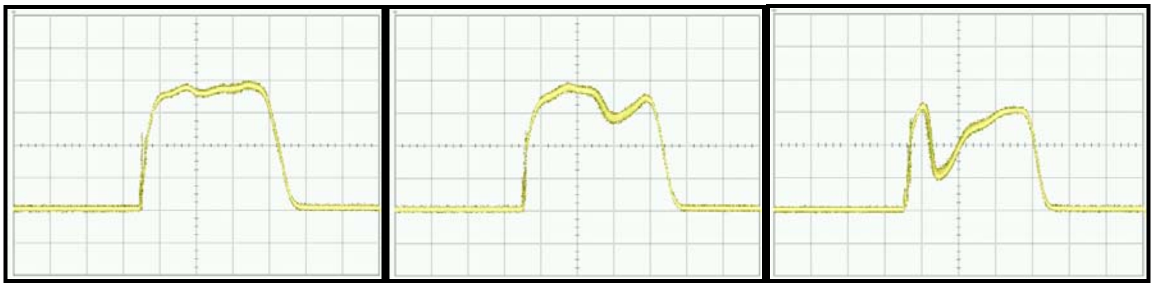


Figure 3.12. 1064 nm V75 DBR Laser unbalanced interferogram showing consistent mode selection from pulse to pulse at 20 ns with a 700 mA peak current at 20°C (left), 35°C (center), and 50°C (right) (x-axis 5 ns/div, y-axis A.U.)

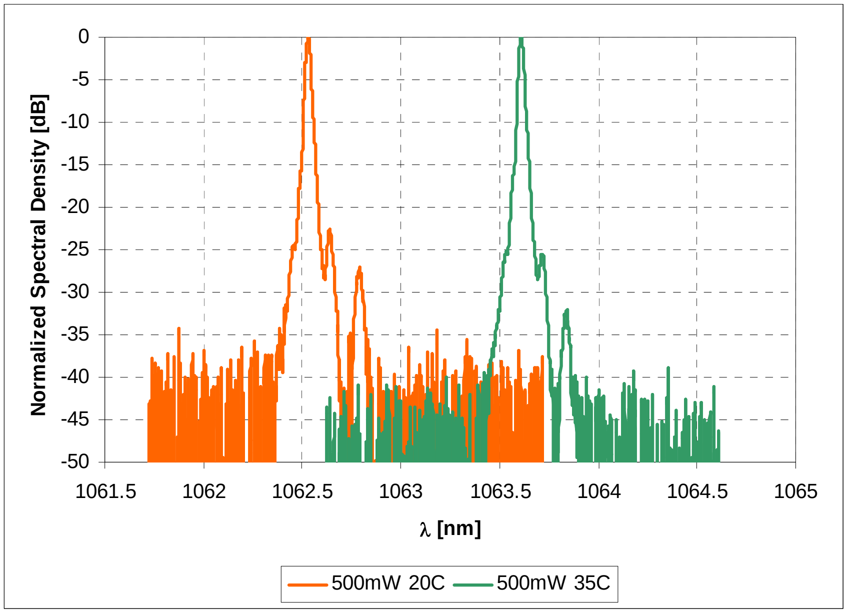


Figure 3.13. 1064 nm V75 DBR Laser optical spectrums in dB scale

For shorter pulses, the maximum usable peak current was increased significantly. For a 4 ns pulse, the peak usable current was extended to 850 mA or approximately 600 mW peak power. An interferogram at 4 ns for 850 mA peak drive current is shown in Figure 3.14, with the optical spectrum at the same operating conditions shown in Figure 3.15. Some devices have a little noise immediately following the gain switch peak, as seen in the interferogram in Figure 3.14. This noise is present in the optical pulse and stems from the process of the device finding equilibrium with the correct laser cavity mode after the gain switch peak. This noise is present immediately following the gain switch peak and typically subsides in less than 400 ps.

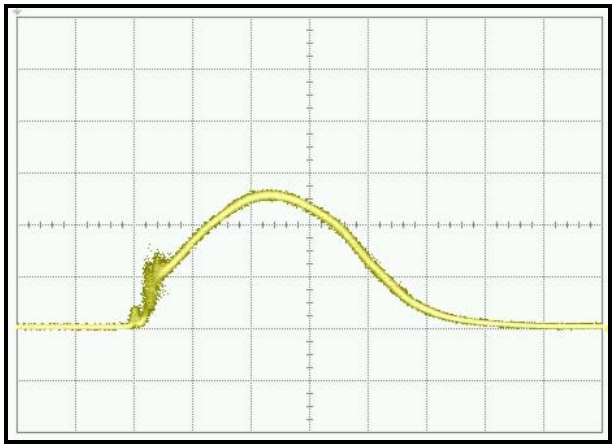


Figure 3.14. 1064 nm V75 DBR Laser interferogram for 4 ns pulse with 850 mA peak current at 35°C (x-axis 1 ns/div, y-axis A.U.)

