

Verdi V: Superior Performance and Reliability

The Verdi V is the world's most popular green CW laser with over 5,000 units installed in the field. Key to this success has been the superior reliability that Coherent has assured is built into each of the systems that ships from the factory.

Introduction

Since its introduction in 1997, Verdi™ V has been the leading choice in 532 nm diode-pumped solid-state (DPSS) lasers for scientific applications ranging from ultrafast oscillator pumping and holography to materials studies. The single-mode ring cavity design of the Verdi provides unmatched coherence, an industry leading low noise output, and long term power and pointing stability. These specifications make the Verdi the premiere choice for CEP stabilized amplifier systems.

Key to the Verdi's success and of paramount importance for any system is the reliability of the laser. The Verdi is considered the ruggedized workhorse of the DPSS world. High dependability minimizes cost of ownership and guarantees high productivity, which is a particular advantage in labs where the laser system is a shared resource. Many DPSS lasers suffer from limited pump diode lifetime and expensive consumables akin to plasma tubes in legacy ion lasers. However, in the current family of Verdi lasers, the mean time to failure (MTTF) for fiber array package (FAP) pump diodes is now greater than 50,000 hours. If operated at 80 hours per week, this translates to over 10 years of average diode lifetime.

Verdi's incredible overall reliability is a result of intensive testing, analysis and ongoing improvement, making Verdi products the best characterized laser in its class. This whitepaper describes some of the key aspects of how Coherent has achieved and maintained Verdi unmatched reliability.

Reliability Testing

All DPSS lasers contain electronic, active/passive photonic components as well as metal fabricated components with sources of variation attributable to

both design specifications and subsequent manufacturing operations. However, Verdi products are designed with active and passive stabilization techniques to address or eliminate sources of variations that detract from performance and reliability. This attention to design and manufacturing details ensures that the performance and lifetime will be achieved over a wide range of ambient operating conditions.

Coherent employs Highly Accelerated Life Testing (HALT) during the Verdi's development and improvement phases as an efficient means to rapidly substantiate design, and have created processes that continue to extend Verdi performance and reliability. HALT is the application of quantified thermal and/or vibration stress tensors well beyond the expected operating and shipping conditions. In the test, stresses are applied until the Verdi experiences a fault or failure. The difference between the operating or shipping specification and the applied stress tensor(s) is the "design margin." The greater the design margin, the more robust the product is to everyday use conditions. Rigorous failure analysis and corrective actions accompany this objective testing protocol, thus providing an efficient and analytical approach to identifying key parameters and specification tolerance requirements. The products are repeatedly tested until the design and manufacturing specifications are defined tight enough to eliminate sources of variation that affect product reliability and performance.

However, Coherent goes a step further in its reliability assurance. A Highly Accelerated Stress Screen (HASS) test is applied in the manufacture of each Verdi to ensure that both the design and process margins are continually being achieved and maintained. Similar to HALT, HASS uses the same approach of applying thermal and/or vibration stress tensors. The HASS stress tensor levels are set between the product specification and the HALT limits so as not to artificially age the laser, yet ensures the design and process margins are maintained. Yield data and rigorous failure analysis are used to monitor supplier and build quality.

HALT and HASS efficacy is derived by accelerating several well known physical failure mechanisms.

Stress Tensor	Physical Phenomenon	Associated Failure Mode
Extreme Temperature (Hot & Cold)	Diffusion, Stress Relieving	Contamination, Alignment stability
Rapid Thermal Cycling ($\pm 80^{\circ}\text{C}/\text{minute}$)	Coefficient of Thermal Expansion (CTE)	Intermittent performance, Alignment stability,
6 Degrees for Random Vibration	Resonance Frequency, Interference, Particulate Generation	Alignment stability, contamination,

In adopting the HALT and HASS process, and addressing all of the above mentioned stress tensors, unknown mechanical or thermal failures of the laser are minimized, thus making the reliability of Verdi unmatched in the industry.

The Benefits of PermAlign

Key to high reliability in the Verdi is the mounting technique used on optics in the laser cavity. Coherent employs its PermAlign™ to greater reduce failures associated with the mounting and alignment of optics in a precise and robust manner. PermAlign eliminates the need for traditional opto-mechanical mounts which typically include adjustment screws and one or more locking screws to freeze the final adjustment. Optics need to be moved typically in 5 or 6 degrees of motion during the alignment process and hence traditional optics positioning become very complex primarily due to the discrete number of adjustments associated with such a method. In contrast, PermAlign technology fuses two metal structures together to form a monolithic structure that provides up to six degrees of alignment adjustability and therefore greatly reducing the number of mechanical components. Simple series reliability analysis multiplies the reliability probability of each discrete element to predict the overall system reliability. The PermAlign advantage is there are approximately 80% less discrete parts which equates to a significantly more reliable optics platform.

