REDUCING THE COST OF TEST IN LASER DIODE MANUFACTURING

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Today's optoelectronic component manufacturers face significant pressures to reduce price, shorten time to market, and respond quickly to specialized customer requirements. As product margins shrink, the cost of testing during the manufacturing process becomes a significant part of total manufacturing cost. To gain competitive advantage, manufacturers are seeking ways to minimize cost of test by reducing the initial cost of equipment, increase throughput, utilization and yield, and minimize engineering and other recurring costs. While many of the issues related to cost of test are common to all optoelectronic components, this article focuses on laser diodes in order to provide an interesting case example.

According to Strategies Unlimited[1], worldwide production of laser diodes will reach 606 million units in 2004. Production requirements for laser diodes range from very high volume production of simple low power devices used in CD and DVD players to much lower volume production of high power lasers used in material processing. Laser diodes and many other optoelectronic components are more costly to test than the mature active components of the electronics industry due to the combined optical and electrical nature of the devices.

A flow chart for a typical TO-can laser diode packaging and test production line is shown in Figure 1. Wafers enter at the upper left-hand side of the diagram and undergo various processing and test steps before ending up as finished product. Typical electro-optical tests are summarized in Table 1.

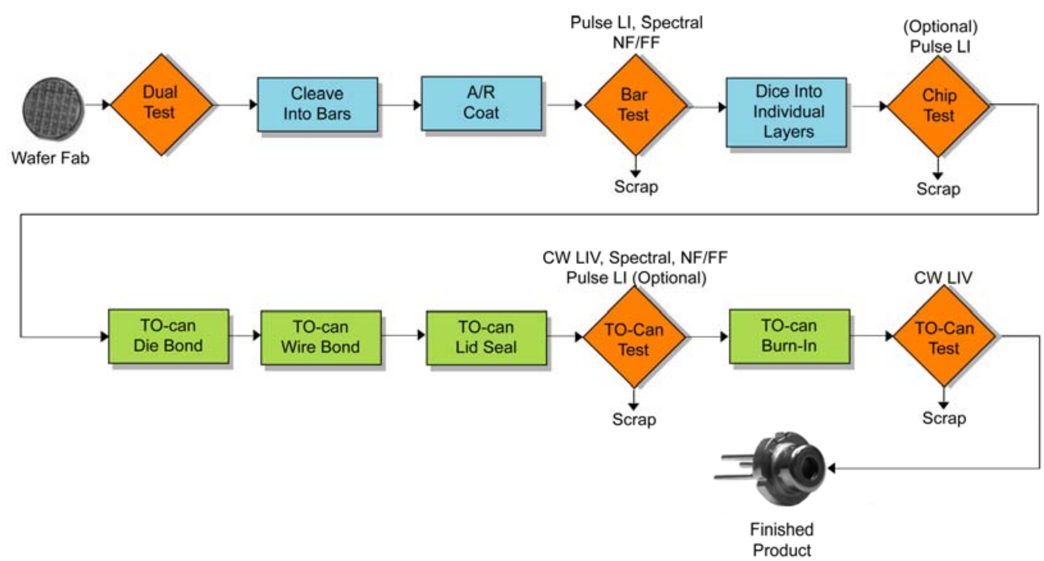

Figure 1. Typical Laser Diode TO-can Packaging Line

Abbreviation	Description
LIV	**L-I-V Test**. Characterization of light output (L) and voltage (V) of the laser vs forward current (I). If the laser has an integral monitor photodiode, then photodiode current is also measured vs laser current.
Pulsed LIV	**Pulsed L-I-V Test.** LIV test performed in pulse mode to avoid self heating of the laser. Chip tests are normally performed in pulse mode.
FF	**Far-Field Test.** Measurement of the optical output of the laser diode as a function of beam angle.
NF	**Near-Field Test.** Measurement of the optical power density distribution across the output facet of the laser diode.
Spectral	**Spectral Test.** Measurement of the optical output spectrum of the laser diode.

Table 1. Typical Laser Diode Tests.

