Delivering Superior Performance from the Coherent CUBE Laser System

Advanced manufacturing, quality and testing protocols are necessary to achieve benchmark performance, reliability and consistency from diode laser systems.

Introduction and Overview

Packaged, diode laser systems have had tremendous success in displacing older laser technologies in bioinstrumentation applications such as flow cytometry, confocal microscopy, medical imaging, and genomics, as well as in inspection and graphic arts. This is because diode laser based systems offer a unique combination of compact size, output stability, beam quality and low maintenance requirements. Yet, system integrators and end users continue to demand even more from these lasers in all these areas. This whitepaper details recent improvements that Coherent has made in all aspects of our Coherent CUBE™ series of diode laser systems in response to this need. Specifically, these enhancements include new levels of optical, mechanical and electrical performance and consistency, backed up by the industry's most comprehensive testing, evaluation and certification programs.

SUPERIOR OPTICAL PERFORMANCE

Feature and Benefit Summary

CUBE lasers now set a new standard for guaranteed performance with superior beam quality (M^2) for this class of laser: specifically, $M^2 \leq 1.2$ *at the 90/10 clip level.* This enables more efficient and predictable use of the laser output, i.e., higher usable power, whether the application involves fiber coupling, beam combining or tight focus. It also means less scattered light and background signal in most applications. This translates into higher signal-to-noise ratios and hence faster data acquisition times.

Limitations of Conventional Laser Testing

Traditionally only the far-field beam profile was included in the specifications for these lasers, usually in the form of a M^2 value for beam quality (M^2 = 1 for a perfectly Gaussian beam profile), a beam divergence value, and a beam asymmetry specification. The far-field is a somewhat arbitrary term meaning a distance along the beam that is many times greater than the beam waist Raleigh range. Moreover, the M^2 value in the far-field was typically only specified and certified for the central 68% of the beam intensity, the so-called "84/16 clip level." This is perfectly fine for well-behaved lasers that naturally produce smooth beams with a circular cross-section, as with a higher performance DPSS laser or OPSL laser.

But visible CW lasers like the CUBE family are based on edge emitting laser diodes, where the laser light is emitted from a small edge facet. Because of the small dimensions of the facet, the beam is initially highly divergent. And because of the asymmetric slot-like shape of the facet, the dimensions and divergence of the beam are different in the X and Y directions. Plus in some diodes, the raw beam has astigmatism – the X axis appears to diverge from a different beam waist location within the diode chip than does the Y axis. Simple and mature solutions are long-established in the laser industry for all these issues, which are well-corrected in the CUBE laser's internal beam-shaping system. Using a single-mode diode, the result is a non-astigmatic, well-collimated far-field beam with a choice of symmetric (circular) or elliptical beam profiles*. However, because of the initial beam characteristics and the use of the beam-conditioning optics, a single 84/16 far-field M^2 measurement can be an insufficient test of performance.

Two examples illustrate this point. The original specifications for CUBE lasers included a M^2 of < 1.5 at the conventional 84/16 clip levels. (M^2 and other beam propagation parameters are measured at Coherent using an NIST referenced Coherent ModeMaster™ – the accepted industry standard beam analyzer). Figure 1 shows test data for a 405 nm laser where a

**A few manufacturers offer multimode diodes as a cheaper alternative, but the beam quality and noise characteristics cannot match those of systems based on single-mode diodes.*

ModeMaster measurement of beam parameters at the 84/16 clip level would have indicated that this laser met the M^2 specification quite well. The nominally circular output also met specified parameters for asymmetry and beam diameters in both X and Y planes.

