Improving DPSS Laser Performance with 880 nm Diode Lasers from New FACTOR Series

Summary of Advantages

- Pumping at absorptions with lower quantum defect – minimized thermal lensing – better output mode quality
- Lower absorption – better heat distribution – higher output power
- Wavelength insensitive pumping (for 888 nm) – reduced operating cost
- Polarization independent pumping (for 888 nm) – reduced system complexity
- Single emitter format – maximized efficiency

DPSS laser manufacturers can utilize new longer wavelength pump diode lasers to construct products having higher power *and* superior beam quality. These characteristics are particularly valuable when supporting precision applications in micromachining and advanced packaging. Specifically, 878.6 nm, 885 nm and 888 nm lasers all provide more efficient end pumping of Nd doped crystals than the legacy 808 nm wavelength. This improvement in pumping supports higher power scaling and better optimization of mode quality, resulting in significantly improved DPSS output, particularly for harmonic generation. This document explains the benefits of this new FACTOR series pump lasers in detail.

Less Waste Heat – Minimized Thermal Lensing – Better Mode Quality

Pump energy converted into waste heat reduces laser efficiency and requires an effective cooling scheme. But, in end-pumped DPSS lasers, an even bigger issue is that the waste heat produces strong thermal lensing in the laser crystal constraining the laser design and compromising beam propagation. This negatively impacts transverse mode quality and limits the ability to scale single mode DPSS designs to higher power. Yet, many important applications for end-pumped DPSS lasers involve precision micromachining, e.g. solar cell scribing, drilling of microvias, where manufacturers need higher power to increase process throughput and lower unit costs.

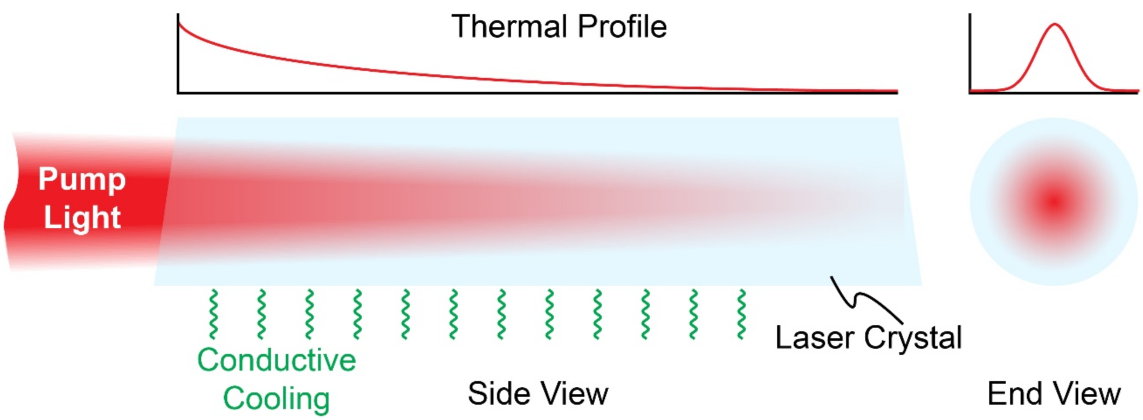

Figure 1: *End pumping can provide better mode quality, but thermal lensing can be a hurdle to achieve better beam quality.*

With 808 nm pumping, a major source of the waste heat is the large quantum defect – the difference in the photon energy of the pump light versus the laser emission at 1064 nm. But using pump light in the 880 nm wavelength window lowers the quantum defect by over 30%. This produces a major improvement in laser efficiency and a corresponding reduction in thermal lensing, simplifying the challenge of achieving the low M^2, TEM_{00} output needed for advanced materials processing applications.

(In the technical language of laser physics, the legacy 808 nm wavelength creates a four-level Nd laser whereas 880 nm drives a quasi-three-level quantum pathway).

