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Photonic Test & Measurement Instrumentation

WhitePaper

Simplifying Parametric Analysis of Laser Diodes

L/I/V Analysis

L/I/V testing is universally regarded as the basic testing methodology for laser diodes, since many significant opto-electronic parameters can be measured or derived from the test results. Consequently, these are the most common tests performed during device development, production and implementation, as well as throughout the lifetime of the device.

In L/I/V testing, L refers to the laser diode output power, I refers to the laser diode current, and V refers to the voltage across the laser diode. A full suite of testing involves measuring how L and V vary as a function of I, and how these relationships are affected by device temperature. Of particular importance is the relationship between L and I.

Figure 1 shows a generic example of a typical L/I curve for an edge emitting laser diode. As the current is increased from zero, the device emits a low level of non-coherent light (LED radiation) that slowly increases until the threshold current (I_{TH}) is reached. The device then starts to emit intense coherent (laser) light, which increases linearly as the current increases.

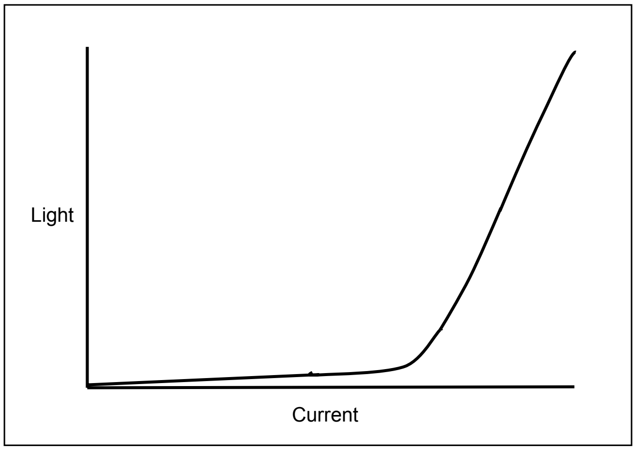

Figure 1
Generic Example of a Typical L/I Curve

Figure 2 shows how laser diode current varies with applied voltage in a typical I/V curve. As the voltage increases, no current flows until the voltage exceeds the small internal bias resulting from the p-n diode junction. As the voltage is further increased, the current increases nearly linearly

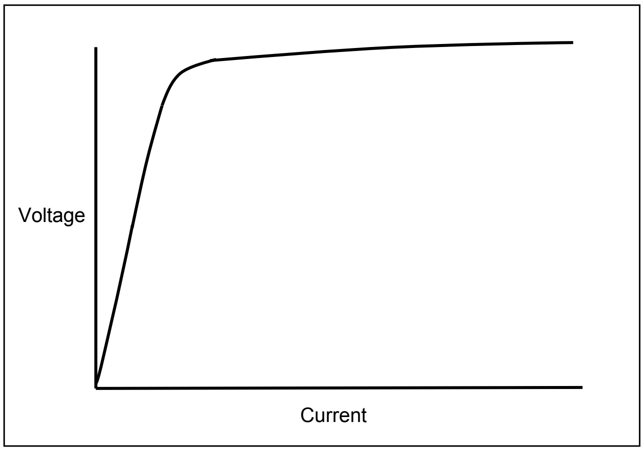

Figure 2 - Laser Diode Current Variation

Purpose of L/I/V Testing

There are a number of reasons to characterize a laser diode using L/I/V testing. In an R&D program, different doping schemes, device architectures and heat sinking methods may be investigated in order to yield improved devices. The ability to quantitatively characterize all aspects of device performance is critical in evaluating the efficacy of each modification. Only by quantitative evaluation is it possible to converge on a solution that delivers the desired performance without compromising other device parameters. For instance, consider the specific task of developing high power laser diodes for pump applications. In this type of development program, the L/I/V curves are used to determine:

- Differential efficiency of the chip (dL/dI)
- Kink-free power realized
- Heat-sinking efficacy (offset between pulsed and CW threshold)

L/I/V testing is just as important in pilot and volume production lines. This is particularly true for high-value laser diodes, such as those used in fiber optic systems. Source and pump laser diodes for these systems typically carry selling prices of hundreds or even thousands of dollars. With such high values, manufacturers must avoid adding value (and cost) to units that would not result in shippable product. Consequently, the purpose of L/I/V testing is two-fold - to identify and reject any units that would fail in the field, and to identify any statistical increase in reject parts that would indicate a production line problem.