Critical Component Lifetime

A highly integrated product like a DPSS laser is only as reliable as its constituent components. This issue has been thoroughly and successfully addressed in Verdi

lasers. In addition to using only high-grade components from well-proven electronics suppliers, every Verdi laser undergoes a thorough burn-in test, such that any early component failures are detected and corrected before reaching the customer.

As mentioned earlier, in first generation DPSS lasers the pump diodes were regarded as long-lived yet consumable components. Periodic replacement of these diodes had a major impact on the overall cost of ownership of DPSS lasers. Unlike most other DPSS laser manufacturers, Coherent is a fully integrated laser company that makes its own diodes, including the fiber coupling and packaging. As part of the reliability improvement activities, causes of early diode failure were identified. These turned out to be output facet degradation, cooling issues and packaging (mounting). Cooling issues were resolved by the use of high efficiency microchannel cooling of the diodes—lower operating temperature equals longer diode lifetime. Facet degradation was solved by switching to a unique architecture called Aluminum-free Active Area (AAA™). The packaging (mounting) failure was successfully addressed using a hard gold-tin solder to affix the diodes to the cooled copper mount. The end result of these improvements was increased efficiency and higher lifetimes.

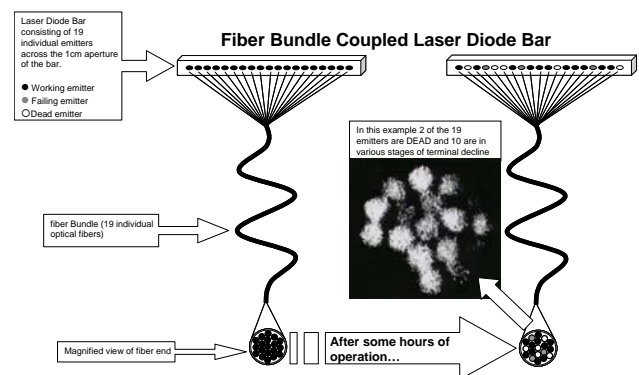


Figure 1: In lasers where the diode array is coupled using a fiber bundle, failing or dead facets in an aging diode array result in an irregular pump intensity profile.

Another way in which the useful lifetime of the pump diodes has been extended is the use of a single fiber to channel the FAP output to the laser crystal. Most DPSS laser manufacturers use a fiber bundle, where each of the diode array output facets are individually coupled to a single fiber. However as diode arrays age, their decline is characterized by the failure of one or more emitters. When the fiber bundle is directly

imaged into the Nd:YVO₄ rod, dark emitters cause a change in the pump pattern, no longer mapping as efficiently into the desired TEM₀₀ output mode. This means the M² of the laser may decline.

For the Verdi, the FAP light is homogenized into a single pump fiber that maintains a circular pump profile independent of the number of active diode emitters. Any resultant drop in output power from a single failed emitter is automatically compensated for in the single fiber pump by a slight increase in FAP drive current. This “smart” architecture maintains the specified laser output power and M², and subsequently extends the effective lifetime of the FAPs.

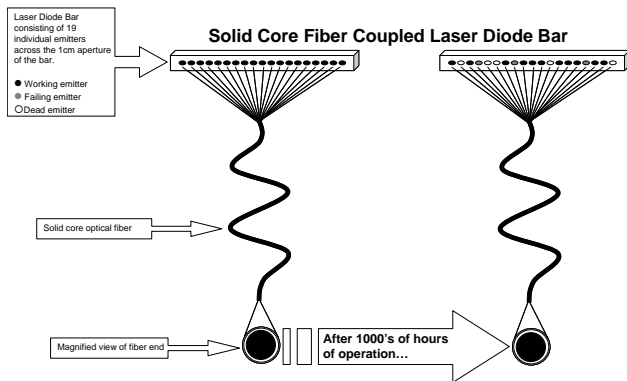


Figure 2: In Verdi V lasers, the diode array output is homogenized in a single connecting fiber ensuring the same circular pump profile, even if several facets eventually fail.

And lastly, even though the MTTF of Coherent FAPs in Verdi lasers now exceed 50,000 hours, further steps have been taken to minimize the potential cost impact of Coherent diode failure. Specifically, second generation Verdi lasers use a more efficient pumping scheme, meaning even our 10 Watt and 12 Watt models use a single FAP rather than the two diode arrays commonly used in other DPSS lasers.

