APPLICATION NOTE

ILX Lightwave®
A Newport Corporation Brand

Pulsing a Laser Diode

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Introduction

Relatively high peak powers and efficient operation have made pulsed laser diodes ideal for applications such as solid-state laser pumping and range finding. These higher peak powers are made possible by the fact that pulsed laser diodes are usually operated at relatively low duty cycle, and therefore low average power. As a result, they do not generate significant heat. CW laser diodes, on the other hand, are designed to handle more heat than pulsed laser diodes. This follows from the fact that during continuous-wave operation, thermal resistance of the device causes the junction temperature to rise substantially. As such, CW laser diodes typically must be well mounted in a heat sink package and/or cooled thermo-electrically.

Pulsing a laser diode can be a powerful analytical tool for testing its quality and thermal efficiency. This article describes methods of testing laser diodes by driving them with a current pulse. It then presents several factors which can make pulsing a laser diode a frustrating experience, and suggests ways to overcome or avoid them. Also presented is a simple experiment in which an ILX Lightwave LDP-3811 pulsed current source is used to drive a typical laser diode. Here, the problems of pulsing a diode are dramatized. Lastly, typical applications of the LDP-3811 are described.

Why Pulse a CW Laser Diode?

The ability to pulse a CW laser diode at low-duty-cycles is very useful in diode evaluation. The applications fall into two broad areas. The first is prepackaged pass/fail testing; the second is device characterization. Both applications take advantage of the fact that driving a laser diode in a pulsed manner will not generate significant heat. Testing and characterization can then be accomplished

with minimal thermal effects.

Pre-package Testing

For this type of application, a low-duty-cycle pulse can be used for wafer or bar level testing after the semiconductor fabrication process. A single-point light measurement or L/I curve (light output vs. drive current) can be performed to "prescreen" wafers after processing. Defective wafers can then be eliminated prior to expensive dicing and packaging operations, and yield numbers and performance can be established for the fabrication process. (Note that for these tests, relative measurements are more important than absolute accuracy.)
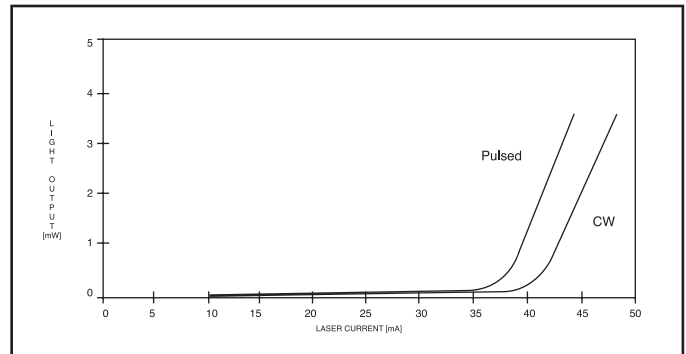

Figure 1: Pulsed and CW L/I curves of a typical laser diode.

Characterization Testing

A second area of pulse testing is characterization of packaged devices. Much of the industry documentation concerning laser diode characterization recommends pulsed as well as CW testing. (One such document is Technical Advisory TA-TSY-000983 entitled "Reliability Assurance Practices for Optoelectronic Devices" published by Bell Communications Research.) Temperature sensitive parameters such as output power, wavelength, and threshold current can be evaluated by comparing pulsed and CW operation. L/I curves of a typical laser

diode are shown in Figure 1.

These curves are shown for continuous wave operation as well as for low-duty-cycle pulsed mode. The increase in threshold current and slight decrease in slope efficiency of the CW curve (compared to the pulsed curve) is mainly a result of the rise in junction temperature due to thermal resistance of the device. (Pulsewidths used for pulsed L/I curves are typically 100 to 500ns, with a duty cycle of less than one percent; heating effects are therefore insignificant.)

A pulsed versus CW L/I curve can also be used to verify the quality of the thermal transfer of the die/package interface. By calculating the equivalent junction temperature rise under CW operation, temperature coefficients can be determined. This testing method is much faster than temperature cycling. Also, unusually large differences between the CW and pulsed L/I curves may indicate poor die attachment or a leaky junction, and are often a signal to poor laser quality.

For these testing applications, absolute accuracy is important. Since correlation to CW performance is required, the pulsed drive amplitude must be accurate. As with any testing application, repeatability is also very important.