Defining the Cost of Test

Before examining ways to reduce the cost of test, it is necessary to define the major components, which can be broken down into fixed and recurring costs factored by yield, utilization, and throughput, as shown in the following Equation 1.

$$\text{Cost of Test} = \left[\frac{\text{Fixed Cost / Lifetime}}{\text{Utilization x Throughput}} + \text{Recurring Costs)} \right] / \text{Yield} \qquad [1]$$

$$= \frac{\text{Total Costs (\$)}}{\text{Good Part}} \qquad [2]$$

When combined, these components allow us to calculate the total cost of test required to produce a known good part at each test step.

Fixed costs normally include the capital cost of the test equipment amortized over its useful life. Fixed costs should include the cost of engineering required to design and develop test systems that are built in house. Engineering costs can be high for unique components for which no standard test equipment exists. These costs should also be included and amortized over the useful life of the test system.

Recurring costs include ongoing expenses required to support the test process during manufacturing:

- Production labor and associated supervision
- Engineering costs to maintain the test system
- Facility costs such as floor space and utilities
- Consumable items
- Repair, maintenance, and periodic calibration

Laser diode manufacturing tends to be relatively labor intensive and manufacturers are constantly seeking ways to optimize the cost trade-off between fixed cost capital investments required for higher levels of automation and a strategy to lower recurring labor costs.

Yield is the number of good parts at the output of an individual test process divided by the total number of parts tested. Utilization is the percentage of time that the test equipment is in use. Maximum utilization occurs when test equipment is used continuously 24/7 and decreases when test equipment requires frequent repair or maintenance.

Throughput is the number of devices tested per unit of time. Test throughput rates for optoelectronic components are often low due to the manual handling that is often required in many of the processing steps. The burn-in process step in laser diode manufacturing shown in Figure 1 imposes a particularly low throughput due to the fact that each device requires a burn-in period of 10 to 40 hours.

The cost of test shown in Equation 1 includes only the costs associated with the manufacturing process itself after the part has been released to manufacturing. Other significant test costs are associated with reliability testing and lost opportunity costs resulting from time-to-market. In the case of laser diodes used in telecommunication applications, these costs can be particularly high due to competitive pressures, the rapid evolution of the technology, and the frequent requirement for part qualification to meet standards such as GR-468[2] or GR-3013[3]. For example, GR-468 requires long-term aging tests of 2,000 to 5,000 hours (2.8 to 6.9 months), creating a significant time-to-market factor for new devices.

Strategies for Reducing Cost of Test

Cost of test can be reduced by working on any of the terms in Equation 1. However, achieving lowest cost of test requires careful attention to all of the terms.

Strategy #1 - Reducing Test System Capital Cost

The initial cost of the test system is perhaps the most visible element of the cost of test equation. While it is important to minimize the initial cost of this equipment, it is equally important to consider the cost of internal engineering support required to design, debug, and qualify the final test system, especially if a high percentage of the final system is designed and built in-house. In the final analysis, it is often more cost effective to purchase a vendor supplied system for $100,000 rather than build a system in-house that incorporates $50,000 worth of equipment but also requires a substantial engineering effort to design the hardware and software, procure the parts, and then assemble and debug the system.

Moreover, internal test system development time can also create a significant impact on time-to-market. In the end, all optoelectronic component manufacturers must have some in-house test engineering capability, and the optimum balance between test system outsourcing versus design/build in-house must be analyzed for each test process.

Test system lifetime is just as important as the initial cost. Usually, the most significant factors affecting test system lifetime are the flexibility of the system to accommodate new package styles and test parameters and the long-term commitment of the test system vendor to the products. In order to maximize lifetime, choose a vendor with a history of success in optoelectronic test systems and a long-term commitment to the business area.

Strategy #2 - Increase Throughput

Test throughput is calculated by dividing the total number of parts tested by the time required to test them. Factors that impact throughput include handling time, temperature settling time, and the time required for the actual functional test. A practical example is provided by a final test process for a TO-can laser intended for telecommunications applications. Surprisingly, many of these tests are still done manually, one device at a time. In many cases, these lasers are only tested at ambient, clean-room temperature, eliminating the need for temperature control. However, in some cases, tests at -20°C, 25°C, and 75°C are required, and this latter last case will be used to illustrate ways to improve throughput.

