Pulse Testing Of Laser Diodes

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Thermal management is critical during the testing of laser diodes at the semiconductor wafer, bar, and chip-on-carrier (submount) production stages. This has led to pulse testing of laser diodes to minimize power dissipation. Still, pulse mode testing requires careful selection and configuration of test equipment to avoid measurement errors and achieve the most cost-effective results.

L-I-V Testing

Basic Light intensity-Current-Voltage (L-I-V) testing is an I-V test with the addition of optical power measurements. This test is primarily used to sort laser diodes or weed out bad devices before they become part of an assembly. The device under test (DUT) is subjected to a current sweep while the forward voltage drop is recorded for each step in the sweep. Simultaneously, instrumentation is used to monitor the optical power output of the laser's front facet and rear facet. The resulting data is then analyzed to determine laser characteristics, including lasing threshold current, quantum efficiency, and "kink" detection (localized negative slope in the first derivative optical power output vs. injection current curve).

L-I-V characteristics are a function of laser temperature, which must be tightly controlled during the test, just as in normal operation. The principal reasons for performing low duty cycle pulsed L-I-V testing are thermal management, thermal response, and transient response. Typically, these issues arise because of the need to perform DC testing of laser diodes prior to mounting on a thermal management device, such as a heat sink or TEC (thermoelectric cooler - also called a Peltier device).

Vertical cavity surface emitting lasers (VCSELs) can be tested at the wafer stage prior to dicing because they radiate optical power perpendicular to the wafer plane. Although many VCSELs can be tested in non-pulse mode due to their high efficiency, higher power devices require pulse testing in the early stages of production. This avoids high thermal gradients that would induce mechanical stresses if non-pulse DC testing were performed.

The first opportunity to test an edge emitting laser diode is at the bar stage, where a linear array of diodes is cut from the wafer to expose the sides where light exits. After the wafer has been cut into bars, the edges of the bar are polished to form a suitable optical interface. The individual diodes on the bar then undergo L-I-V testing before further processing. The data from these tests are used to correlate optical performance characteristics, electrical characteristics, and semiconductor process information.

After a laser diode has passed the bar stage tests, it is diced into chips, which are mounted on sub-carriers. These are small metallic or ceramic mounts designed to ease handling of tiny laser chips during final assembly of the laser diode modules (LDMs) in which they are used. Chip-on-carrier or chip-on-submount testing is performed to ensure that performance characteristics have not changed during the dicing and mounting steps.

Thermal Effects

When a laser diode is properly mounted on a TEC and operated in an LDM, its temperature is maintained within ±0.005°C. During a typical uncooled, non-pulsed L-I-V test, self-heating affects electrical and optical performance of the laser. An internal temperature shift changes the forward voltage drop, dynamic resistance, quantum efficiency, and other characteristics. With short duration pulses (typically, <1µ and <1% duty cycle), the laser diode's average power dissipation has minimal thermal effects.

Nevertheless, it has been found that laser diodes with poor pulsed L-I-V performance may pass non-pulsed DC testing. These faulty devices often cause high bit error rates in LDMs used for fiber optic data communication systems. Another class of failures is characterized by good pulsed L-I-V characteristics while failing non-pulsed tests. Typically, these devices become optically unstable a few microseconds after lasing is initiated, accompanied by optical output dropping to a fraction of the expected power level. Therefore, comparing pulsed and non-pulsed L-I-V sweeps at appropriate production stages provides a better indication of DUT performance and the effectiveness of thermal management devices built into the LDM.

Pulse Parameters

The first challenge in an L-I-V pulse test is delivering constant current pulses with suitable magnitude, duration, duty cycle, and rise and fall times. To optimize kink detection, the difference in pulse characteristics between adjacent current steps in the L-I-V sweep must be as deterministic as possible. Two common methods of delivering current pulses are a pulsed constant current source coupled directly to the laser diode, and use of a pulsed constant voltage source driving a known resistance. The pulsed current source is the more deterministic of these two methods. By comparison, when applying a pulsed voltage source to a laser diode, the dynamic resistance of the laser must be considered. As current through the laser increases, the resistance decreases. When using a voltage source for an L-I-V sweep, compensating for this resistance shift greatly complicates delivery of known currents.