Problems in Pulsing Laser Diodes

Pulse testing requires additional care to achieve accurate and repeatable results. With the increased speed comes additional noise (and time dependence) not encountered in CW test set-ups. The following paragraphs list areas of concern and offer recommendations which, if followed, will help achieve successful and safe laser diode testing.

Impedance Matching

When pulsing a laser diode at high speeds, normal transmission line effects become a concern. In order to achieve a rise time of, say, 10ns, the cable must have a bandwidth above 100MHZ. At these frequencies, transmission line theory is used to determine the performance of the system. (There are many books on transmission line theory. One is listed in Reference 1.) The basic consideration for proper transmission of high-speed pulses is to maintain a controlled impedance for the system. To maintain clean pulse waveforms at the laser diode or load, the cable to the diode must be properly terminated. If the impedance of parts of the system are different, loss of power output occurs due to reflections of the signal at the junctions. These reflections can create a standing-wave pattern on the transmission line, which manifests itself as ringing on the pulse. In this case, distortion and even damage to the laser can occur.

The output stage of the ILX Lightwave LDP-3811 current source was designed to drive a standard 50Ω transmission line. Because the LDP-3811 is a current source, reflections due to a load mismatch will not be absorbed by the source impedance, but will rather be re-reflected. This will cause a standing-wave pattern on the transmission line and pulse ringing will occur, as stated above. Since the dynamic impedance of a laser diode is typically much smaller than 50Ω, a matching network must be used. In it's simplest form this can be a resistor (in series with the diode) whose value is equal to the difference between 50Ω and the dynamic impedance of the diode. As a rule of thumb, a 47Ω resistor is a good starting value. (See "Dynamic Resistance" section below.) Additional matching may be required if the diode has a significant reactive component or if stray reactive elements are present. For judicious

matching, microwave Smithchart techniques are recommended. Both references 1 and 2 provide a good discussion of this topic.

Dynamic Resistance
The impedance of a laser diode is complex, but some simplifying assumptions can be made. By its nature, it is non-linear. Any matching will apply to specific conditions. During turn-on, a laser diode will exhibit high impedance, then change abruptly to a low impedance. This phenomenon has a tendency to cause aberrations during pulse rise time. It is the low impedance portion that must be matched to the transmission line. Typical values of "on" resistance (R_{on}) range from $1/2\Omega$ to 20Ω. The total load-matching impedance should be 50Ω, therefore a termination resistor with a value of ($50 - R_{on}$) ohms should be inserted in series with the cathode (coax center conductor) as stated above. The value of R_{on} can easily be determined with an I/V curve from a curve tracer or test system. Alternately, it can be determined by manually measuring two points above the voltage knee, where: $R_{on} = (V1-V2) / (I1-I2)$. Of course, for lasers that have a resistance that changes substantially with voltage, frequency, or temperature, there will be some degree of mismatch and aberration that will be very difficult to eliminate.

The power rating of the termination resistor should also be addressed. At full output, the LDP-3811 pulsed current source can deliver 12.5W, most of it going to the load-matching resistor. The power rating of this resistor must be adequate to handle the maximum current at the duty cycle that is expected to be delivered by the system. Also, the resistor should be low inductance, therefore a wire-wound resistor should not be used. For many applications with low threshold lasers, a small chip resistor (surface mount type) or metal film will provide excellent results.

Mounting / Fixturing
Two issues become important when considering the mounting of a laser diode which is to be pulsed. First, the impedance to the diode must be controlled. This is usually achieved by the use of a 50Ω transmission cable with relatively short leads. Secondly, the capacitance added to the diode must be minimized. This is especially important when considering the package capacitance, since the diode anode or cathode is often connected to the case. The LDP-3811 current source output holds the anode at a constant voltage. Hence, when the current is pulsed, the voltage waveform on the cathode is a square wave. If the cathode is connected to the case, (or worse yet, to the case, mount, optical table, and earth ground), then the parasitic capacitance between these structures will cause slow rise times and stray signal pickup, making repeatable results difficult.

To minimize this capacitance effect, it is desirable to have very little conductive surface connected electrically to the laser, typically on the order of a few square inches of metal in the mount. Of course, some configurations of laser connections are more sensitive to this than others.