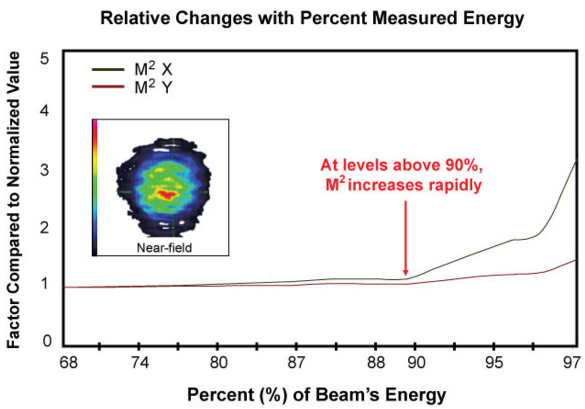

Figure 1 – Laser beam with unacceptable performance in approximately 10% of the beam energy

The data above is normalized to a value of 1.0 to show at what percentage the beam's energy becomes misbehaved. Beyond this point the normalized values fall apart showing the unusable portion of the beam. Closer examination of the false color beam intensity map from the CCD camera indicates the slight appearance of a donut mode. Figure 2 shows a 640 nm laser where again the 84/16 beam data met specification. But this time, increasing the data set to include progressively more of the beam's energy shows that every specification, including M^2 performs until the 97% level. Clearly this latter example is a much more desirable laser.

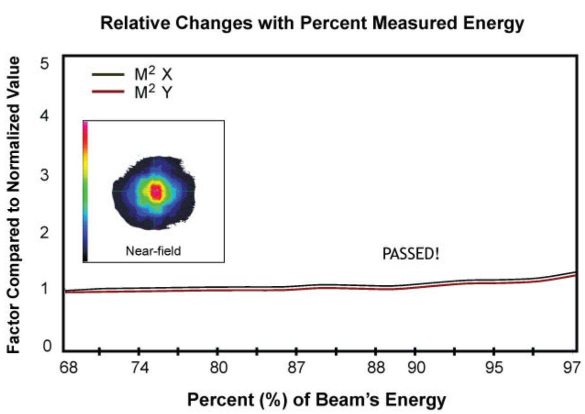

Figure 2 – Laser beam with impressive performance

What does this mean? For the end user, over 10% of the power in the first laser fails to meet the specified M^2 limit of ≤1.2. In the case of fiber coupling, the result would be considerably lower power transmission into the fiber. In a system where a collimated beam is created, the beam may clip the edges of optics creating scattered light and noise problems. For bioinstrumentation applications requiring a small spot size, the focused spot may exceed target dimensions, causing crosstalk, lower resolution and other data quality problems.

Unique Testing and Certification Protocol

What do we now do at Coherent to avoid the "Figure 1" scenario? Because Coherent is a vertically integrated laser company with a strong history building and supporting beam measurement tools, we have been able to successfully address this issue head on. First, we have configured the Coherent ModeMaster to make measurements at the 90/10 clip level. Now final QC on every CUBE laser involves measurements of the M^2, beam waist and beam divergence data at this more demanding but more informative level. Every CUBE laser is shipped with this final test and verification. We are the first (and currently only) supplier to measure at the 90/10 clip level. We are the only supplier with this level of detailed measurements and collection at this depth of laser system parameters.

Second, we have started inspecting every laser for its near-field performance as part of optics alignment, final QC and certification. That's because a higher quality near-field means more usable power in the far-field. And minor beam errors as shown in Figure 1 are often easier to spot in the near-field which is much more sensitive to problems such as hot spots, lens misalignment, and so forth. Moreover, near-field problems can cause higher coupling losses for fiber-based applications than can minor far-field aberrations. This is particularly true for single-mode polarization maintaining fiber which demands the highest quality input beam for efficient coupling. Figure 3 shows three near-field intensity images recorded with a CCD camera under this new protocol. All three of these lasers show excellent near-field symmetry and mode-quality and were passed as acceptable under this new testing regime.

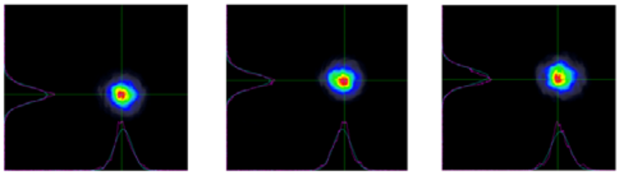

Figure 3 – High quality near-field images with good symmetry and minimal modes/distortion

With CUBE, we have improvements and control beyond the specified values on the data sheets. Specifically, we only ship lasers that exceed specifications rather than simply meet them, so that every laser will deliver specified performance beyond the full term of its warranty period. In the parlance of our six-sigma quality control program, CUBE lasers are rejected at any stage of manufacture unless they meet performance targets called "Control Limits" which are more demanding than the specification limits.

