# Commercial High-Efficiency 885-nm Diode Lasers

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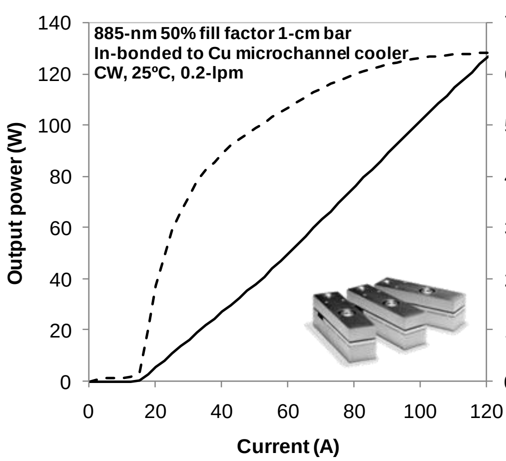
Neodymium-doped solid state lasers continue to be the laser source of choice for industrial applications. Direct pumping of the upper Nd laser level at 885-nm (rather than at the more traditional broad 808-nm band) offers the potential of improved performance through a reduction in the lasing quantum defect, thereby improving system efficiency, reducing cooling requirements, and enabling further TEM00 power scaling. Because of the narrow 885-nm absorption feature in Nd:YAG [1], certain systems may benefit from the use of wavelength-locked diode pump sources, which serve to narrow and stabilize the pump emission spectrum to keep it closely aligned to this absorption feature. To date, high power diode laser locking schemes such as internal distributed feedback Bragg gratings and externally-aligned volume holographic grating optics, VHG's, have not been widely implemented due to the increased cost and assumed performance penalty of the technology. However, recent advancements in the manufacture of stabilized diode pump sources which utilize external wavelength locking now offer improved spectral properties with little-to-no impact on power and efficiency [2]. Furthermore, improvements in manufacturing processes are rapidly reducing the cost of the approach. In this work, we discuss progress in the performance and reliability of commercial high-efficiency 885-nm diode laser pump sources.

The laser diodes described herein are all grown by metallorganic chemical vapor deposition (MOCVD) and wafers follow a standard broad area diode laser fabrication procedure. Figure 1 illustrates results for the commercial high-efficiency 885-nm design in cm-bar array format bonded to microchannel-coolers. 50% fill-factor bars achieve >100W and 65% power conversion efficiency. Eighteen such bars were placed on lifetest at 110W, 40 ºC. Figure 2 illustrates the normalized power versus time for the test. To date, >100,000 hours have been collected with no observed failures, defined here as >20% power degradation.



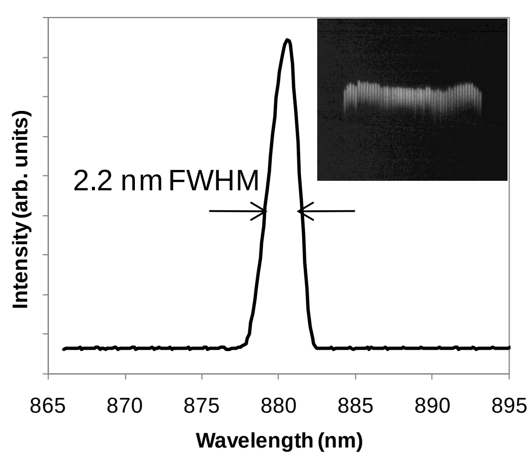




**Figure 1.** (Left) 50% fill-factor 885-nm microchannel cooled bars deliver >100W and 65% conversion efficiency. (Right) Typical lasing spectrum of one such bar. Inset depicts a spatially-resolved emitter spectrum taken at 100W [3].

