Sapphire Advantage: Ease of Installation

Ease of Installation – Sapphire combines inherent Optically Pumped Semiconductor Laser (OPSL) advantages, including small size, low power consumption and low thermal demands, with value-added features such as multiple (analog, serial and USB) control interfaces and high unit-to-unit consistency.

Advantage: Sapphire™ lasers are compact. The Sapphire LP laser head is as small as 125 mm x 70 mm x 34 mm (4.9 in x 2.8 in x 1.3 in).
Benefit: They take up less valuable space, simplifying integration. System integration costs can be further lowered by enabling proximity to the interaction region.
How? Small solid-state components, simple PermAlign™ mounting, and folded cavity design.

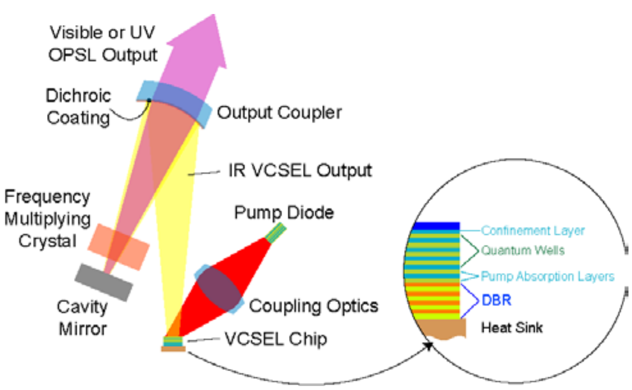

Figure 1: *Sapphire lasers utilize optically pumped semiconductor technology to produce near infrared laser light that is converted to visible output by intracavity frequency doubling.*

Figure 1 schematically illustrates the main components of an OPSL such as the Coherent Sapphire. All these active and passive components are solid-state, delivering the advantages of small size, high efficiency, consistent volume fabrication, and long-term reliability. Moreover, the relaxed geometric tolerances for pumping, as described in Sapphire Advantage Note #2) means the entire laser cavity and pump arrangement can be designed to be very compact. In a Sapphire laser, all optical components are fixed to a single block, simplifying assembly/alignment and enabling semi-robotic automated assembly. The optics are aligned to optimum positions and then permanently held in position by Coherent's patented PermAlign method. This technique provides superior long-term stability compared to traditional multi-part adjustable/lockable mounts, and allows for smaller physical dimensions.

Depending on the wavelength, Sapphire LP models provide powers up to 300 mW. To obtain higher power in Sapphire HP models, a larger pump diameter and higher pump powers are applied (see Sapphire Advantage Note #2). But a larger pump diameter means a larger mode volume. And in most commercial laser designs, increasing the mode volume would require a correspondingly longer cavity in order to maintain a stable TEM_{00} beam profile, i.e. a larger laser head. But in Sapphire HP models, a folded cavity is used, incorporating optics to uncouple mode diameter and cavity length, as described in Sapphire Advantage Note #2. As a result, even a 500 mW Sapphire HP laser head measures only 215 mm x 140 mm x 51 mm (8.4 in x 5.5 in x 2.0 in). Moreover, unlike many other diode-pumped lasers, increasing the pump power is non-problematic due to the non-sensitive pump geometry and the fact that there is no appreciable thermal lensing in the gain medium. This is because the chip is very thin and is effectively cooled from its rear mounting surface.

Low Power Consumption – Low Thermal Load

Advantage: Sapphire lasers have high wall plug efficiency meaning low power consumption and low waste heat.
Benefit: Lowers the power budget for OEMs and makes Sapphire lasers and their applications very green compliant.
How? OPSL technology is all solid-state, highly efficient and features relaxed pumping wavelength requirements.

Sapphire lasers utilize all solid-state technology meaning they are inherently much more efficient at converting electrical power to optical output, compared to traditional ion lasers. But OPSLs, like the Sapphire, also have a key advantage over solid-state lasers based on optical gain crystals such as Nd:YAG and $Nd:YVO_4$. That's because while both the OPSL and DPSS laser technologies feature laser diode pumping, the OPSL's gain conversion medium is a III-V semiconductor chip, rather than a laser crystal. This monolithic chip contains layers of tertiary quantum wells (InGaAs) alternated between binary (GaAs) layers – see Figure 1. These binary layers are optimized to efficiently absorb pump radiation – with an absorption coefficient orders or magnitude higher than a typical laser crystal. In fact, the entire chip is less than 10 microns thick yet can absorb the pump radiation more completely than a laser crystal several milimeters in length.