The maximum source signal amplitude for a pulsed L-I-V test typically exceeds the nominal operating current of the laser diode by a factor of two. The majority of telecommunications transmitter lasers are pulse tested up to several hundred milliamps while pump lasers for EDFAs (erbium doped fiber amplifiers) and Raman amplifiers may be tested up to 5A. The majority of pulse testing is performed with 500ns to 1μs pulse widths at a 0.1% duty cycle. These test conditions are driven by the desire to minimize the average power dissipation while keeping test duration as short as possible.

The rise and fall times of the high current pulses should be fast enough to preserve the flat time at the top of the current pulse. The sum of the rise time and the fall time should be less than 30% of the total pulse width to allow for signal settling time and flat time at the top. On the other hand, keeping the slew rate as low as possible reduces the high frequency spectral content, which helps reduce pulse transmission problems and settling time.

Reflection, Refraction, and Impedance Matching

When a ray of light passes between media of differing indices of refraction, reflections are likely to result. These reflections can result in constructive or destructive interference and may strongly affect the performance of the optics system. The index of refraction of a given media is the ratio of the speed of light through the media divided by the speed of light through a vacuum. Therefore, care must be taken to prevent the effects of unwanted reflection in an optoelectronics system. For instance, an antireflective coating, quarter-wave plate, or optical film with appropriate index of refraction, located between the two materials to be interfaced, improves coupling and reduces reflections. This type of refractive index matching is a routine design technique in a system of optical elements.

Similar considerations apply to electrical transmissions. The speed of an electromagnetic pulse through a material is a function of the material's impedance. As in the optical realm, a change in propagation speed as a signal passes between different materials or impedances will result in coupling loss and reflections. Here too, reflections can result in constructive or destructive interference; the resulting signal can exceed the desired level and impact system integrity. Again, steps must be taken to optimize signal coupling and minimize unwanted reflections. This is crucial in the application of high-speed pulses to laser diodes during testing; otherwise, erroneous results are obtained and laser damage can occur. Impedance matching transformers and circuits are the electrical transmission equivalents of refractive index matching devices. Such circuits are sometimes required to minimize pulse signal reflections and losses.

Pulse Delivery

Typical voltage pulse sources, as well as many current pulse sources, have a characteristic output impedance of 50 ohms. This is a good "match" for a standard 50-ohm coax cable, and ensures minimal signal distortion when a pulse is transmitted on such a cable that is terminated in a 50-ohm impedance. However, a typical laser diode has a characteristic impedance of about four ohms. Connecting a 50-ohm coax directly to the 4-ohm laser diode results in a severe impedance mismatch.

One way to reduce the mismatch is to place a resistor in series with the laser diode. The optimal resistance value is the transmission line impedance in ohms, less the laser diode characteristic impedance, or approximately 46 ohms. Unfortunately, this technique has a seriously negative side effect. To overcome the added resistive load, the pulse source must generate a voltage equal to the resistance of the load times the desired current. According to Ohm's Law, the voltage needed to overcome the 50O load and drive five amperes is 250V. This is not only a safety hazard to personnel, but also a hazard to fixturing and components. With this level of test voltage, imagine the results of poor electrical contact between the DUT probe and a laser chip. A 250V arc would be immediately followed by a 5A current flow. The laser diode is unlikely to survive this event and remain useful.

The most elegant method of avoiding this mismatch is to use a pulse source and transmission line with a characteristic impedance identical to that of the laser diode. When this is the case, the potential required to drive a 5A pulse through a 4O impedance is only 20V.

The distance that a pulse must travel also affects the quality of the signal at the laser diode. Just like a light pulse traveling through optical media, an electromagnetic pulse suffers dispersion or pulse lengthening. Any reflection from the transmission line termination travels back up the line and is either reflected again, or is absorbed by the drive circuit. If the drive circuit and laser diode generate reflections, the length of the transmission line strongly affects the settling time of the signal. A short cable helps reduce settling time and improve test throughput by reducing the time between reflections.