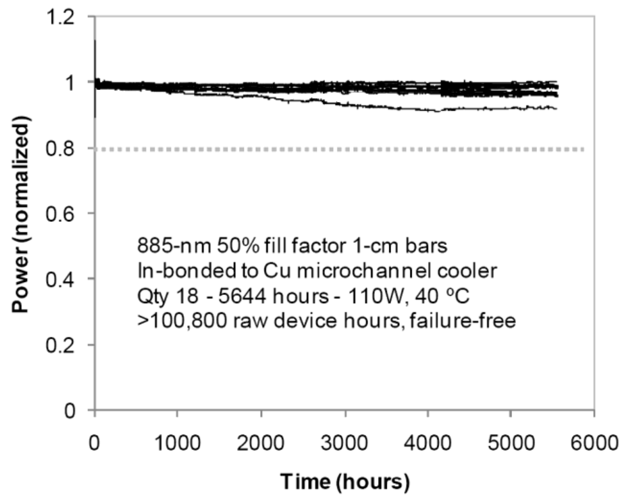



**Figure 2.** Accelerated aging test of 18 bars has shown >100,000 raw device hours, failure free [3].

Wavelength-locking at the bar-level is achieved through the use of an integrated volumetric holographic grating with the fast-axis collimating lens (VHG-FAC) [4-6]. This approach provides feedback to a small cone of the divergent beam exiting the emitters, relaxing the alignment tolerances necessary to achieve good locking and thereby reducing dependence on bar smile [6]. This approach causes a perturbation of the optical mode inside the laser cavity, resulting (in this case) in an 8% power penalty relative to the unlocked performance. Figure 3 illustrates the results of a 7-bar vertically-stacked array of VHG-FAC locked 885nm bars. The array is operated CW at 25ºC, with the power, efficiency, and lasing spectrum measured at time zero and after 1100 hours of operation. The stack is rated to 700W (100W per bar), but in this case, only tested to 650W due to current limitations of the power supply. As shown, the power, efficiency, and lasing spectrum remain unchanged after 1100 hours of operation, indicating the high robustness of the approach.

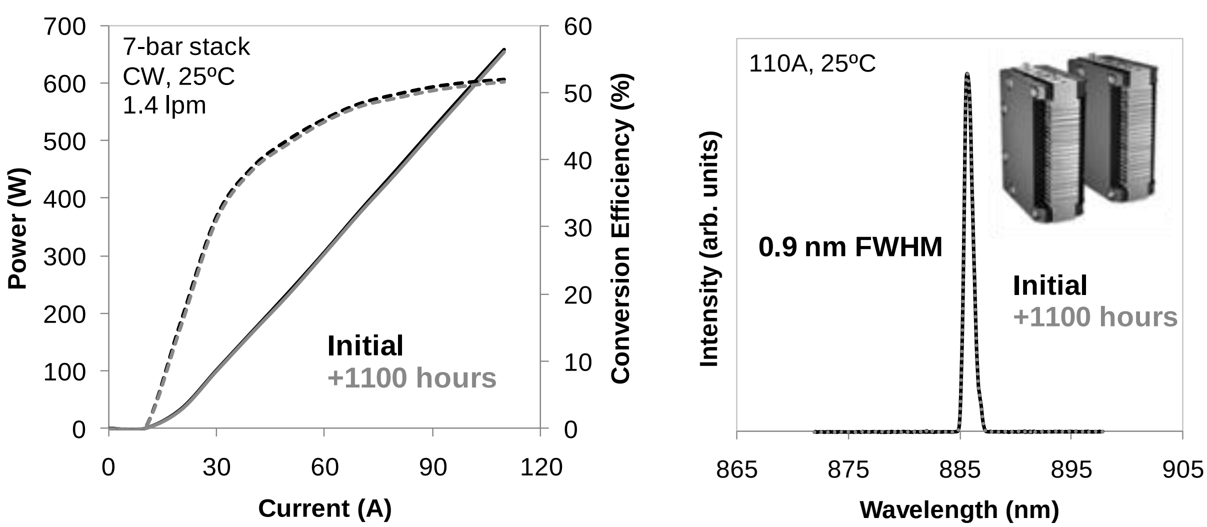



**Figure 3.** A 7-bar stacked is wavelength-locked with integrated volume Bragg grating fast-axis collimating lenses (VBG-FAC); without optimization, the observed power penalty due to wavelength locking is ~8%. (Left) The wavelength-locked VBG-FAC 7-bar stack operates at 650W (measurement limited to 110A, typical rating is 100W/bar) and 52% conversion efficiency. The power and efficiency remain unchanged after 1100 hours of operation. (Right) The wavelength-locked stack achieves 0.9 nm FWHM spectral bandwidth, which also remains unchanged after 1100 hours of operation [2].