The end result is a typical conversion efficiency of pump to laser light of more than 30%. In addition, due to the resonator design and excellent beam parameters, this laser light can be frequency-doubled with efficiency in the 80% range – see Figure 2 and 3.

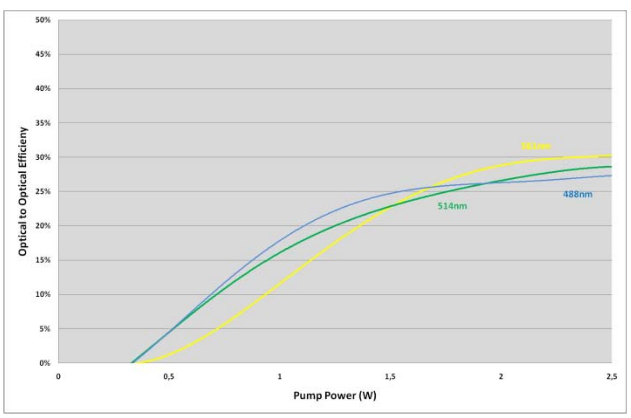

Figure 2: *The strong absorption of the pump light by the GaAs in the gain chip and the excellent beam parameters of a Sapphire laser are major factors leading to high optical-to-optical conversion efficiency at the fundamental wavelength and frequency doubled.*

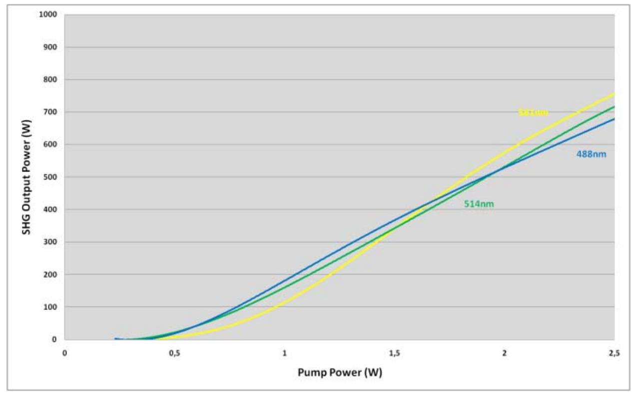

Figure 3: *Sapphire lasers utilize highly efficient (up to 80%) intracavity doubling. Together with their high optical-to-optical efficiency, this means that just 2.5 Watts of pump diode power can be converted to 700 mW of visible output.*

High efficiency also means that less of the input electricity ends up as waste heat. Because waste heat must be dissipated in many instances, a lower thermal load is a tangible benefit for system integrators and instrument builders.

Another factor contributing to lowering thermal management requirements is that in an OPSL, the pump diode wavelength does not have to be tightly controlled. That's because at wavelengths shorter than their bandgap, the GaAs layers have a broad and truly continuous absorption profile, so changes in the pump wavelength have no effect on efficiency or performance. In contrast, in DPSS lasers, based on $Nd:YVO_4$ or Nd:YAG, the absorption peak in the laser crystal is narrow, demanding a precision in the pump wavelength of typically 0.5 nm. So in those lasers, even minor shifts in pump diode wavelength can significantly affect laser performance. And the output wavelength of the pump diodes strongly depends on their operating temperature, which therefore must be closed-loop controlled using a TE cooler. In some DPSS lasers, operating this cooler represents a sizeable proportion of the total power budget. Moreover, this is input power that can never be converted into laser light – it is only converted into heat. But in Sapphire lasers, the pump diode temperature does not have to be separately and actively controlled. It is sufficient to maintain a safe thermal operating range of the laser head via monitoring and control of its baseplate/heatsink.

Multiple Control Interfaces

Advantage: Every Sapphire laser controller comes standard with RS-232, USB and analog connectors.
Benefit: For both OEMs and end users, this simplifies full integration into an instrument or experiment. It also enables fast diagnostics in case of any operational problems.
How? With the use of miniaturized smart electronics.

All Sapphire LP laser controllers are now equipped with 3 interface plugs: a 9-pin RS-232, mini USB, and 25-pin analog DBS 25 (all female), which provide the end user or system integrator with unmatched flexibility in how the laser is controlled and monitored. Needless to say, Sapphire also can be operated without these interfaces in an autostart mode. This mode is activated by setting dip switches on the controller. The laser is then simply switched on/ off using the power control.