In general, it is desirable to have a mount that provides:
1. Electrical isolation from the rest of the system
2. Careful transmission line termination with minimum inductance, (i.e. very short leads)
3. Good thermal coupling and/or control
4. Good positioning repeatability
5. Easy access to the device under test

Electrical and thermal isolation (in the case of thermo-electrically controlled mounts) are often addressed together by using plastic screws (or

metal screws with plastic shoulder washers) to hold the assembly together. When the cost can be justified, using a substrate made of Beryllium Oxide can provide insulation and thermal coupling in one material.

Power Supply Earth Capacitance

A good power supply will have a floating output. This means that the supply can be connected across a load with a potential different from that of earth. For DC voltage and current supplies, this is accomplished by isolating the internal circuit ground from earth ground. In a pulse supply, capacitive coupling from the circuit ground to earth ground (usually through the transformer windings) can cause degradation in the pulse output. This occurs when the circuit ground must move with respect to earth ground at the same rate as the pulse rise time. The stray capacitance of the transformer and chassis will degrade the pulse response. Test setup configuration can be modified to remedy this in most cases. (An isolation transformer on the power-line connection will usually help reduce these effects.)
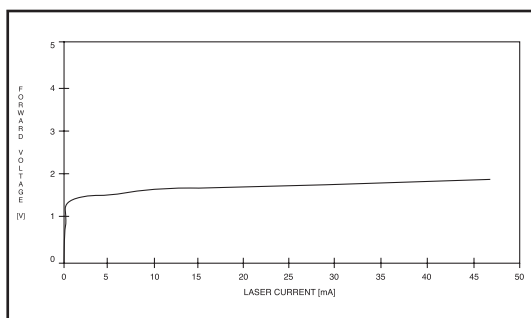

Figure 2: Typical laser voltage V/I curve.

Disadvantages of Voltage Pulsing

In laser diode test situations, it is a relatively common practice to pulse the diode with a voltage source, usually for no better reason than convenience. However, a laser diode is inherently a current dependent device, and should be driven as such. Figure 2 depicts a typical V/I curve for a laser diode. One can see that if the temperature of the device (and its V/I characteristics) change, large current fluctuations (and thus large changes in light output) can result, even if the voltage is held constant. Similarly, very small fluctuations in drive voltage would correspond to dramatic changes in current and output power. As such, it is much more difficult to achieve accurate pulsing with a voltage source.

If a voltage source is used to pulse the diode, empirical measurements will be required to determine the diode current. These measurements will need to be repeated for different types of diodes or if a large variation in dynamic impedance is expected. Voltage pulsing also has the disadvantage of a low impedance source. Most voltage sources have greater instantaneous current capability than current sources. This capability contributes more transient current to the load during pulsing. Current transients can be especially large if the circuit is disconnected, then reconnected while the output is on.

The advantages of driving a laser diode with the ILX Lightwave LDP-3811 current source include load-independent control, direct current measurement, transient protection, and lower overshoot and spikes which may damage the device.

Synchronized Data Acquisition

Making repeated measurements of a desired event, where one or more parameters are varied, can be very tedious and time consuming, especially when large quantities of synchronized data are required. Remote control of both the source and measurement instrumentation is useful for automating data collection. The ILX Lightwave LDP-3811 is unique in that it offers both GPIB control and Trigger In/Out functions. Using a GPIB interface, a host computer can send a command to an instrument (to deliver a

test signal), and then read source instrument-triggered events (measurements) from another remote device. For example, a simple system for generating pulsed and CW L/I curves would consist of an IBM or compatible PC with a GPIB Interface card, the LDP-3811 pulsed supply with GPIB, an ILX LDM-4407 diode mount, a calibrated detector and related signal processing electronics, and an HP 3457A multimeter.

The GPIB interface allows remote control of the pulse supply and other GPIB addressable instruments from a host computer at a distance of up to 20m away. A total of 15 devices can be connected together on the same GPIB interface bus. All front panel controls of the LDP-3811 are addressable through the interface, allowing for quick, easy, and flexible test set-up and control.

