100 W high-brightness highly-manufacturable low-SWaP multi-emitter blue laser diode source

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ABSTRACT

This paper describes the family of blue laser modules developed in Convergent Photonics, relying on a proprietary architecture of spatial and polarization multiplexing and making use of the same platform and assembly lines of similar 9xx nm laser diode multi-emitters. This proprietary technology leads to high emitted power, together with unprecedented - for blue laser sources - low SWaP (Size Weight and Power consumption) and high brightness, suitable for a cost reduction over high volume productions. Present realization is an extremely compact (53 mm x 138 mm x 14.6 mm) laser source, based on a spatial and polarization multiplexing of 20 diodes, with a 114 um core / 125 um cladding multimode fiber output. Prototypes demonstrated power in excess of 100 W at 450 nm, with 95 % of emitted power filling only 0.15 numerical aperture (N.A.).

Keywords: semiconductor lasers, high power laser diode module, blue diode lasers

1. INTRODUCTION

High power blue laser diode compact sources have been reported as extremely attractive for material processing, especially of high reflective materials such as copper and gold, and also enabling promising medical applications. Key challenge is the increase of the emitted power while ensuring high brightness (as required by industrial applications like cutting or additive manufacturing), compact size and low *cost-per-watt,* therefore enabling high volume productions as per Near Infrared (NIR) diode laser sources.

To fulfill these needs, a family of blue laser multi-emitter modules has been developed in Convergent Photonics, relying on a proprietary architecture of spatial and polarization multiplexing. By using the same platform and assembly lines of similar 9xx nm modules, is achieving an unprecedented low SWaP (Size Weight and Power consumption), high brightness and cost reduction. Present realization demonstrated power in excess of 100 W on 114 um core fiber, by this extremely compact laser source.

2. PACKAGING DESIGN AND MODEL

The packaging architecture combines single emitter laser sources coupled into an optical fiber. The mechanical package and the optical layout have been adapted from the analogous architecture used for the laser products emitting at 9xx and 796 nm, currently assembled in Torino facility of Convergent Photonics in a consolidated production line [1]. The adoption of this packaging solutions for the 450 nm wavelength range enabled a new and attractive product family for applications which need high brightness, low cost and compact high power laser sources in visible range.

This product family is based on the core technology of semiconductor laser devices mounted on a submounts (Chip on Carrier, CoC) and soldered on a platform (package). In order to scale up the optical power, a combination of spatial multiplexing (*s-series package*) is used, together with, for the higher power products, a polarization multiplexing (*d-series package*). The optical layout, including fast and slow axis collimators, reflecting mirrors, polarization beam combiner components, focusing lenses, has been designed considering the output power and brightness required target.

2.1 Optical design and simulation

In the presented work, the optical power is scaled combining spatial and polarization multiplexing. In the spatial multiplexing, beams from each single emitter are collimated by a-cylindrical lenses along the Fast Axes (FA) and Slow Axes (SA), in order to correctly manage the different divergences of the beam along parallel and transverse axes. The collimated beams are then stacked together and directed toward a focusing lens to be launched in a fiber. The optics specifications are defined by simulating the emitter source and beam propagation through the optics. The model tracing [2], [3], [4] is based on the easiest assumption of gaussian beams propagating through aberration-free thin lenses, nevertheless, thanks to its extremely low computational cost, this model is useful to roughly determine the features of the optical elements to be used, according to the target NA and magnification. The characteristics of the fiber launch are evaluated in terms of magnification and Numerical Aperture (NA) of the coupled beams. An example of this simulation output is shown in Figure 1.