To summarize our new CUBE testing regime, all lasers are evaluated using both near-field and far-field camera, a ModeMaster (to measure M^2, beam diameter, symmetry and divergence), a NIST-traceable power meter, and a polarization measurement. Plus, the beam specifications are measured and guaranteed for the 90/10 clip level versus the legacy industry standard of 84/16. A complete portfolio of final certification data is recorded with every laser.

Incoming Component QC

But what about the lasers that don't pass the new stringent testing regime? Obviously it's important for Coherent and our customers to minimize our manufacturing costs by minimizing failure at final test. Exhaustive analysis logging of pass-fail data has indicated that the majority of beam problems are caused either by defects in the laser or defects in the molded aspheric lens used for collimation. An extreme example of the latter is shown in Figure 4. Here a beam hot spot is directly traceable to a dimple in the center of the asphere lenses, a feature that was probably created when this glass lens was released from the mold. For this reason, we have implemented a rigorous testing and QC of diodes and asphere lenses. We reject any diodes or lenses that don't meet our new standards. This has had two positive results at Coherent.

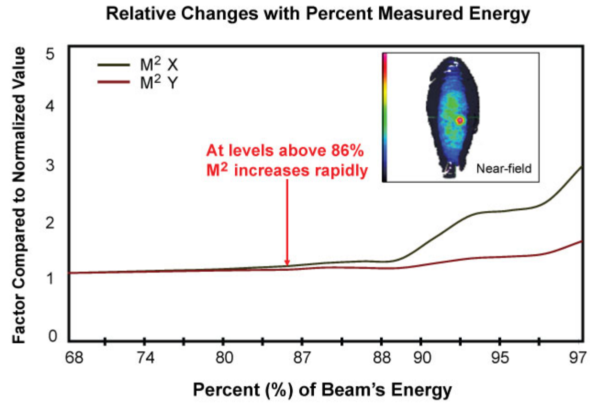

Figure 4 – Poor lens quality creates poor near-field.

First, the number of CUBE lasers failing even our new rigorous testing has fallen to almost zero; higher yields allow us to contain manufacturing costs. And second, in conjunction with our six-sigma quality program, the statistical spread of CUBE performance is now incredibly tight as shown in Figure 5 by the narrow spread of M^2 values for a recent batch of 405 nm to 785 nm CUBE lasers. This industry-leading laser output consistency simplifies integration and thereby lowers costs for customers, resulting in extremely predictable performance of the final instrument or system.

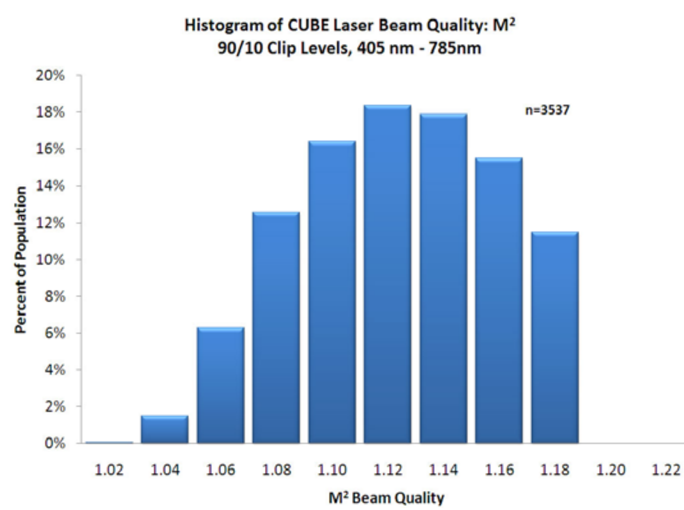

Figure 5 - Histogram of CUBE Laser Beam Quality: M^2 90/10 Clip Levels, 405 nm to 785 nm Products

SUPERIOR MECHANICAL PERFORMANCE

Feature and Benefit Summary

CUBE Lasers are designed, manufactured, and HALT tested to be the most physically robust lasers in their class. This makes them the most reliable choice for demanding applications where they may be subjected to mechanical vibration or environmental stresses.