Telcordia Test Requirements

To be used in telecom applications, devices must be tested according to stringent Telcordia protocols during all stages of development. In the case of laser diodes, these tests are defined by GR-468-CORE: "Special Procedures and Test Methods for Lasers." This extensive set of protocols defines performance tests for bare laser diodes, packaged devices, and laser diode modules. Much of this testing is based on detailed L/I/V analysis. However, once a device has reached volume production, most manufacturers test production units using a series of tests that constitute a subset of GR-468, based on their own (and their customers) experience of what is critically important. Typically, this is the minimum suite of tests that has been statistically proved to have the same efficacy in weeding out defective products.

The following is a partial list of the statistically important Telcordia tests that involve L/I/V analysis

Threshold current must be measured for every device and its value must fall within a pre-determined range for each device type. Threshold current measurement can thus be a simple pass/fail test. However, Telcordia also requires testing the temperature sensitivity of the threshold current. As the temperature of a laser diode increases, it inevitably takes more current to create lasing action. GR-468-CORE sets no specific value for the rate of change (dI_{TH}/dT), only that this rate must fall within a pass range guaranteed by the manufacturer.

The linearity of the L/I plot must also be verified. Above threshold, this plot should be linear over the normal working range for most laser diodes. Moreover, the slope must fall within a specified range for the particular device, and should be linear within a predetermined specification.

The L/I plot should also be verified to contain no kinks greater than a specified minimum value. Kinks or discontinuities in the L/I plot may be due to defects in the laser diode or abrupt changes in its output mode structure. In pump laser diodes, the value of the product is directly related to kink-free power, so knowledge of this parameter is critical.

With any laser diode, as the drive current increases, the output reaches saturation, i.e. a maximum value. This saturation limit may be a result of non-radiative recombination of charge carriers, current leakage through junction defects, or even device voltage breakdown. It is important to verify how far this saturation occurs beyond the normal specified working range of the particular laser diode type.

The I/V curve must also be carefully examined as part of Telcordia testing, and any unusual behavior of this curve should be noted. The voltage should be measured at several specified current levels, and must fall within a predetermined band (typically ±5%) of the "normal" value for that current. In particular the voltage at I_{TH} must fall within a predetermined tolerance. I/V testing is typically performed at various stages of fabrication and packaging. In each case the "before" and "after" measurements are compared to make sure that device performance is unaffected by these manufacturing.

Most packaged laser diodes and laser diode modules incorporate a monitor photodiode whose current is proportional to the laser output power. This is usually located at the back of the package where it measures the power output from the rear facet of the diode chip. It is important to verify that this is functioning correctly. In fact, Telcordia testing requires measuring the relationship between true output power and monitor signal, often called the front-to-rear tracking ratio. In addition, each device must also be tested for thermally induced tracking errors - how the tracking ratio changes with temperature. This requires L/I/V testing at several different operating temperatures over the laser diode's specified operating range.

In fiber-coupled devices, Telcordia testing also requires measurement of the coupling efficiency. This is the ratio of the raw output power from the laser diode chip and the amount of power exiting the other end of the fiber. This is accomplished by separate L/I/V testing at the chip on carrier (COC) and finished module stages.

Finally, since device temperature is so important to laser diode performance, the effectiveness of the temperature control must be verified. This includes measurement of the thermal impedance of the interface between the chip and its heat sink and/or mount. While this is not strictly a L/I/V test, it does require some of the same instrumentation and is often performed at the same time. One method is to test the bare diode - without heat sink - using a pulsed current source. After the diode is bonded to its heat sink both pulsed and CW tests are performed. The difference in I_{TH} between pulsed and CW operation provides critical information about the die bond quality.

Test System Requirements

In order to perform all these measurements, a test system must meet a number of important requirements. First and foremost, it must be able to operate a laser diode while

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simultaneously performing high resolution measurements of drive current, light output power and voltage, and monitor photodiode current. The system should also provide the means to control a laser diode's thermoelectric cooler and the ability to vary the operating temperature during testing.

In the volume production environment, every device must be tested. In order to minimize the cost impact of this testing, it is very advantageous to have a high speed test system that performs Telcordia tests in the minimum possible time. Moreover, the test system should be as automated as possible, in order to further reduce testing costs.