The Trigger In/Out functions allow synchronization of the source signal and measurement signal. For this purpose both trigger input and output connections are present. Both trigger signals are TTL level compatible. When in "EXT TRIG" mode, the diode pulse is triggered under external control from the "TRIG IN" port. This port is used to synchronize the pulse to the diode with an external event. The pulse width is set from the 3811. The "TRIG OUT" port is driven from the current source pulse. It is used to synchronize an external event to the laser drive pulse. This is helpful during high-speed light pulse measurements such as box-car integration, and sample-and-hold acquisition. Trigger In/Out delay and jitter are specified with respect to the current output pulse. This is important when setting up and calibrating your measurement system; these delays must be accounted for as well as the delay between the source pulse and the resulting light pulse.
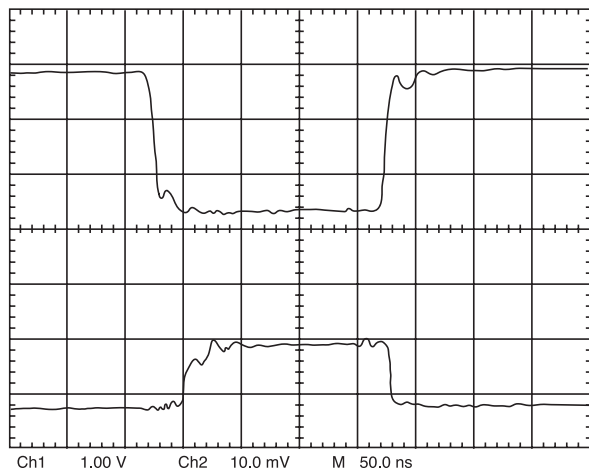
Experiments

The purpose of the following experiments is to show the effects of mismatch and stray reactance on pulse waveforms when driving a laser diode. For each test configuration, the diode pulse and resultant light output are recorded to show the change in pulse waveforms caused by modifications to the test setup. The light pulse response will amplify variations in drive current by the slope in L/I curve. The basic test setup used in these experiments is shown in Figure 3. The setup includes the ILX Lightwave LDP-3811 pulse current supply, a 50Ω transmission cable, a Mitsubishi 4405 laser diode, an ILX LDM-4412 temperature-controlled laser diode mount, and a Newport 875 high speed PIN photodetector. To illustrate some of the potential problems listed previously, modifications to the interface from the LDP-3811 to the laser were made, and the effects documented.
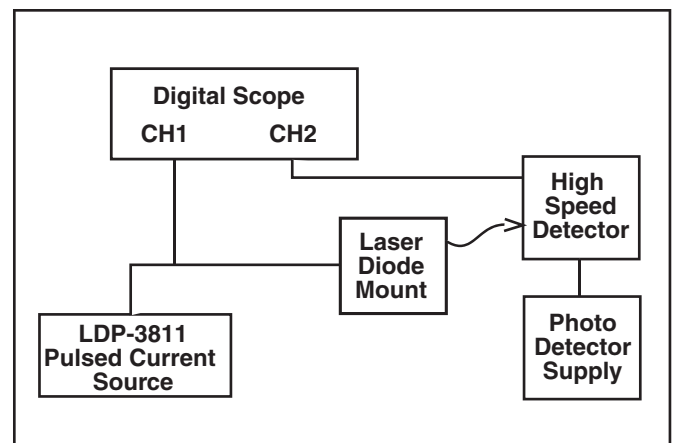

Figure 3: Experimental test setup. Instruments used in this test setup are: ILX LDP-3811 Pulsed Current Source, Tektronix Digital Scope, Newport High Speed Detector, and ILX Custom TO5 Laser Diode Mount.

Note that for all the following oscilloscope traces, the upper channel is channel 1, and channel 2 is the optical pulse.

**Figure 1A: 45 ohm load in series with laser diode (good load matching)**

Ch1 1.00 V   Ch2 10.0 mV   M 50.0 ns
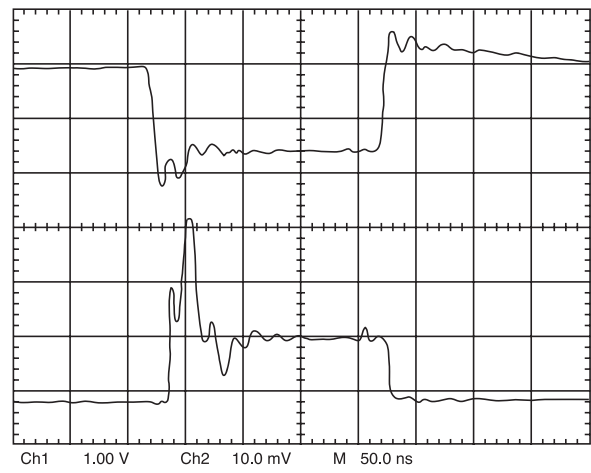
Figure 1B: 25 ohm load in series with laser diode (load mismatch)