Confirming Pulse Integrity

For accurate test results, pulse integrity is essential. At first thought, it might seem reasonable to connect a scope probe across the laser diode to view the voltage signal shape and amplitude at the junction. However, this apparently simple test is fraught with potential problems. Before undertaking such a test, ask yourself: Can the oscilloscope ground be connected to the low potential lead of the laser diode without affecting the laser's pulse output? If not, can the scope ground be floated, or can the scope operate off batteries? Is the scope probe suitable for operating in the range of 500MHz to 1GHz?

All connections to a laser diode must be approached with caution. For example, what seems to be a harmless scope probe can drastically alter electrical characteristics by appearing as the transmission line equivalent of an unshielded, unterminated conductive stub. This changes the impedance at the probe connection, results in reflections from the unterminated stub, and can result in destructive undershoot.

Using a shunt resistor to monitor the current pulse is an acceptable technique, provided the resistance is a small fraction of the laser diode resistance, and the shunt resistor has low capacitance and inductance. A common wire wound resistor is not a good choice, as it would create a high impedance path for the high frequency components of the current pulse.

Capturing Pulsed Laser Optical Output

One of the most difficult tasks in DC pulse testing is capturing the pulsed optical output of the laser diode, particularly its peak values. The short duration optical pulse is not a friendly signal for most commercial optical power meters. Typically, optical power meters are designed for high precision measurements that often require many seconds of integration time to complete one reading. While it is possible to use these instruments, they require long integration periods that accumulate several thousand laser pulses. Then the firmware, or an external PC-based test program, must calculate peak optical power using the assumption that average power is a function of the duty cycle for the current pulse driving the laser. A further assumption is that the integral of the noise signal is zero.

Because of optical power meter deficiencies, test engineers have devised faster, more accurate methods for pulsed L-I-V testing. Historically, the most common method has utilized a combination of rack-mounted instruments, along with fairly complex, custom-designed software running on a PC controller. Besides the PC used for test sequencing and signal analysis, the equipment list for this second generation system includes a pulse source, optical measurement components (photodiode detectors, etc.), a pair of high-speed voltage-to-current converters, and a high-speed multichannel DSO (Digital Sampling Oscilloscope)

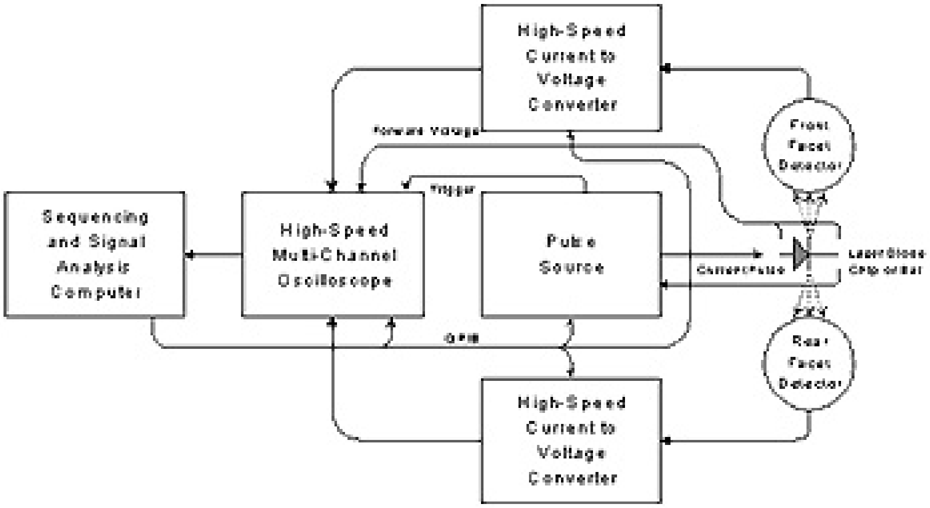

Figure 1. Second Generation Pulsed L-I-V Test System

A typical test sequence for a second generation pulsed L-I-V test system is as follows:

1. The oscilloscope is set for triggering by the pulse source's external trigger output.
2. The current-to-voltage converters are set to a suitable range based on I-V sweep values.
3. The pulse source is configured for the first current step (typically 0.25mA.)
4. The pulse source is triggered by the PC over the GPIB bus.
5. The oscilloscope captures the forward voltage drop and optical output of the laser diode.
6. The control computer downloads the waveforms from the oscilloscope via the GPIB.
7. The control computer then analyzes each trace to identify the flat portion of the pulse and calculates the corresponding value.
8. The pulse source is then reset to generate the next pulse in the sweep.
9. The oscilloscope is armed and the pulse source is triggered.
10. Steps 5 through 9 are repeated up to 2000 times per L-I-V sweep.