Lower Absorption – Longer Rods – Higher Power Scaling

The strong absorption at 808 nm produces high absorption near the input facet of the crystal. Thus increasing the length of the crystal and increasing the pump power beyond an optimum point serves mainly to increase thermal lensing and the possibility of damage to the laser crystal.

In contrast, the lower absorption over 880-890 nm means the pump light penetrates further into the crystal without the severe intensity gradient. This allows more efficient pumping of a longer crystal with higher pump power. It also lowers thermal gradient along the pump direction and its contribution to thermal lensing.

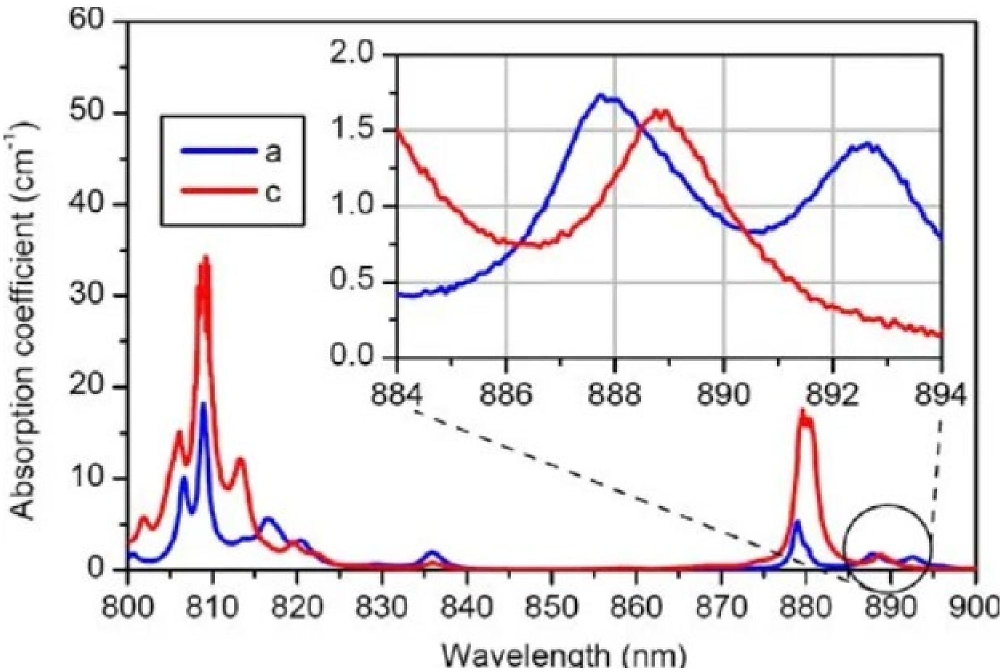

__Figure 2:__ The near infrared absorption spectrum of Nd:YVO$_4$.

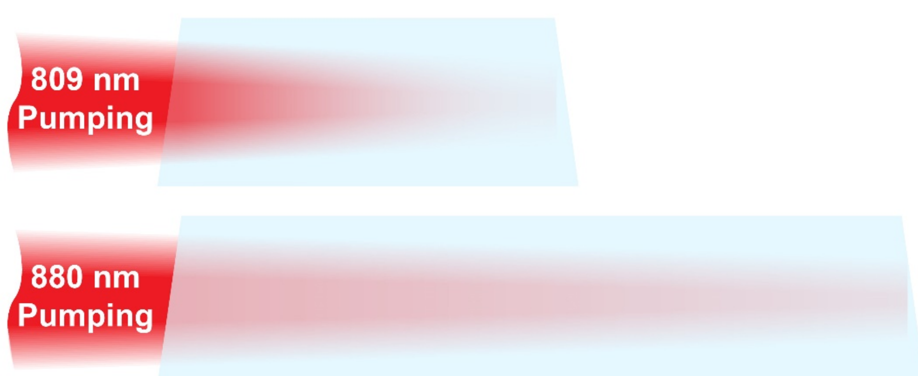

__Figure 3:__ Distribution of absorbed pump power in a Nd:YVO$_4$ crystal depending on the pump wavelength.
Top: 809 nm pumping of a short crystal with low penetration depth.
Bottom: 880 nm pumping of a long crystal with smooth absorption over the whole crystal length.