Ch1 1.00 V   Ch2 10.0 mV   M 50.0 ns

Experiment 1: The first experiment shows the effect of load mismatch on the pulse waveform. Figure 1A shows the pulse response for a diode with a 45Ω series resistor. This provides a good impedance match at the load. Figure 1B shows the response if the 45Ω resistor is changed to 25Ω. This represent about a two-to-one mismatch. The mismatch resulted in a significant increase in input transient and additional ringing before the pulse settled.
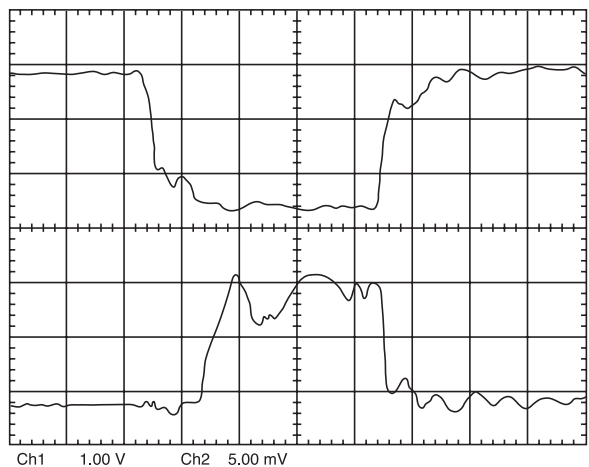

**Figure 2A: Cathode connected to mount (added capacitance)**

Ch1 1.00 V   Ch2 5.00 mV
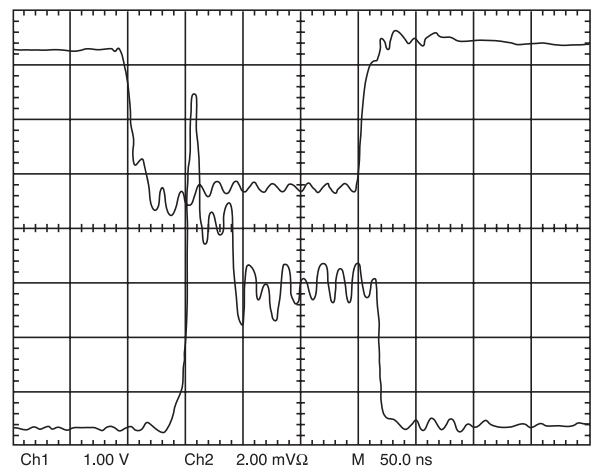
Figure 2B: 4" wire added to "good " cable (added inductance)

Ch1 1.00 V   Ch2 2.00 mVΩ   M 50.0 ns

Experiment 2: The second modification was to add stray reactive impedance to the load. Refer back to Figure 1A, which shows the standard response with a good load match (45Ω resistor). Figure 2A shows the effects of adding additional capacitive reactance. For this graph, the drive cable cathode was electrically connected to the optical table. Figure 2B shows the effect of increased inductive reactance. For this graph a 4-inch piece of 28 AWG wire was added to both the Anode and Cathode side of the 50Ω cable at the diode mount. The added inductive reactance causes increased current spikes. Significant ringing is also introduced as a result of mismatch.
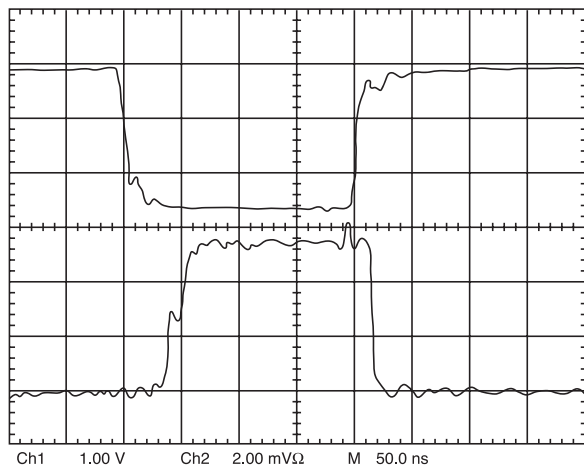
Figure 3A: 50 ohm load
**(45 ohm load in series with laser diode)**
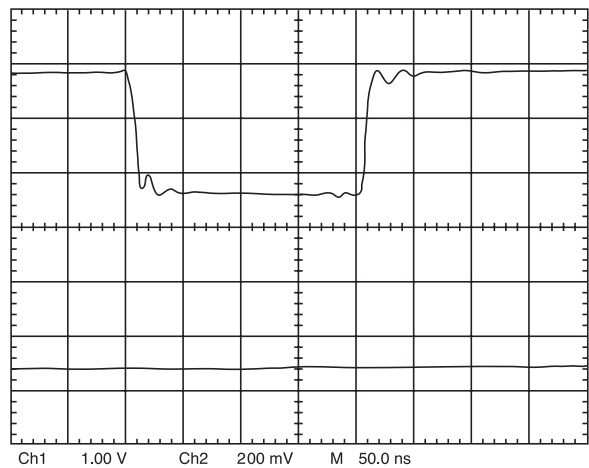
Figure 3B: 50 ohm resistive load only