High-brightness fiber-coupled packages based on arrays of single emitters offer numerous advantages over bar-based solutions, and are driving the development of high-performance diode lasers in hard-soldered, single-emitter formats [7-8]. Figure 4 illustrates the performance of nLight's commercial high efficiency 885-nm laser diode in a single 200-µm-stripe, 3 mm cavity length format; the chip is AuSn-soldered to a coefficient of thermal expansion-matched heatsink and tested continuous-wave at 25ºC. These chips are shown to deliver >15W and 66% conversion efficiency. Results from a step-stress reliability study show a mean-time-to-failure >250,000 hours (~28 years) at the rated 8A, 25 ºC operating condition with 90% statistical confidence. Note the failures are assumed to follow an exponential model with temperature and current acceleration following an Arrhenius ($E_a$ = 0.45 eV) and power (m = 4) law, respectively [9].

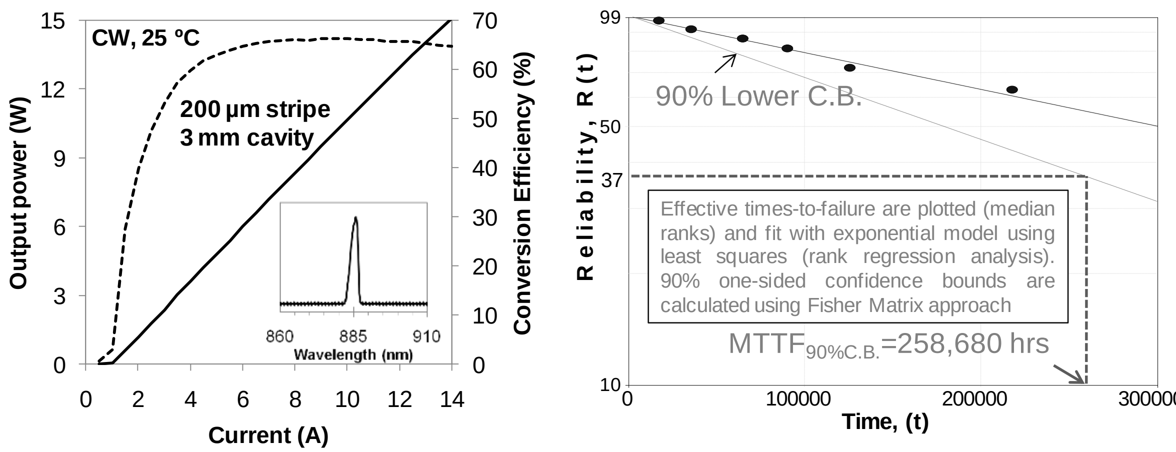



**Figure 4.** (Left) 200µm stripe hard-soldered single-emitters operating at 885-nm deliver >15W and >66% power conversion efficiency. The inset depicts the optical lasing spectrum measured at 10W. (Right) Effective times-to-failure are plotted versus time and fit with an exponential model using rank regression analysis. The plot shows reliability versus time. Six device failures were recorded in an accelerated lifetest study of total quantity 19 chips, with temperature acceleration assumed to follow the Arrhenius law (with $E_a$ = 0.45 eV) and current assumed to follow a power law (with m = 4).

These chips are collimated in the fast axis and wavelength-locked with an optimized VHG. Figure 5 illustrates the power and efficiency versus drive current and lasing spectrum before and after wavelength locking. As shown, the device suffers minimal (~1.7%) penalty to the power as a result of lensing and locking; the locked chip maintains >64% conversion efficiency while the spectrum is narrowed by nearly an order-of-magnitude to 0.3 nm FWHM. Note the residual penalty to performance is attributed to imperfect AR coatings on the surfaces of the fast axis collimating lens and volumetric Bragg grating, and it is expected that further optimization would allow for a reduction in the observed power penalty to below 1%.

These single emitters form the building blocks for nLight's Pearl™ conductively-cooled, fiber-coupled package platform [7-8]. Figure 6 illustrates the power and efficiency versus current for a module consisting of 16 unlocked emitters coupled into a 400 µm, 0.22NA fiber. The module is rated to 100W and delivers >58% conversion efficiency, measured from the fiber. Packages which utilize wavelength-locked emitters and are coupled into smaller core fibers for higher brightness are also available.