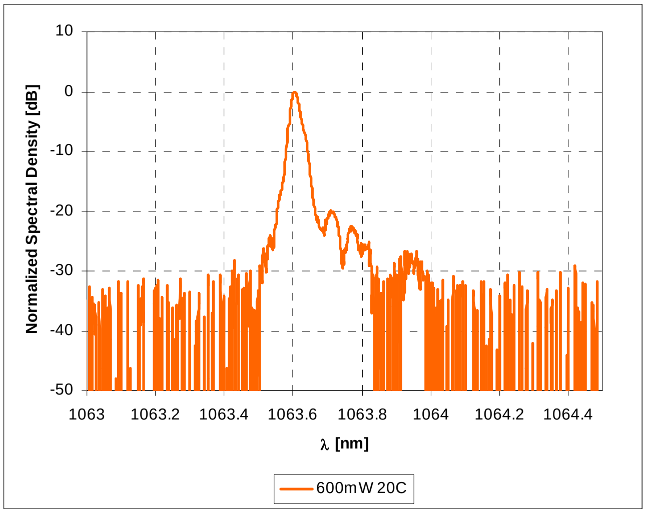


Figure 3.15. 1064 nm V75 DBR Laser optical spectrum in dB scale at 4 ns, 850 mA peak drive current, and 35°C.

3.5. Operating Notes for 4 ns to 50 ns Pulses

Due to the uniqueness of each laser diode manufactured, some devices may exhibit a secondary spectral mode at certain windows of operating temperatures and currents. This occurs due to the fact that the laser cavity can support more than one longitudinal mode. Photodigm's V75 DBR laser structure is designed to minimize the possibility of a second mode being supported. However, some devices may be able to operate at a primary longitudinal mode for most pulses and occasionally operate at a secondary mode for other pulses. This alternating longitudinal mode operation will only be an issue for applications that are particularly wavelength sensitive, such as second harmonic generation. This phenomenon can typically be remedied by operating the device at a temperature of approximately 20°C higher than the operating temperature at which the phenomenon occurs. The phenomenon may also be affected by the peak current as well, as some devices exhibit better operation past a minimum current level.

4. Pulsed Power Measurements

Pulsing of the laser diode can have advantages for certain applications in that higher peak powers can be obtained when pulsing than can be obtained under CW conditions due to reduced heating of the device. Laser diodes can typically produce several times more peak power than CW power as long as the duty cycle is not too high. Shown in Figure 4.1 (red curve) is the light-current characteristic curve for a Photodigm V100 1064 nm DBR laser for pulsed operation. Under CW conditions, this device began to rollover at approximately 400 mW optical output power operating at 600 mA injection current. As can be seen under 15 ns pulses at 10 kHz, this same device was able to achieve well over 1W before significant rollover occurred. It is advisable to not operate a device in the region were the device performance begins to rollover, as this rollover indicates either significant heating of the active region or added current leakage through another pathway. For the V100 device, the maximum operating peak current should be limited to approximately 2.5 A. However if good spectral stability is also required, the maximum operating current would be limited to before the onset of the optical pulse breakdown.

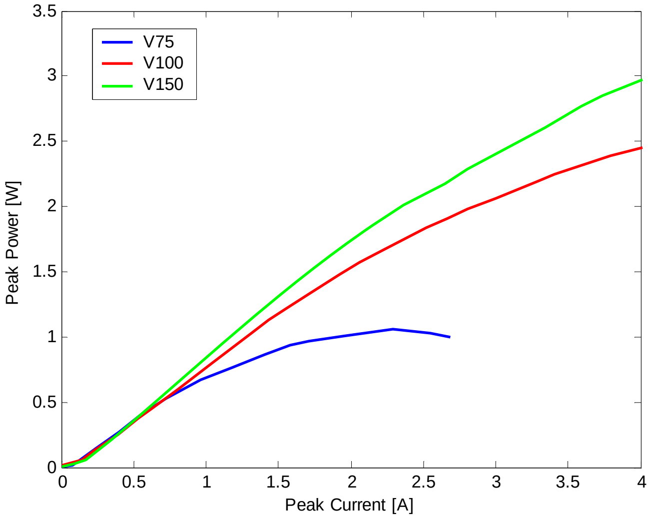


Figure 4.1. Photodigm 1064 nm DBR light-current characteristic curves for the V75, V100, and V150 versions under 15 ns pulses at 10 kHz

The point at which a specific device will begin to rollover is dependent on pulse width, peak current, and repetition rate. Care must be taken to ensure that the device is not driven too hard as this can seriously degrade the lifetime of the device or destroy it. For a specific pulse width and repetition rate, it is best to perform a light-current characteristic sweep and determine where the device light-current characteristic slope or slope efficiency degrades by 10-20%. The device should be operated at a peak current level lower than this point of slope degradation.

5. Recommendations

The device selected depends heavily on the requirements of the application. If a superior spectral performance is required for a gain-switching application, any Photodigm DBR laser will suffice; although, the V100 or V150 devices will yield a higher peak power if drive capability is available. If superior spectral performance is required for an application requiring pulses in the range of approximately 1 ns to 50 ns, a Photodigm DBR V75 laser is the device of choice. If raw power with some spectral stability is the need, the V150 is the correct device for the application.