Sapphire Advantage: Low-Noise

Low-Noise – Sapphire™ lasers are the only frequency-doubled, visible, CW lasers to avoid "green noise" without requiring costly and complex stabilization schemes.

Advantage: Sapphire lasers are characterized by low output noise.

Benefit: Improved signal-to-noise ratios in most applications provide shorter data acquisition times in high throughput applications such as flow cytometry and better data quality in imaging applications such as confocal microscopy.

How? Optically Pumped Semiconductor Lasers (OPSL) do not suffer from the "green problem" present in many DPSS lasers.

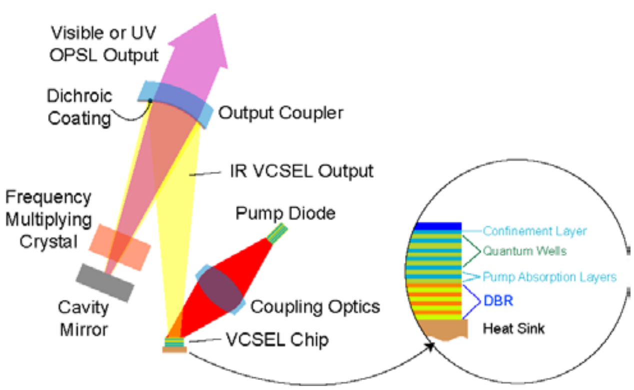

Figure 1. *Sapphire lasers utilize optically pumped semiconductor technology to produce near infrared laser light that is converted to visible output by intracavity frequency doubling.*

Figure 1 schematically illustrates the main components of an OPSL laser such as the Coherent Sapphire. A large area VCSEL (vertical cavity surface emitting laser) type chip is pumped by one or more laser diodes. This monolithic III-V semiconductor chip contains layers of tertiary quantum wells (InGaAs) alternated between binary (GaAs) layers. These binary layers are optimized to efficiently absorb pump radiation, resulting in a high population of charge carriers. This leads to population inversion and recombination in the quantum wells, which emit near infrared laser light. Behind these absorption/emission layers are several alternating high index and low index layers that act as a low-loss DBR (Distributed Bragg Reflector) mirror optimized for the specific OPSL fundamental. The output wavelength is determined by the size and stoichiometry of the InGaAs quantum wells in the VCSEL structure, and can be optimized to produce output anywhere from 700 nm to 1200 nm. In Sapphire lasers, the lasing wavelength is finely tuned and narrowed to a handful of longitudinal modes by means of an intracavity birefringent filter (BRF). Intracavity frequency doubling efficiently then converts the near-IR fundamental to a wavelength in the visible and beyond, providing a choice of potential output wavelengths between 350 nm and 600 nm.

OPSLs such as Sapphire are not the first solid-state lasers to produce CW visible output through the use of intracavity frequency doubling. However, many of the earlier diode pumped solid state (DPSS) lasers suffer from output noise due to a phenomenon called "green noise," or the "green problem."

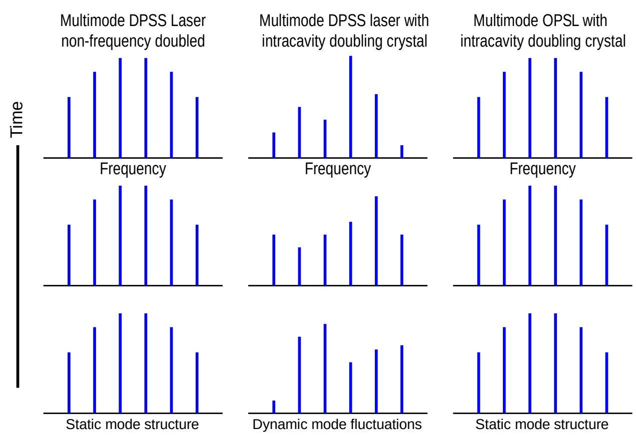

Figure 2. *With DPSS lasers operating on multiple longitudinal modes, intracavity doubling causes chaotic mode behavior. This does not occur in OPSLs because of the short upper state lifetime.*

With cavity lengths measured in centimeters or even tens of centimeters, CW near-IR lasers can support many longitudinal cavity modes. Usually in such lasers, the intra-cavity beam intensity is divided between multiple longitudinal modes, each with a slightly different frequency (see Figure 2). When a doubling crystal is inserted into a fundamental intra-cavity beam with multiple longitudinal modes, it creates chaotic behavior of these modes resulting in intensity noise in both the fundamental and doubled output.

The reason for this noise is that when a doubling crystal is inserted inside the cavity, both second-harmonic generation (doubling the frequency of one longitudinal mode) and sum-frequency generation (adding the frequencies of two different longitudinal modes) are possible. Sum-frequency generation directly couples different longitudinal modes and thereby enables dynamic interactions between longitudinal modes which compete chaotically for the same finite available gain. Because the upper state lifetime of the gain medium (the laser crystal) is many orders of magnitude longer than the cavity round trip time, these effects build up over several cavity roundtrips. The final result is a chaotic situation, where different modes alternate between high and low power. This long-recognized instability phenomenon is called the "green problem," [ref 1] since the first commercial CW lasers using intra-cavity doubling were green DPSS lasers, where the laser fundamental at 1064 nm is frequency-doubled to generate green output at 532 nm. Of course, this can be eliminated in high performance scientific multiwatt DPSS lasers (e.g., the Coherent Verdi V series) by forcing the laser to operate on a single stable cavity mode. But this rigorous approach is not economically practical for many lower power applications.

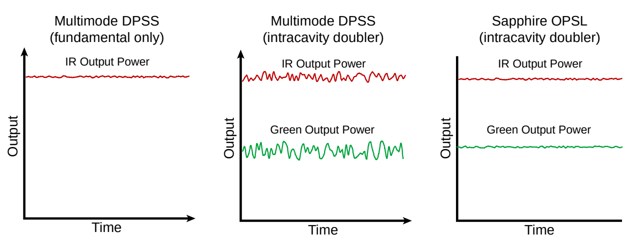

Figure 3. *Intracavity doubling causes chaotic green noise in DPSS lasers operating on multiple longitudinal modes. It cannot cause this chaos in OPSLs like Sapphire because of these lasers' very short upper state lifetime.*

Fortunately, OPSLs like Coherent Sapphire lasers are inherently free of green noise, because this noise source is a fundamental consequence of the upper state lifetime of the gain material. Specifically, in a DPSS the upper state lifetime is in the microsecond regime. But with OPSL technology used in Sapphire lasers, the gain medium is a semiconductor material where radiative and non-radiative recombination of charge carriers are both very fast processes. As a result, the effective upper state lifetime is a few nanoseconds or less, i.e. on the timescale of the cavity round trip time. Thus, on the laser mode timescale there is no stored gain, only instantaneous gain. The behavior of the individual cavity modes therefore is determined solely by the cavity, the gain just follows along.

If the cavity is properly aligned and stable, as in the case of Sapphire lasers, then even though the OPSL is operating on multiple longitudinal modes, there is no green noise whatsoever from the frequency doubling process. As a result, Sapphire lasers offer excellent noise characteristics in an economical format: <0.25% rms noise over the range 20 Hz to 2 MHz. This makes these lasers an optimum choice for even the most noise-sensitive applications.

Reference

1. T. Baer, *Large amplitude fluctuations due to longitudinal mode coupling in diode-pumped intracavity-doubled Nd:YAG lasers*, J. Opt. Soc. Am. B, vol 3, **9**, pp 1175-1180 (1986).