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Lowering the Cost of Test

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APPROACHING TEST STRATEGICALLY CAN PROVIDE ECONOMIC BENEFITS.

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 seek ways to minimize the cost of test by reducing the initial equipment cost; increasing throughput, utilization, and yield; and minimizing engineering and other recurring costs.

Consider diode-laser testing as an example. Each of the test steps during manufacturing contributes to the overall cost of test (see figure). Diode-laser manufacturing tends to be relatively labor intensive. Manufacturers work to optimize the cost tradeoff between increased fixed-cost capital investments required for higher levels of automation and various strategies to lower recurring labor costs through efficiency gains or moving production to areas with lower labor costs. Usually, manufacturers choose a mix between the two alternatives—some investment in simple automation, and some process simplification and pursuit of lower cost of labor.

Before examining ways to reduce the cost of test, let's define the major components, which can be broken down into fixed and recurring costs factored by yield, utilization, and throughput:

$$\text{cost of test} = \left[\frac{\text{fixed costs/lifetime}}{\text{utilization} \times \text{throughput}} + \text{recurring costs}\right] / \text{yield}$$

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. Such costs should include the price of the 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, so they should be included.

Recurring costs include ongoing expenses like production, labor, and associated supervision that are required to support the test process during manufacturing; engineering costs to maintain the test system; facilities costs such as floor space and utilities; consumable items; and repair, maintenance, and calibration.

We define yield as 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 for continuous use of test equipment 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 required in many of the processing steps.

The cost-of-test equation includes only those costs associated with the manufacturing process after the part has been released to manufacturing. Other significant test expenses are associated with reliability testing and test-process development, which increase time-to-market and result in lost opportunity cost. In the case of diode lasers used for telecommunication applications, these numbers can be particularly high due to competitive pressures, the rapid evolution of the technology, and the frequent requirement that parts qualification meet standards like the Bellcore/Telcordia standards GRE-468 or GRE-3013.[1–2] The GRE-468, for example, requires long-term aging tests of 2000 to 5000 hours (2.8 to 6.9 months), creating a significant time-to-market barrier for new devices.

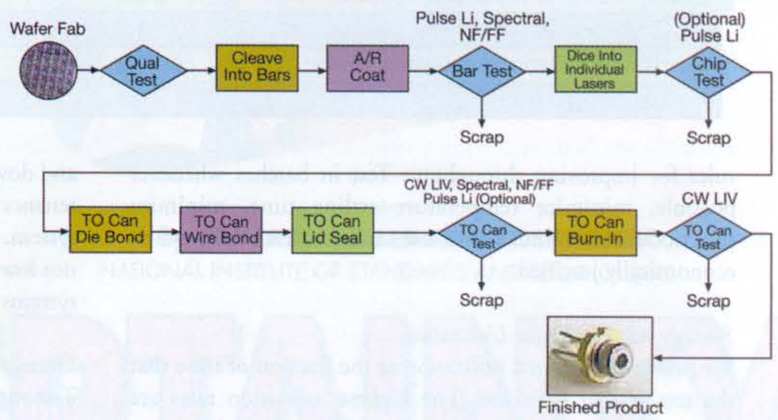
Reduction Strategies

We can reduce the cost of test by addressing any one of the terms in the equation. Truly minimizing cost of test, however, requires careful attention to all of the terms. Let's take a look at each, in turn.

Strategy #1: Reduce Test System Capital Cost

The initial cost of the test system is perhaps the most visible element of the equation. Although it is important to minimize this figure, it is equally important to consider the cost of the 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. Purchasing a vendor-supplied system often provides a more economical solution than building an in-house system. Consider a vendor system priced at $100,000. Perhaps an in-house system would incorporate only $50,000 worth of equipment, but it would also require engineering man hours to design the hardware and software, procure the parts, assemble the system, and debug it. The time required for this internal test-system development significantly impacts time-to-market for the product.