Some systems also incorporate "boxcar" averagers to help accelerate testing. By integrating a series of pulses of the same source magnitude, the boxcar averagers eliminate the need to analyze every individual pulse. An average of 100 pulses may be required to achieve adequate system resolution and accuracy. Averaging this many pulses may take less time than downloading scope traces over the GPIB bus and analyzing the waveforms with the PC. Sometimes, this throughput enhancement is obtained at the cost of less accurate data. For instance, a boxcar averager cannot discriminate between the desired signal and ringing at the top of the pulse waveform.

Test times for 500-point pulsed L-I-V sweeps typically range from tens of seconds to several minutes, depending on equipment configuration and data analysis methods. Such a system is limited to no more than 3000 tests per day, which assumes 100% uptime and state-of-the-art robotic component handling. Regular calibration, maintenance, and WIP (work-in-process) flow irregularities will likely reduce the actual throughput to about 85% of maximum, or 2500 parts per day.

The total cost of a production test system like that in Figure 1, including equipment purchases, custom software development, and system integration, is about $100,000.00 to $150,000.00. This cost can be doubled if the system includes robotic component handling.

A Faster, High-Accuracy Alternative

A few laser diodes and/or applications may be relatively insensitive to test system prices and operating costs. However, lasers used in fiber optic communication systems and optical data storage devices are sold in highly competitive markets. The production of these lasers would benefit from a lower cost alternative to the test systems just described.

A recently developed alternative for pulsed L-I-V testing is a class of instrument that includes all the instrumentation functionality shown in Figure 1. This type of instrument is essentially a pulsed source-measure unit with an output impedance and cabling that closely matches the impedance of the laser diode (Figure 2.) The measurement portion of the system incorporates multichannel data acquisition, dedicated timing circuitry, high-speed current-to-voltage converters, and a digital signal processor (DSP) that emulates DSO functionality and controls much of the measurement sequence.

Caption: Figure 2. Keithley Model 2520 Pulsed Laser Diode Test System

With this new solution, the sequencing of the L-I-V sweep is orchestrated by an internal DSP that is programmed only once via the GPIB bus for a given test sequence. Once programmed, the DSP can execute complete pulsed L-I-V sweeps without interaction with other equipment or the control computer. In fact, the instrument provides control signals directly to the component handling system via a digital I/O port.

By having the DSP as an integral part of the digitizing channels, fast analysis of captured pulse measurements are made without the time-consuming analysis sequence described earlier for the rack-and-stack system. In the second generation system, Steps 6 and 7 of a test sequence (described earlier) consume 10 to 20 seconds of test time per pulse. This consists of DSO trace downloading on the GPIB, pulse analysis with a test algorithm, and subsequent averaging of the samples over their flat time. The high-speed DSP in the latest system can accomplish these tasks in the off time between pulses. This results in a pulsed L-I-V test time of only a few seconds, and software complexity is greatly reduced.

Compare the test sequence for the rack-and-stack system to the following one for the new approach:

1. The new system is programmed with the pulse and sweep parameters.
2. The test is initiated.
3. The control computer receives an interrupt when the test is complete and data is downloaded via the GPIB bus.

With individual test times of only a few seconds, up to 15,000 devices per day can be tested, even with the assumption of only 85% system utilization due to WIP flow irregularities, maintenance, etc. Because the cost of the new system is a fraction of the older one, and has higher throughput, purchasing additional make-up capacity to reduce production planning uncertainties can be cost justified.

One design approach to this type of system is to include both pulsed and non-pulsed operating modes. This dual functionality allows both types of L-I-V sweeps to be performed on a single platform, using the same measurement channels. Comparing pulsed and non-pulsed test results provides more complete information on DUT performance. Also, the dual mode source can be located in a remote test head, which shortens the distance between the pulse source and the laser diode without having to physically locate the instrument at the laser test station. The shorter cable length reduces measurement settling time and helps improve accuracy.

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About the Author

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