Rugged Product Design

The first key to CUBE's superior stability is the modular design built around a rugged monolithic construction. As shown in Figure 6, a one piece metal brass block contains the diode, collimation lens and optional anamorphic prisms for beam circularization. In Fiber Pigtailed (FP) series products, the block also includes the laser welded coupling lens and fiber launch. Enclosing all alignment-critical elements in this monolithic block offers two advantages. First, the entire block can be precisely temperature-controlled using a sensor and thermoelectric (TE) cooler. This makes laser alignment immune to any effects caused by changes in ambient temperature. Just as important, this monolithic block approach is the best to secure the internal optical alignment of a CUBE laser from outside vibrations and shocks. This makes CUBE lasers ideal for use in systems in industrial and other harsh settings and also makes them well suited for use in instruments with moving parts and potential resonances. CUBE lasers deliver the same performance whether they're sitting on an optical table in a temperature controlled lab, or mounted on a noisy production line taking real time data in industrial environments.

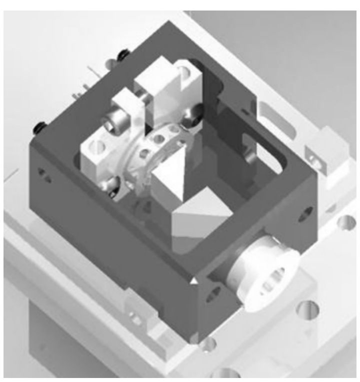

Figure 6 – Monolithic block Diode/ Optics /Fiber Construction on TEC

HALT Testing – Unbeatable Reliability

The other half of CUBE's rugged stability is our comprehensive Highly Accelerated Life Testing (HALT) program designed to find the lasers' "discovery limits" and also to understand any potential early fatalities. In short, these heat, freeze, and shake tests are structured to push the lasers well beyond the normal expected operating environment and thereby accelerate any reliability issues – see Figure 7. The lasers are operated during the entire testing protocol to monitor the beam and record the internal diode and temperature measurements.

Stress Test	Maximum Survivable Exposure
Cold Step Stress	-80°C
Hot Step Stress	140°C
Vibration	$40g_{rms}$
Combined Stress Test Result	**Pass** -50°C to 95°C and $40g_{rms}$

Figure 7 - Stress testing and product limit discovery

For representative models of our CUBE lasers, HALT testing encompasses a cold stress test, heat stress test, and vibration test to find their failure limits. Representative samples must then pass a combined stress test, often referred to as "heat, freeze and shake." All these tests are carried out inside a thermal test chamber. The freeze test involves rapidly stepping the temperature between ambient and successively lower values to discover the failure point. For CUBE lasers that point is currently below minus 80°C. The heat test involves the opposite scenario with CUBE lasers typically not failing until stepping to temperatures above +140°C. The mechanical test involves shaking the test platform with random vibration motion at increasing levels of acceleration. This tests whether CUBE lasers can withstand beyond 40 g_{rms} of random acceleration. The CUBE verification units must also pass a combined stress test summarized in Figure 8. This involves a 90 minute testing protocol in which the temperature of the lasers are rapidly stepped between minus 50°C and plus 95°C as the vibration level is successively stepped from 10 to 45 g_{rms}.

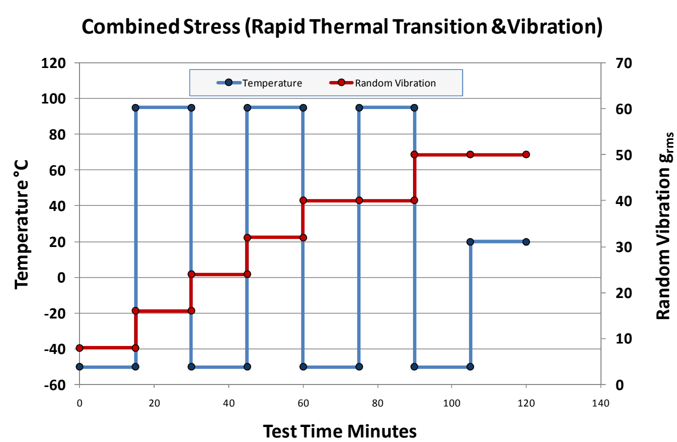

Figure 8 –Combined stress (Rapid Thermal Transition & Vibration)