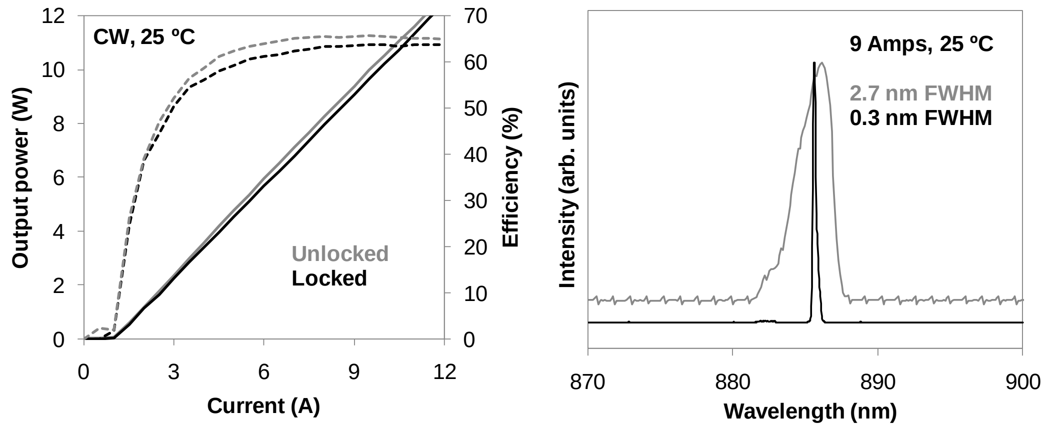



**Figure 5.** (Left) Light and efficiency curve of a single 200 µm stripe hard-soldered emitter before and after wavelength-locking with a VHG. Unlocked, the diode (tested continuous wave at 25 ºC) produces >12W at 66% conversion efficiency. The power and efficiency are decreased by less than 2% after VHG-locking. (b) Optical lasing spectrum of the emitter before and after locking, taken at 9 amps, and plotted on a linear scale. As shown, the VHG reduces the spectral width by nearly an order-of-magnitude [2].

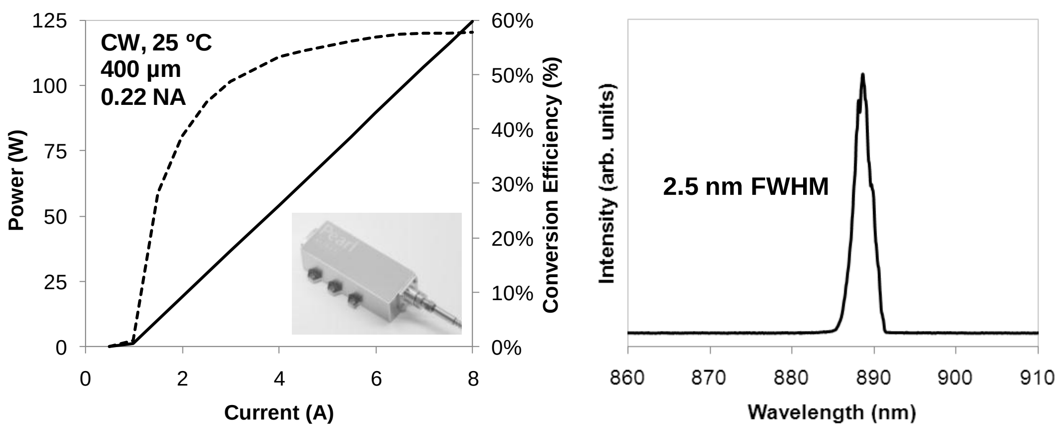



**Figure 6.** (Left) Light and efficiency curve of a 100W-rated 885-nm Pearl™ module coupled 400 µm core, 0.22 NA fiber. (Right) Typical lasing spectrum of the module measured at 100W.

## References


[1] P. M. Frede*, et al., Optics Lett.,* vol. 31, pp. 3618-3619, (2006).

[2] P. Leisher, *et al., Proc. SPIE*, vol. 7198, (2009).

[3] P. Leisher, *et al., Proc. SPIE*, vol. 7325, (2009).

[4] A G. Steckman, *et al., IEEE J. Sel. Top. Quant. Elect.*, vol. 13, no. 3, pp. 672-678, (2007).

[5] L. Glebov, *Photonics Spectra*, Jan. (2005).

[6] B. Köhler, *et al., Proc. SPIE*, vol. 7198, (2009).

[7] S. Patterson, *et al*., *DEPS 20$^{th}$ SSDLTR*, (2007).

[8] S. Karlsen, *et al., Proc. SPIE*, vol. 7198, (2009).

[9] H. Pfeiffer, *et al., OFC Conference*, no. ThN4, (2002).