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Combining Fiber Alignment and Device Characterization Helps Laser Diode Module Manufacturers Reduce Production Costs

Laser diode modules (LDMs) are crucial components of fiberoptic networks because they convert electrical voice and data signals into the light beams that are transmitted through the network's fiberoptic cables. To ensure the integrity of data transmitted through the fiber, a laser diode module must be operated under a very narrow set of conditions, and must be built and tested even more stringently. The need to remain competitive is a constant incentive for LDM manufacturers to find faster, more effective methods for producing and testing these devices.

LDM manufacturers are turning their attention to two areas of the process: fiber alignment phase and device characterization. Fiber alignment involves positioning the end of an optical fiber "pigtail" lead over the laser diode's emitting surface to achieve the most efficient collection and transmission of light from the diode, then the pigtail is mounted permanently. Device characterization involves a series of electrical and optical tests that allow the manufacturer to quantify the LDM's performance.

In a traditional production line, fiber alignment and device characterization are separate operations that may share little more than the use of an optical power sensor to measure LDM output. While fiber alignment is a mechanical assembly step that uses analog feedback to locate the best mounting point for the pigtail, characterization requires making a series of detailed light, current, and voltage (LIV) measurements on the finished product.

Conventional Automated Fiber Alignment

Before attempting to combine fiber alignment and LIV characterization, it's important to understand the scope of each operation.

Keithley Instruments, Inc.
28775 Aurora Road
Cleveland, Ohio 44139
(440) 248-0400
Fax: (440) 248-6168
www.keithley.com

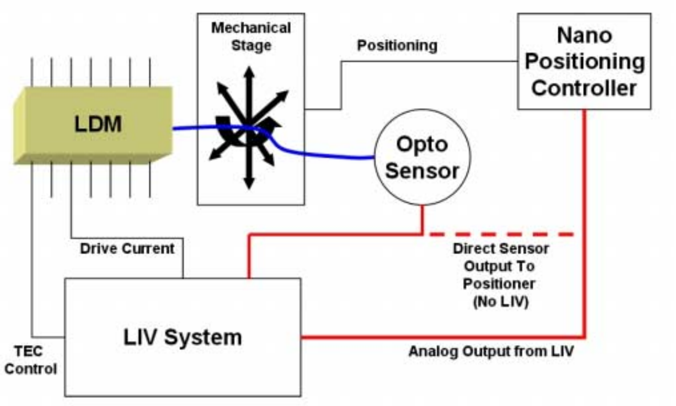

Figure 1. The simplest fiber alignment process drives the fiber positioning equipment directly from the optical sensor. By introducing optimized LIV instrumentation, high response speed and dynamic range can be maintained for the analog drive signal, while the system is available immediately for precise LIV characterization.

The physical region of the laser diode junction that emits light is microscopic, requiring alignment of the fiber to within 0.001mm (typical). The alignment process would take hours to perform manually. Fortunately, nano-positioning equipment that locates the best mounting point for the optical fiber can be used to automate alignment. The process is usually performed at a fixed LDM temperature, with the laser diode driven at maximum power output. A photodetector attached to the other end of the optical fiber pigtail supplies an analog signal that drives the positioning mechanism.

Once the beam is detected, the positioning equipment adjusts the pigtail position as light measurements are made. When the point of maximum brightness is located, the tip of the pigtail is mounted permanently to the laser diode. Much of the alignment process is spent searching for the edge or “skirt” of the beam. Using more sensitive measurement instrumentation and sensors allows faster detection of the laser beam skirt, speeding the alignment process.

LIV Testing

During LIV testing, the LDM is characterized at various drive current levels. Typically, these tests require transferring the LDM from the alignment stand to a computer-controlled test stand containing current and voltage sources, an instrument to power and control the thermoelectric cooler inside the LDM, one or more photodetectors or other sensors, and sensitive current measurement capability. These instruments are typically integrated into an LIV test system that generates plots of the relationship of light output (L), drive current (I), and voltage characteristics (V) of the LDM. Functional requirements of a typical LIV test system include:

- Precise current sourcing to drive the LDM laser diode.
- Ability to measure sub-picoamp currents (1pA = 10^{-12} amp) with femtoamp-level resolution (1fA = 0.001pA). Although test speed is important, measurement accuracy and precision are the overriding concerns.
- Precise control of the thermoelectric cooler (TEC) that regulates the operating temperature of the LDM. Temperature control to ±0.01°C is necessary to ensure consistent wavelength output from the LDM and protect the device from damage due to overheating.
- Ability to power a range of optical sensors, and to process sensor output to produce readings in the required engineering units.

