

Progress in Fiber-Coupled, High-Brightness, High-Power Diode Laser Pump Sources

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Current high-power, fiber-coupled diode laser systems are fabricated using laser diode bars with beam-shaping optics. Although bar-based systems can couple impressive amounts of power into a fiber, they operate with low overall efficiency due to device cross-heating and poor fiber coupling efficiency. These systems are large, complex, and cumbersome. nLIGHT Photonics has developed a high-power, fiber-coupled product line based on individual emitters instead of laser bars, making possible compact, bright, efficient systems that can be implemented over a wide range of wavelengths [1].

nLIGHT maintains that there are distinct advantages for using single emitters over laser diode bars including improved device performance, improved yield, increased reliability, and simplified optical design. Where diode laser bars suffer from cross-heating, single emitters can spread heat laterally, reducing the diode junction temperature and increasing the power available from each emitter. For instance, diode bars are often limited to a linear power density of <20 mW/ μm where single emitters can be run in excess of 50 mW/ μm . Single emitters also have a yield advantage over the bar approach as individual emitters can be screened and selected. Diode laser bars are susceptible to epi defects and processing irregularities, reducing yield and increasing cost. Additionally, single emitters have a much smaller area than diode bars, mitigating thermal expansion mismatch between the diode and the submount thus reducing packaging strain. Where diode laser bars typically have mean-time-to-failure (MTTF) values in the 10,000-20,000 hour range, single emitters can be made with MTTF values much greater than 100,000 hours. Lastly, the optical design for imaging the active area of the emitters onto a fiber is straightforward and can be extremely efficient.

The performance, yield, reliability, and design advantages of single emitters translates directly into improved system performance. The high linear power density of individual emitters translates into a brighter and more efficient diode laser, which translates into a brighter system. The individual emitters can be independently collimated and then focused onto a fiber, with greater than 95% fiber coupling efficiency. The geometry of the unit and corresponding optics can be chosen as to reduce the dead-space between emitters, while maintaining the power and brightness of the individual lasers which can be operated in the 50-60% efficiency range. The result of this approach is a box with unsurpassed reliability, efficiency, and brightness, all in a box that is small, compact, and conductively cooled. In contrast, the beam shaping optics of bar-based systems transforms the asymmetric output of the laser diode bar, collimating and focusing the light into fiber. However, imperfections in the beam-shaping optics lead to fiber coupling efficiencies typically in the 70-80% range. Additionally, due to device cross-heating the diode laser bar typically has efficiency values in the 40-50% range. The resulting overall system is typically 30-35% efficient, and needs to be actively cooled.

nLIGHT's high-brightness "Pearl" product line was designed to have a small footprint and still produce high output power. We have two commercially available modules designs with remarkably small dimensions: $96.5 \times 50 \times 19.5$ mm³ and $124 \times 50 \times 23$ mm³. Pictures of these modules are shown in Fig. 1. Even though the form factor is very small, these devices can sustain extremely high power per unit volume. For instance, the smaller Pearl module consists of 10 emitters and can operate in excess of 80 W coupled into a 200 μm fiber, while the larger box, containing 16 emitters, can produce over 120 W of optical power into a 200 μm , 0.22 NA fiber. These power values correspond to a Power / Volume value in excess of 0.9 W/cm³. LIV curves for the two units are shown below in Fig. 2. In comparison, multi-bar fiber-coupled modules have a power per unit volume value between 0.05 and 0.26 W/cm³. Typical single-

bar fiber-coupled modules can improve this value to between 0.25 and 0.75 W/cm³. However, these systems are typically limited to less than 40 W of optical power.

In addition to high power from a small footprint, the Pearl product line can be designed for high brightness [2]. To address the high brightness market, we have coupled 6 emitters into a 100 μm fiber, producing over 40 W of optical power into a 0.22 NA fiber. This corresponds to a brightness of over 5.5 MW/cm²*steradian, an extremely competitive value. This brightness is maintained without sacrificing efficiency, as the system demonstrates an electrical to optical efficiency of over 45% at the operating point, as shown in Figure 3.

Where high efficiency is needed, we have fabricated a module with 16 emitters that produces over 100 W of optical power coupled into a 400 μm 0.22 NA fiber that achieves over 60% peak and 59% operating electrical to optical efficiency, as measured at the distal end of the fiber. We believe this to be one of the most efficient high-power, high-brightness, fiber-coupled systems built to date. These data are shown in Figure 3.



Figure 1. (Left) Photograph of a Pearl module that can hold up to 10 single emitter diodes. The dimensions for this box are 96.5 x 50 x 19.5 mm³ (Right) A high-power Pearl module with dimensions of 124 x 50 x 23 mm³.