In addition to these HALT tests, a random selection of CUBE lasers are installed in a life test station. The twin purposes here are to confirm the expected lifetime and if/when the lasers eventually fail to perform, to employ root cause analysis and further refine the design/manufacturing methods to henceforth eliminate any common failure mechanism. With regard to stress and life testing, we know of no competitive laser that is subject to such rigorous testing and comprehensive documentation thereof.

SUPERIOR ELECTRICAL PERFORMANCE

Feature and Benefit Summary

CUBE lasers deliver unmatched performance in terms of RMS noise and ESD (electro-static discharge) protection. Moreover, the entire CUBE product line recently underwent additional certification to qualify for the latest CE standards. The low laser RMS noise translates directly into reduced noise in the final applications, i.e. higher signal-to-noise data, enabling superior data and/or faster acquisition times, which are both value-added competitive advantages. Combined with the impressive Level 4 ESD robustness shows the CUBE laser is designed for electrical isolation for the laser diode and control electronics. This is strong evidence of the superior design in the laser electronics for performance and reliability.

Designed and Built for Low Noise

The specification for noise in CUBE lasers has recently been lowered to ≤0.1% RMS over the range 10 Hz to 10 MHz, the lowest noise available for this class of laser. There have been three improvements that have enabled this state of the art performance. The first is the use of strong grounding plane strategies, which eliminate inductive coupling between physically close but electrically isolated components. The second is power supply enhancements to yield better electrical isolation between circuits. And the third is the use of ferrite isolators at key circuit locations to suppress high frequency influences. The end result of these improvements can be seen in Figure 9 which shows a histogram of the RMS noise of a random group of CUBE lasers of different models and at various output powers. Not only do all the lasers meet the noise specification, but notice the tight grouping, i.e. high unit to unit consistency. Over 75% of the lasers have a total RMS noise level between 0.05% and 0.07% meaning the noise spread for over 75% of the lasers is 2 parts in 10,000 – a remarkable result for lasers of both different power and different wavelength.

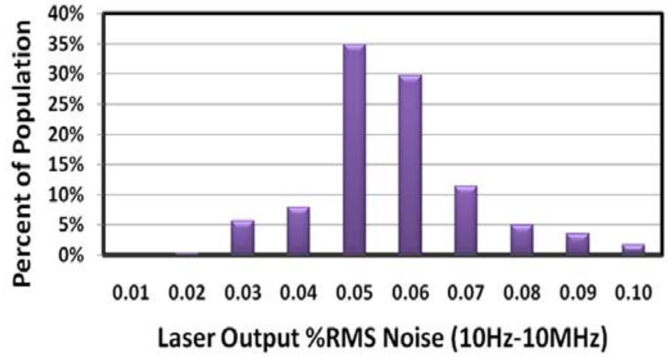

Figure 9 – Histogram of CUBE Laser % RMS Noise for 405 nm to 785 nm

Conclusion

Superior performance and reliability of any laser stems from attention to detail in all three areas of engineering importance: design, manufacturing test and certification. The CUBE lasers of today offer better performance and reliability than any competitive laser and are even better than the CUBE lasers of just a couple of years ago. The following list summarizes the most important improvements behind this accomplishment:

- Additional manufacturing tooling for beam instrumentation and quality control
- Detailed review of manufacturing methods and process by three independent engineering groups
- Extensive manufacturing test data collection
- Addition of manufacturing control limits
- Better near-field beam quality with rejection of irregular beams
- Improved beam performance with 90/10 clip levels for ModeMaster measurements
- Added far-field beam quality measurements and specifications
- Additional in-process storage temperature sample testing and verification
- Improved laser output RMS noise performance specifications
- Reliability and stress testing
- Recertified to latest standards for CE testing for emission and immunity