Where a higher level of control and integration is required, the RS-232 and mini-USB provide the simplest options for integrating a Sapphire laser with external computer control. They use an identical command set to both control the laser using command type functions and monitor multiple aspects of laser operation via queries.

The following table lists just a few of these standard commands to show how easy it is to directly access these functions. In addition to correctly sequencing and coordinating power on and off with other system safety functions, the query error returns can be used to automatically shut down the laser when necessary, alert the system operator, and diagnose any problems.

OEMs in particular will appreciate the alternative to control Sapphire lasers instead via the multi-function analog interface. When this interface is engaged, it automatically takes precedence over the RS-232 and USB interfaces. The use of a 25-pin DBS connector for this analog interface enables a larger number of dedicated in/out signals to be simultaneously supported.

Command	Meaning
"NOMP"	Type: Query. Return the Nominal output power.
"P"	Type: Query and Command. Sets or reads the Laser Power. A query returns the actual measured Sapphire output level in a numerical and floating-point value. (For all queries and commands, the power units are mW).
"PI"	Type: Query. Reads the Power-In value from the Analog Interface connector and returns the value in an A-to-D count (12 bit value).
"HH"	Type: Query. Returns the total usage hours stored in the Head EEPROM. Hours are updated every time there is a least minimum current flowing through the laser diode.
"PST"	Type: Query. Returns the controller temperature.
"SP"	Type: Query. Reads the set power (i.e., setpoint of output power). The set power can be changed by using the "P" command.
"STA"	Type: Query. Reads status of laser head: 1 = Start up 2= Warmup, 3= Standby, 4= Laser on, 5 = Laser ready, 6= Error.

Table 1: *A small subset of common commands and queries that simplify integrated control and monitoring of Sapphire operation through either their RS 232 or USB interfaces.*

FFF – Identical Form Fit and Function for all Sapphire LP Models

Advantage: The lasers within the Sapphire LP series provide a comprehensive range of output powers and wavelengths, but all have the same form, fit and function.
Benefit: For both OEMs and end users, this simplifies integration of multiple lasers into an instrument or experiment and/or an upgrade in power or change in wavelength.
How? Through the use of miniaturized smart electronics and a common technology platform.

Another factor enhancing ease of integration is that all Sapphire LP models provide identical form, fit and function regardless of their wavelength or output power. They have identical mechanical features (dimensions, weight, connector types and geometries) and identical optical parameters (xy beam position and beam angle at laser head exit, beam waist position, divergence) and a common interface protocol – see above. This means whether you need 20 mW of yellow at 561 nm or 200 mW of blue output at 488 nm, the lasers are directly interchangeable – true plug-and-play. This is important for OEMs and end users who want to switch wavelengths or upgrade power or who want to integrate an additional wavelength into an existing Sapphire application. In contrast, obtaining this selection of wavelengths and powers without OPSL technology would require multiple technologies with different physical packaging and beam properties, even when from the same vendor.

High Unit-to-Unit Consistency

Advantage: Sapphire lasers are characterized by exceptionally low unit-to-unit variation.
Benefit: OEMs can minimize the need for wide adjustment in downstream optics, lowering system complexity and cost. Plus Sapphire laser heads can be exchanged in the field with minimal downtime for system realignment.
How? Relaxed alignment requirements and the use of robotic, semi-automated assembly eliminate human subjectivity during fabrication.

OPSL resonators have relaxed alignment requirements, particularly for pumping geometry, compared to other solid state lasers - see Sapphire Advantage Note #2. Moreover, Coherent's PermAlign technology for aligning and fixing optical components, allows for the semi-automatic manufacturing of the laser resonator using component pick-and-place techniques analogous to those long-used in the electronics industry. With Sapphire, this has enabled Coherent to implement the most automated production line for any high performance commercial visible laser. The precision and stability of this manufacturing process, together with eliminating human operator subjectivity in production, yield superior unit-to-unit consistency. This can be highly beneficial, for example, in a flow cytometer, where field-replacement of a laser head is relatively simple and does not require cumbersome and intensive re-alignment of the beam within the instrument.

To summarize, the Sapphire's small size, low power consumption and low thermal demands combined with its multiple control interfaces and state of the art flexibility ensures superior reliability and performance for OEMs and end users alike.