In addition, the test system must incorporate flexible software with the ability to carry out sophisticated multiparameter tests, such as determining the temperature sensitivity of I_{TH}. At the same time, the software should provide the means to log and analyze the test results in a format that can be readily exported for documentation. Finally, the software must be straightforward and intuitive in order to simplify the testing process and lower the training requirements.

System flexibility is also important, because laser diodes come in a wide variety of formats, sizes and electronics requirements. A test system must be able to handle all of these device types, including the unpackaged chip, chip on carrier, fiber pigatiled laser in a butterfly package, and so on.

The ILX Solution

The LPA-9080 Laser Diode Parameter Analyzer

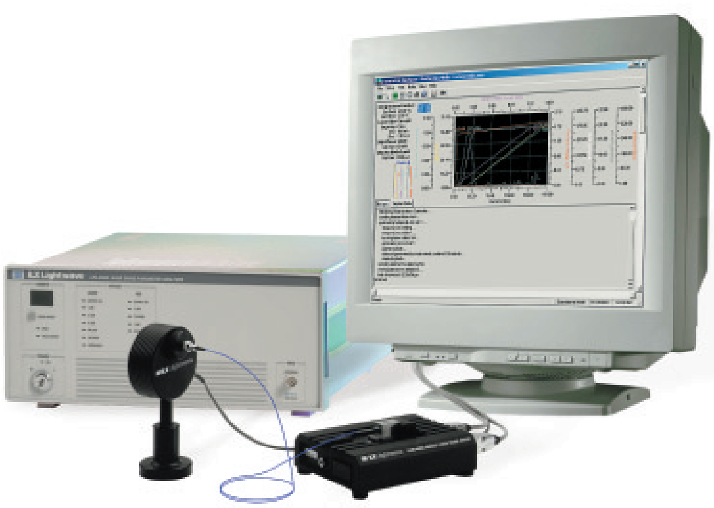

Figure 3
LPA-9080 Laser Diode Parameter Analyzer

All these needs are met by the LPA-9080 series of Laser Diode Parameter Analyzers from ILX, the industry's only "one box" instrument specifically designed for automated L/I/V testing of laser diodes. This is an integrated, PC-supported test platform, consisting of a single control unit and optional SPA-9000 software package. The single control unit interfaces to a PC through a standard GPIB connection, with no need to install special hardware in the computer. The LPA-9080 contains a high resolution, low-noise current source, a multi-range optical power meter, and a high output temperature controller. The entire system is optimized for high speed and is able to generate curves with 1000 individual data points in just a few seconds.

The current source provides high resolution and linearity for precision driving of a wide range of laser diodes. The design of this state-of-the-art current source draws on ILX's 16 years of experience in providing laser diode current drivers for demanding test applications. For example, the circuitry incorporates fast shut-off and adjustable compliance voltage to provide maximum protection of the laser diode. In addition, the current driver is optimized for extremely low noise and high absolute accuracy, enabling high current setpoint resolution. The current supply also supports external modulation input, allowing end users to perform highly customized L/I tests such as L/I kink diagnostics. Four different models are offered at this time, with a choice of current ranges up to 200 mA, 500 mA, 2 A and 4 A.

The integrated power meter offers similar standards in absolute accuracy while enabling high-speed measurements of laser output power. This power meter provides 12 separate gain ranges to allow the end user to utilize any ILX power measurement head and most third party photoconductive optical detectors. Since some applications require optical alignment of the diode to the power head, the power meter includes an analog output to support real time visual metering.

The LPA-9080 also incorporates a high performance temperature control unit, including a low-noise current source to drive Peltier (thermoelectric or TE) coolers and a feedback loop to accept inputs from all commonly used thermistor sensors. This means that device temperatures can be precisely controlled and varied using their integral TE cooler, and that bench mounted devices can be cooled using the mount's cooling unit.

When it comes to bench top mounting, ILX offers the industry's widest range of options. This includes mounts to hold all standard and custom diode configuration, including chip on mount, butterfly packages and generic TO cans.

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SPA-9000 Parametric Analysis Software

For ease of test integration and operational simplicity, there are no front panel controls on the LPA-9080. All control is entirely software-driven, via the unit's GPIB interface. While the goal of the LPA-9080 is to provide as much high quality L/I/V data as rapidly as possible, the goal of the SPA-9000 software package is to condense and analyze this data to provide critical information.