Integrating Alignment and Characterization

In the past, it was difficult to find a way to combine fiber alignment and LIV testing because each process has significantly different priorities. Traditionally, the accuracy of fiber alignment has been a function of the mechanical precision of the nano-positioning mechanism. Alignment speed has been governed by the response of the sensor and circuitry used to drive the positioning mechanism. Therefore, at this stage, the response speed of the instrument is more important that the ability to make high resolution current measurements.

In contrast to the fiber alignment process, device characterization demands high accuracy and precision. These differing demands create a conflict when attempting to combine the two processes, which is one important reason they have not been integrated into one operation in the past. However, current generations of instruments offer the flexibility needed to perform high speed alignment, as well as precise characterization of LDMs. Specifically, these gains can be realized through:

- Availability of a wider dynamic measurement range during alignment
- Use of more sophisticated algorithms during alignment that are optimized for specific device types.
- Faster transition from alignment to characterization routines.

The Benefit of High Speed and Wide Dynamic Range

Beam alignment is a time-intensive operation. In fact, a major portion of alignment time is spent searching for the laser beam itself. ***Figure 1*** shows an integrated fiber alignment/LIV system in which the output of the optical detector enters a power meter in the

LIV system. This signal remains in the analog domain up to the point at which it is applied to the nano-positioning controller. The power meter should be fast enough to ensure the analog control portion of the loop doesn't create a bottleneck in mechanical control.

Typically, nano-positioning controllers operate from an input signal on the order of 0–2VDC, 0–10V, 4–20mA, or a similar standard loop architecture, and digitize the voltage internally to control the positioning mechanism. By selecting a wider drive voltage range (e.g., 0–10V) to drive the controller, the analog signal can provide ample low-level response to indicate detection of the beam skirt farther from the center of the beam. Another benefit of wide dynamic range is that it minimizes the need for range changes as the system converges on the optimum beam location. Range changes impose resets and additional settling time that can slow throughput.

Alignment Algorithms Optimized for Specific Applications

A "single point" fiberoptic alignment can be performed with the LDM at full power and at a single temperature. This scenario would be adequate if the LDM were always used under the same set of narrowly defined conditions. However, different laser diode applications can involve a broad range of operating conditions. Ideally, fiber alignment should be optimized through a series of measurements at different current levels and temperatures in order to provide a better approximation of the intended real-world LDM application. Physical effects that change optimum location include beam direction, beam profile, wavelength, polarization, back reflections, and LDM temperature.

A more advanced alignment method involves collecting enough information about the actual behavior of the laser over a range of operating conditions, then selecting an optimal mounting target based on the specific application and expected operating conditions for the device.

On-Board "Source Memory" Ensures Rapid Execution

Most modern test instruments offer a high degree of programmability, so they can be optimized for a variety of measurement applications through the use of software-selectable features. The General Purpose Interface Bus (GPIB) is the leading instrument control bus used to program instruments and retrieve data. While the GPIB is a moderately fast bus, it can take considerable time to transmit commands and data between the controlling computer and instrumentation. The use of an instrument's "source memory" is a relatively new development in the control of instrument systems. Source memory can be used to store several complete system test routines, which allow the instrument to control the entire test system autonomously after receiving an “execute” command from the computer.

In the case of alignment and characterization, both tests can be stored within the same instrument system—one setup optimized for high speed alignment, and the other for high precision device characterization—to allow completing both processes without compromising speed or precision.

Conclusion

By integrating more thorough testing capability into the instrumentation used to align the optical fiber pigtail within a laser diode module, a separate LIV characterization test fixture and set-up step can be eliminated from the LDM manufacturing process. The time potentially saved by combining these steps can vary widely from manufacturer to manufacturer. However, typical improvement over processes that use discrete steps for alignment and LIV testing can range from 2× to 10×. These changes in the manufacturing process can also produce LDMs that are more accurately optimized to the range of conditions found in a given real-world application.

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Keithley Instruments, Inc. 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168
1-888-KEITHLEY (534-8453) • www.keithley.com