888 nm – Polarization Independent – Reduced Laser Complexity

End-pumped DPSS lasers deliver the best performance when the laser crystal is cut with the long axis corresponding to the *b* axis in the $Nd:YVO_4$ crystal. But, there are considerable differences between the absorption spectrum in the other two (*a* and *c*) axes at both 808 and 880 nm (see Figure 2). Because the output of the (typically) fiber-coupled pump diodes is randomly polarized, this leads to a somewhat complicated pumping architecture.

Specifically, in order to maximize final output, the fiber output is separated by a polarized beamsplitter. One end of the crystal is then pumped with the optimum polarization vector and the polarization orientation of other output of the beamsplitter is rotated by 90° and then used to pump the crystal from the opposite end.

This isn't required at 888 nm, because the *a* and *c* axes absorption is quite similar. This simplifies both the cost and alignment complexity of the DPSS laser.

888 nm – Reduced Wavelength Sensitivity – Lower Laser Cost

It is common in DPSS lasers to stabilize the pump diode wavelength by filters (usually VBG), because the pumping efficiency is highly sensitive to changes in wavelength and polarization. Active locking of the wavelength adds to the complexity and cost of the laser head. However, the *a* and *c* axes absorptions are very close and of similar magnitude at the 888 nm peak, and are also somewhat broader. This makes the pump efficiency at both polarizations relatively insensitive to small shifts in pump wavelength, thus eliminating the need for active wavelength locking of the pump. This simplifies the laser and lowers component and assembly costs.

Coherent Single Emitter Format Maximizes DPSS Efficiency and Power

Coherent offers fiber-coupled diode laser pump modules at all three of these new, longer pump wavelengths 878.6 nm, 885 nm and 888 nm, while using a single emitter format, with VBG filters integrated internally in the modules. Single emitters are further apart and can be operated closer to maximum output power. This together with a superior beam combining architecture and a proprietary fiber coupling process ensures that the Coherent FACTOR series provides the highest electro optical efficiency (ex fiber) on the market. In turn, this maximizes the overall efficiency of the DPSS laser.

Furthermore, in order to reach the power levels (e.g., >100 W at 1064 nm) needed for high throughput materials processing applications, the laser crystal must be pumped with >150 W of pump light. The cost of the pump diodes scales with both the power level and number of the diode emitters. So, efficient use of the pump diode output power is very important to minimize both the DPSS laser cost and its electrical power consumption. This also means maximizing the power from each emitter.

By using multiple single emitters that eliminate thermal crosstalk, the Coherent FACTOR series of fiber-coupled pump diodes at 876.8 nm, 885 nm and 888 nm can be operated at maximum power and efficiency levels, delivering a DPSS laser with higher power and electrical efficiency.

Figure 4: *Module variants available in the new FACTOR 88x nm series.*

Coherent Vertical Integration Key to Module Performance

Manufacturing fiber-coupled pump modules based on single emitter architecture is not without its challenges but vertical integration at Coherent has provided solutions to all of these. In addition to assembling and testing these modules, Coherent makes all the key components in-house, from the wafers used to make the laser diodes to the VBG filters to the delivery fiber and so on. Having total control over the production of these components ensures high reliability and longevity in providing addition to their high performance.

Automatic Licensing of Coherent's 888 nm Pumping Patent

Coherent pioneered the use of the 888 nm pump diodes, and we hold an exclusive, global patent (# 8,913,644, May 28, 2004) on the application. Typically, employing this technology requires paying a license fee to Coherent. But, this fee is waived when 888 nm diode lasers from FACTOR series supplied by Coherent are employed, thus further reducing production costs, as every single pump module at 888 nm will come with the corresponding license to use it.