The SPA-9000 is an extremely flexible yet user friendly platform, allowing easy creation and storage of custom test protocols and analysis routines using the Visual Basic language. Raw and processed data, such as L/I curves and multiparameter pass/fail criteria can be instantly displayed on the computer screen (see Figure 4). Creation and/or modification of tests is very intuitive, using a sequential series of windows, which makes sure no selection criteria are accidentally overlooked during test creation.

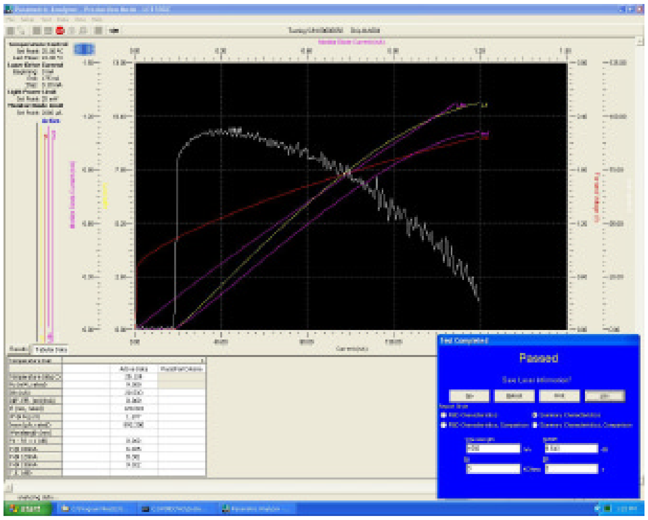

Figure 4 - SPA 9000 Screen Example

The software package is also designed to streamline I/V testing at all stages of fabrication and packaging. In particular, it enables rigorous "before" and "after" comparisons which simplify data analysis and also meets Telcordia specifications.

The data is stored in Microsoft Access® database format for easy export into statistical analysis/archiving databases. To meet the needs of production line operation with multiple operators, the software also includes three different levels of password protected software security to avoid inadvertent modification of important stored protocols.

The software also has a manual control screen - where the computer screen becomes a virtual instrument panel. This permits the LPA-9080 to be used as a conventional laser diode controller for "manual" runs and tests.

Test Example

Measuring Threshold Current Temperature Sensitivity

To understand the utility of the ILX Parametric Analyzer, it is useful to look at a typical example of how it can automatically perform L/I/V analysis in order to derive important characteristic information on a laser diode. The threshold current, I_{TH}, is a function of the temperature of the laser diode chip, increasing as operating temperature is increased. Figure 5 shows a typical plot of I_{TH} versus temperature (T). The rate of change dI_{TH}/dT in mA/°C is defined by

$$\text{Rate} = \{I_{TH}(T1) - I_{TH}(T2)\}/(T1 - T2)$$

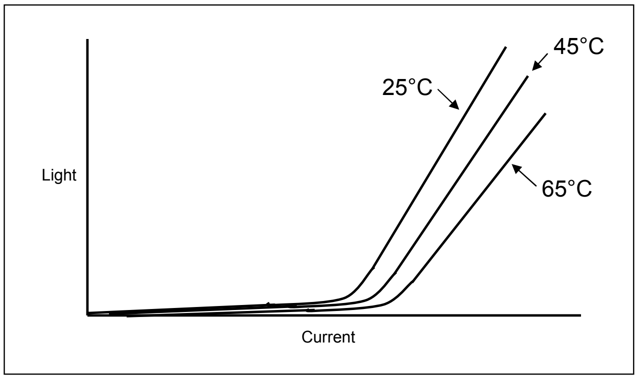

Figure 5 - I_{TH} vs. Temperature

The SPA-9000 software contains a routine to sequentially run L/I/V curves at several different temperatures, determine I_{TH} at each temperature, and then automatically use these values to determine the Rate of Change at each of these temperatures. The value of the Rate is one of the pass/fail criteria automatically built into the software. The test engineer sets the acceptable maximum value before testing commences, and the software analyzes the data to determine if the laser passes or fails.

This is but one example of the complex tests that can be automatically and quickly performed using built-in hardware/software functions, with no requirement for software programming by the operator, and no requirement for the operator to make manual adjustments/changes during the test.