Independent Shipping Tests

In-house reliability tests ensure the reliability of the laser at the factory, but what about the transit of the laser to your facility? To ensure the reliability of the laser remains constant, we have independently tested the crated system for vibration and shock in accordance with ASTM standard D4169, Distribution Cycle 12, Assurance Level II. This includes 23 cm flat edge impacts (pictured), rotational corner impacts (pictured), freefall base and edge impacts, and 180 minutes of 0.52g RMS truck-spectrum (1 Hz to 200 Hz) vibration. At the completion of the test, Coherent lasers operated within specification.

In addition, the crated laser is tested to the ISTA-1H standard. The laser is monitored during the test, and improvements are made to the crate as needed to minimize the forces transmitted to the laser during conditions simulating shipping.



Flat Edge Impact



Rotational Corner Impact

Figure 3: Rigorous testing at Westpak Inc. confirmed the crated laser meets ASTM standard D4169, Distribution Cycle 12, Assurance Level II.

Life Tests

Conventional life tests are also performed, where representative Verdi models are operated under normal conditions until specified end-points are reached. The performance of two units from the current generation of Verdi V 10 lasers are shown in Figures 4.

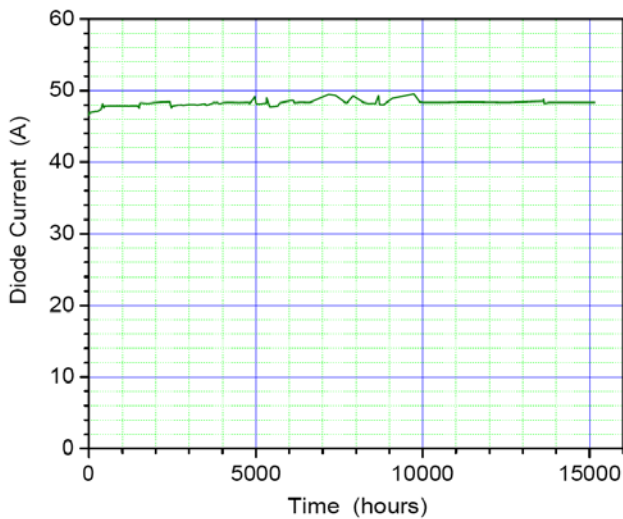
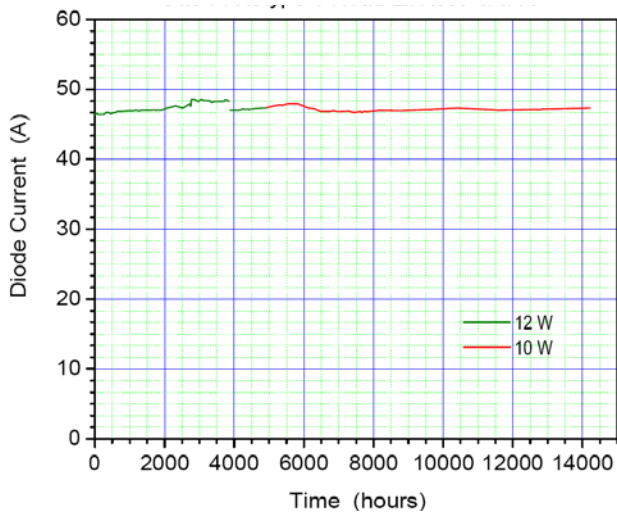


Figure 4: Lifetest data for two Verdi V lasers.

Verdi lasers are “smart” in that they have feedback loops which can automatically adjust the diode drive current to maintain the power at a constant value. Monitoring the drive current is one way to track the overall health and efficiency of the laser.

Service

Inevitably, in the real world, unexpected problems occur. At Coherent, your uptime is our focus. With a global service and support team backed by local parts inventories, we are dedicated to getting your laser up and functioning again quickly.

In addition to getting your laser operating again, our service engineers feed the failure information back to the factory to drive the continuous improvement process. At Coherent, we believe the ultimate life-test is the huge number (over 5000 units) of Verdi V lasers now installed at customer sites around the world.

These applications give us millions of hours of real world operation and “real life” testing, making Verdi the best studied and characterized DPSS laser anywhere. So when you receive your Verdi laser, you’re using a laser with a million plus hours of real world operation behind it.

CE Certification

And finally, of particular interest for our European customers, the entire Verdi product line has been underwritten by re-certification for CE compliance. The certificate for the Verdi V10 model is reproduced below. This exhaustive certification was carried out by an independent body – Bay Area Compliance Lab Corp. (BACL).



Figure 4: Verdi V lasers were recently re-qualified for CE Certification by an independent compliance lab.

Conclusion

At Coherent, we have always understood that reliability is just as important as performance. Anybody can claim reliability, but no other DPSS manufacturer can guarantee it with the confidence of Coherent and its Verdi lasers.