In the simplest case, devices are manually loaded and tested one device at a time. In this case, the throughput is approximately 30 devices per hour based on the itemized times shown in Table 2.

	Manual Load, Single Test Head	Tray-Based, Automated Test
Number of devices tested per load	1	100
System wait time while loading	0.2 min	0.2 min
Total temperature settling time per load	1.5 min	2.0 min
Functional test time (3 tests)	0.3 min	18.0 min
Throughput	30 per hour	297 per hour

Table 2. Throughput Examples for Manual and Semi-Automated TO-Can Laser Diode Test

Not surprisingly, an improvement of almost ten times in throughput can be achieved by testing the lasers in batches and using a relatively simple level of automation. In this case, devices are loaded 100 devices at a time into a tray that is then temperature controlled as a lot. Laser drive current is applied through a relay matrix sequentially to one device after another while an optical power meter head is moved from one device to the next using x-y robotics. System wait time for loading is almost eliminated by loading a new fixture with lasers while the test is in progress. In this case, load time is reduced to the time required to remove the fixture of tested lasers and insert the new fixture. A similar analysis for ambient temperature testing only shows a three times improvement in throughput. Batch processing also integrates well with the burn-in step shown in Figure 1 in which lasers are also processed in batches.

A comparison of these two examples illustrates three general rules for improving throughput:

- Test in batches whenever possible
- Minimize temperature settling time
- Minimize functional test time
- Use automation when economically justified

Strategy #3 - Maximize Utilization

Utilization is the fraction of time that the test system is in use. Highest utilization rates are achieved by operating a test system 24 hours a day, seven days per week with little down time for repair or maintenance. While 24/7 operation is not always practical, some tests can be run unattended to extend the operation time beyond an eight-hour day. In laser diode manufacturing, this is common with burn-in systems where burn-in periods are frequently 10 to 40 hours. The benefit of 24/7 operation is highest when capital equipment and other fixed costs are high compared to the cost of labor.

Utilization is also impacted by system reliability and ease of calibration and maintenance. When selecting a test system vendor, look for a track record of product reliability, modular system design, and responsive after-sales support. Even the most reliable equipment will eventually fail, so you should also consider maintaining spares for critical system components. Finally, when purchasing or designing a system, consider the time and process required to periodically calibrate the system.

Strategy #4 - Reduce Recurring Costs

Generally labor is the largest recurring cost in the cost of test equation for laser diodes. Labor costs can be minimized by implementing higher levels of batch processing and automation, ensuring that tests can be performed by minimally skilled labor, and locating the operation in an area with a low cost of labor. Batch processing and automation require increased capital equipment investment as discussed above, and this investment must be balanced against labor costs. A $250,000 investment in automation may not pay off for a test system that is operated on a 40-hour per week schedule and has a projected life time of four years. The amortized cost of this equipment, excluding maintenance, is just over $30 per hour, which could pay for the services of two to eight people, depending on location. In order to minimize skill requirements, test processes should be designed with simple process steps or software automation that includes a simple user interface and pass/fail indication.

Labor rates vary considerably around the world. Table 3 shows typical labor rates for a laser diode manufacturing test operator (including benefit costs) in Europe, the US, and China. Clearly, the low labor rates available in Asia can be a source of competitive advantage in the cost of test equation.

Location	Average Hourly Labor Cost
Germany, Switzerland	$ 28.00
United States	$ 15.00
China	$ 1.00

Table 3. Typical Production Test Labor Rates Including Benefits, Converted to US Dollars

Strategy #5 - Reducing the Cost of Test Engineering

Test engineering is required to both set up and maintain a test process. These costs can be minimized by selecting equipment that provides a high degree of built in analysis but can also be easily modified as requirements change. Generally, there is an advantage in implementing unique analysis steps with commonly available and well understood software tools such as Excel or Visual Basic. Vendor-supplied software should be well supported and offer tools for exporting data to Excel or Visual Basic for user-developed analysis algorithms.

Conclusion

Cost of test is a significant part of the overall cost of producing optoelectronic components. When the elements of the cost of test equation are well understood, strategies for reducing cost can be developed.

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About the Author

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