Ch1   1.00 V   Ch2   2.00 mVΩ   M   50.0 ns

Ch1   1.00 V   Ch2   200 mV   M   50.0 ns

Experiment 3: To show the difference between a purely resistive load and that of a diode with nonlinear impedance, the two conditions were recorded. In Figure 3A, the diode with 45Ω resistor was used as a load. In Figure 3B, a 50Ω carbon resistor was used as the load. There is a small difference in the waveform, especially during turn-on.   This is where the diode goes through the largest impedance change. Since the turn on and dynamic impedance varies from diode to diode, those with significantly different drive waveforms than a 50Ω resistive load will require additional load matching elements.
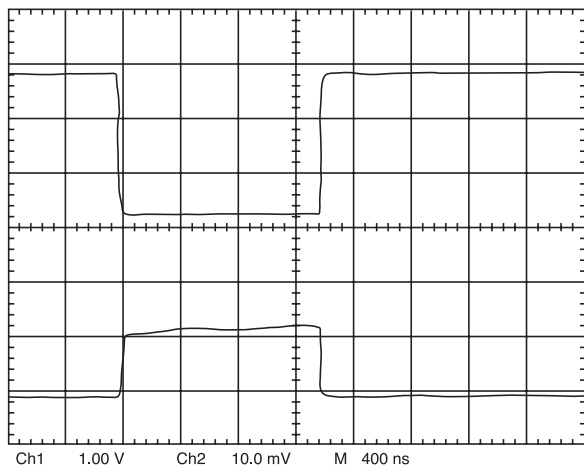

Figure 4A: Grounded anode
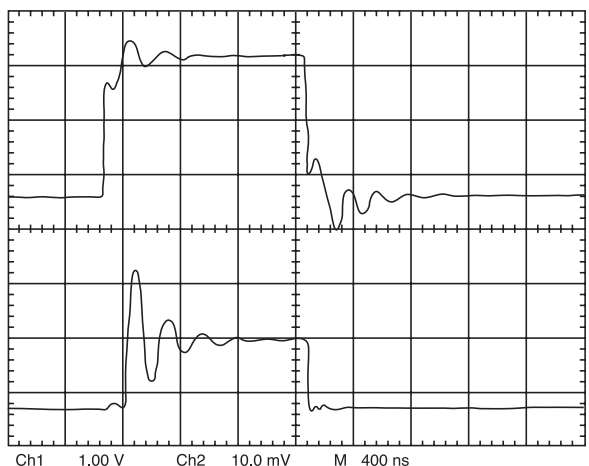
Figure 4B: Grounded cathode

Ch1   1.00 V   Ch2   10.0 mV   M   400 ns

Ch1   1.00 V   Ch2   10.0 mV   M   400 ns

Experiment 4: In this experiment, the effect of earth grounding the cathode was recorded. Figure 4A is the response for the standard configuration (with the diode anode earth grounded). Figure 4B is the response when the diode cathode is earth grounded. The ringing is due to the added capacitive reactance seen by the LDP-3811 output stage. The rise time is also significantly degraded because of added capacitive reactance.