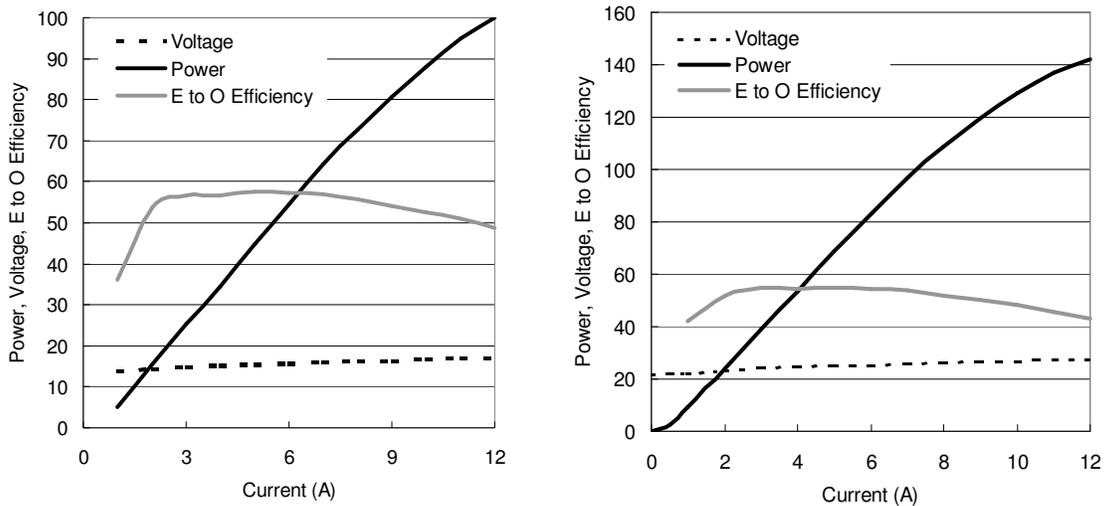


Figure 2. (Left) A Pearl module producing over 80 W of optical power coupled into a 200 μm fiber. The power per unit volume for this module is approximately 0.95 W/cm³. (Right) A high-power Pearl module with an output over 120 W of power also coupled into a 200 μm fiber. The power per unit volume for this module is approximately 0.93 W/cm³. Both of these devices are designed at 976 nm, and have a spectral FWHM smaller than 3.5 nm.

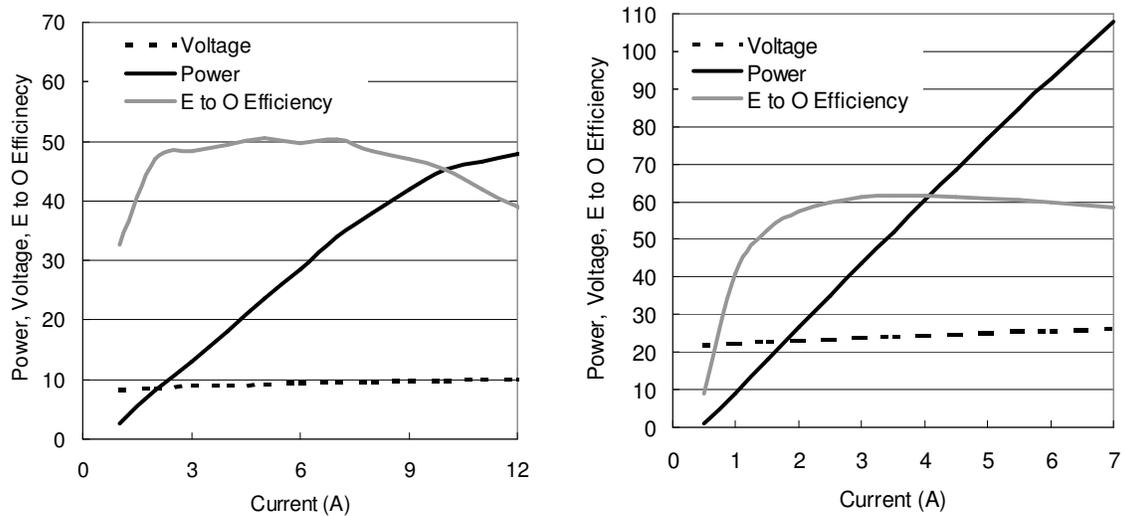


Figure 3. (Left) A Pearl module coupling over 40 W of optical power coupled into a 100 μm 0.22 NA fiber. At 40 W of power the efficiency is just below 50%. The brightness of this module is approximately 5.5 $\text{MW}/\text{cm}^2\cdot\text{steradian}$. The footprint of this unit is 96.5 x 50 x 19.5 mm, and the device lases at 976 nm. (Right) A highly efficient Pearl module with over 100 W of power demonstrates system efficiency of over 55%. This device is coupled into a 400 μm fiber, and lases at 940 nm.

In summary, nLIGHT Photonics has released a product line based on single emitters that demonstrates excellent power and brightness in a compact package. This system offers unsurpassed efficiency, demonstrating efficiency values over 50% at a variety of wavelengths. Additionally, this product line demonstrates excellent brightness, with brightness values over 5.5 $\text{MW}/\text{cm}^2\cdot\text{steradian}$.

References

- [1] S. Patterson, *et al.*, *DEPS 20th SSDLTR*, (2007).
- [2] P. Leisher, *et al.*, *Proc. SPIE*, vol. 6952, (2008).