Test-system lifetime is another important consideration. The most significant factors affecting lifetime usually are the flexibility of the system to accommodate new package styles and test parameters, and the long-term commitment of the system vendor to the products. In order to maximize lifetime, choose a committed vendor that has a history of success in your specific area of interest.



A typical packaging line for a diode laser TO-can features several test steps that offer opportunities for increased efficiency.

Strategy #2: Increase Throughput

We calculate test throughput 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. As a practical example, consider a final test process for a TO-can laser intended for telecommunications applications. Surprisingly, technicians still perform many of these tests manually, one device at a time. In many cases, these lasers are only tested at ambient clean-room temperatures, eliminating the need for thermal control. Some cases require tests at -20°C, 25°C, and 75°C; we will use this latter case to illustrate ways to improve throughput.

In the simplest case, devices are manually loaded and tested one by one, yielding a throughput of approximately 30 devices per hour (see table). Not surprisingly, we can achieve a factor-of-10 improvement in throughput by testing the lasers in batches and using a relatively simple level of automation. In this case, devices are loaded 100 at a time into a tray that is temperature controlled as a lot. A relay matrix applies laser drive current sequentially to one device after another, while x-y robotics move an optical-power-meter head from one device to the next. System wait time for loading is almost eliminated by filling a new fixture with lasers while the test is in progress. This approach reduces load time to the time required to remove the fixture of tested lasers and insert the new fixture.

It is important to note that test conditions control the benefits to be gained by this approach. A similar analysis for ambient-temperature testing shows only a factor-of-three improvement in throughput. Batch processing also integrates well with the burn-in step (see figure), in which lasers are likewise processed in batches.

A comparison of these two examples illustrates the general rules for improving throughput: Test in batches whenever possible, minimize temperature-settling time, minimize functional test time, and use automation only when economically justified.

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

Strategy #3: Maximize Utilization

We previously defined utilization as the fraction of time that the test system is in use. The highest utilization rates are achieved by operating a test system 24 hours per day, seven days per week with little downtime for repair or maintenance. Although 24/7 operation is not always practical, some tests can be run unattended to extend the operation time beyond an eight hour day. In diode laser manufacturing, the latter approach is common for systems with required burn-in periods of 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 positive track record in product reliability, modular system design, and responsive post-purchase 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 for periodic calibration.

Strategy #4: Reduce Recurring Costs

For diode lasers, labor is generally the largest recurring cost in the cost-of-test equation. You can minimize labor costs 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 low labor costs. Labor rates vary considerably around the world. Clearly, the low labor rates available in Asia can be a source of competitive advantage in the cost-of-test equation.

Batch processing and automation require increased capital equipment investment as discussed above; 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 with a projected four-year lifetime. In this example, 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, design test processes with simple steps or software automation that includes an easy user interface and pass/fail indication.

Recurring costs associated with floor-space requirements, utilities, calibration, and maintenance also add to the overall cost of test. Floor space is particularly expensive when located in a clean room; therefore, compact test systems are often desirable. In addition, the cost and downtime associated with periodic calibration and maintenance should also be considered when selecting a test system. Maintenance contracts generally reduce risk but do not lower calibration and maintenance costs. Self-calibrating systems are comparatively rare.

Strategy #5: Reduce Test-Engineering Costs

Test engineering is required to both set up and maintain a test process. You can minimize these costs by selecting equipment that provides a high degree of built-in analysis. It is important to retain flexibility, however, so that you can address future requirements as projects progress or new projects come online. 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 software tools for user-developed analysis algorithms.

Cost of test makes a significant contribution to the overall cost of production, and not just in the case of optoelectronic components. By taking time to understand the tradeoffs, you can optimize your system and approach to your particular manufacturing requirements. **oe**

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References

1. *GRE-468-CORE, Bellcore (now available from Tellcordia Technologies, Inc.), December 1998.*

2. *"Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Short-Life, Information-Handling Products and Equipment," GRE-3013-CORE, Tellcordia Technologies, Inc., December 1999.*