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| Ch1 | 1.00 V | Ch2 | 2.00 mVΩ | M | 50.0 ns |
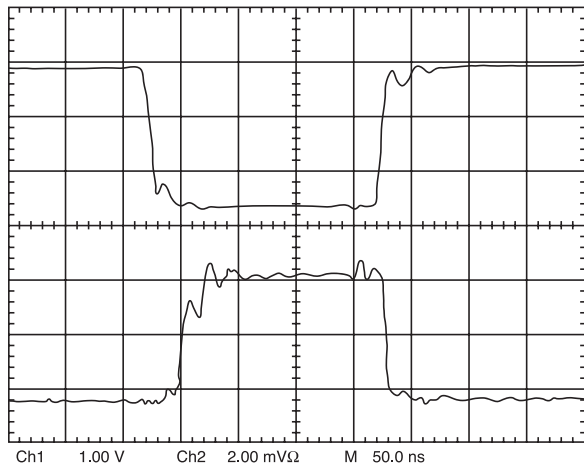
Figure 5A: Laser diode with LDP-3811 Pulsed Current Source

| Ch1 | 1.00 V | Ch2 | 2.00 mVΩ | M | 50.0 ns |
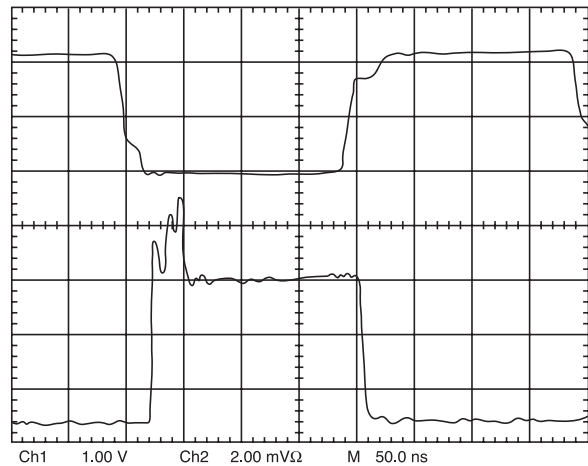
Figure 5B: Laser diode driven by a voltage source

Experiment 5: A fifth test involved comparing the difference between the LDP 3811 current source and a standard voltage-source pulse generator used to drive the laser. The diode with a 45Ω resistor was used as a load for both plots. Figure 5A shows the response using the LDP-3811 current source. To drive the diode with a voltage source at the same current, the required voltage amplitude was calculated. Figure 5B is the response for a voltage pulse. An increase in the turn-on transient, although not evident in the drive waveform, is clearly seen in the light output waveform. This is due to added surge current capacity of the voltage source.

Conclusions

The experiments described above were designed to demonstrate the effects of problems discussed in the beginning of this article. This information should act as a guide to avoid these common pitfalls of generating clean waveforms. Also, this article can be used as a reference to identify problems when irregular and distorted waveforms do show up in a test configuration.

Wide variations in device characteristics and packaging stray reactance require attention to detail when fast rise times are required. However, if care is taken to reduce stray capacitance and properly match load impedances, the ILX Lightwave LDP-3811 simplifies pulsed measurement, and makes it easy to take consistent and repeatable data in a host of applications.

Using the LDP-3811 Current Source

The LDP-3811 from ILX Lightwave is a microprocessor-based current source which is capable of operating in a precision pulsed mode as well as stable CW mode. In addition, the 3811 is unique in that it offers both GPIB control and Trigger In/Out functions. As such, the LDP-3811 is ideal for generating CW vs. pulsed L/I curves as mentioned above, especially since there is no need to switch current sources between tests, an operation which can be harmful to the laser diode (if care is not taken) and cause misleading results.

To acquire pulsed vs. CW L/I data, a host computer can be used to command the LDP-3811 to operate in both pulsed and CW modes (at any amplitude up to 500mA, and at some programmed step). In pulse

mode, the frequency and pulse width are also programmable. The host computer can also be programmed to read a multimeter or digital oscilloscope for 3811-triggered measurements of the diode power (at each programmed current step). A calibration chart for the detector can be stored in a file for access when converting detector voltage to light power. Through some additional programming, L/I curves can be generated for both CW and pulsed currents and displayed on screen or plotted on peripheral plotting device.

As mentioned above, the ILX Lightwave LDP-3811 enables the user to easily adjust pulse amplitude, pulse width (from 100ns to 1ms), and pulse repetition intervals from 1μs to greater than 1ms. This flexibility makes the LDP-3811 extremely useful as a design tool for the engineer who is trying to identify exact drive specifications for products that use laser diodes.

References
1. Rizzi, Peter A. Microwave Engineering. Prentice-Hall, Inc., 1988.
2. Vendelin, George D. Design of Amplifiers and Oscillators by the S-parameter Method. John Wiley & Sons, Inc., 1982.

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