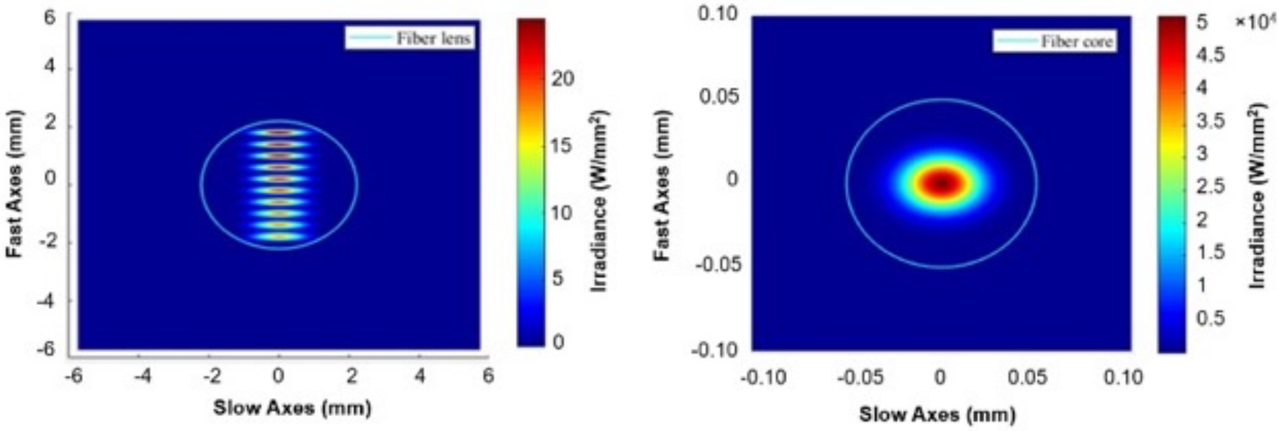

Figure 1: example of simulation with the optical layout of a stack of 10 emitters in 105um fiber core: (*left*) beams stacking at focusing lens entrance; (*right*) focalized beam into the fiber core.

Power scaling by spatial multiplexing is limited by the Beam Parameter Product (BPP) required at the delivery fiber. In order to further scale up power maintaining high brightness, second multiplexing level employs the polarization combining, providing almost a factor of two in term of final optical power. The solution bases on the fact that the diode lasers are completely s-polarized. The module presents two stacks of collimated beams and one of them pass through a half-wavelength plate to rotate their polarization plane, before being focused on the fiber, together with the other stack (Figure 2).

2.2 Mechanical design

For the entire gamma of product at 450nm, only two package cases have been used:

- *s-serie* package with a very compact foot print of 53 mm × 107.5 mm has been designed in order to host a stack of a defined number of CoC for the spatial multiplexing .
- *d-serie* package, foot print of 53 mm × 138 mm able to combine both spatial and polarization multiplexing [5].

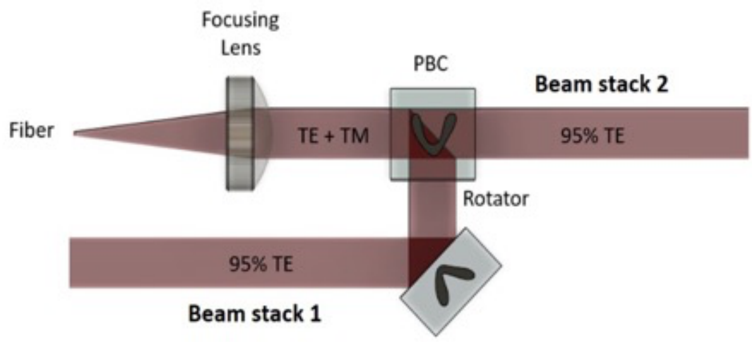

Figure 2: scheme of a polarization multiplexing. Two s-polarized beams pass through a Polarization Beam Combiner (PBC): one beam rotates its polarization plane by a half-wavelength plate, then its contribution is added to the other beam.

The number of single emitters is determined by the simulation, and limited by the quality target required for the output signal. Nevertheless, the package cases are not modified in order to be easily assembled in an already existing production line. This allowed a limited impact on the hardware upgrade of the assembly systems, and a short developing time for the new products.

The CoC are mounted on the package by using a particular technology where a Sn-based soldering preform is locally melted by a laser pulsed beam. The process is performed at room temperature, without any heating cycles or chemical treatment.

CoCs are then electrically connected in series and to the package electrodes by aluminum heavy wire bonding.

Beam coming from each CoC is then individually collimated. A 90 ° reflection allows the beams to be stacked and focused together and launched in the optical fiber previously assembled. As the beam NA is mainly influenced by the number of emitters [6], the stacking distance between beams (as well as maximum number of CoC) has been selected in order to have the desired NA and BPP by the aid of the simulation previously described.

For the polarization multiplexing, in the *d-series* package the diodes are combined in two stacks. One of them pass through a half-wavelength plate, and is overlapped with the other stack by a Polarization Beam Combiner (PBC); the two stacks combined together are then focused on the fiber core through an a-spherical lens.

3. REALIZATION AND EXPERIMENTAL RESULTS

The Convergent's multi-emitters sources are based on GaN CoC emitting at 450 nm, commercially available from Osram. Preliminary results [5] demonstrated very promising combination of power, brightness, compactness and cost with the *s-series* package. A noticeable power improvement, without compromising the beam quality and the device compactness, has been achieved by the polarization multiplexing implemented in *d-series* package. The extremely compact (53 mm x 138 mm x 14.6 mm) multi-emitter is shown in Figure 3; the device has been tested at 20 °C to detect the main lasing characteristics.

Output power from the module fiber (114 µm core, 125 µm cladding) has been characterized in terms of power intensity and beam quality. Figure 3 shows the output power plotted versus the bias current: a power in excess of 100 W, together with a conversion efficiency about 35 % has been demonstrated, with an evaluated internal coupling efficiency of 95% in line with the design expectations.

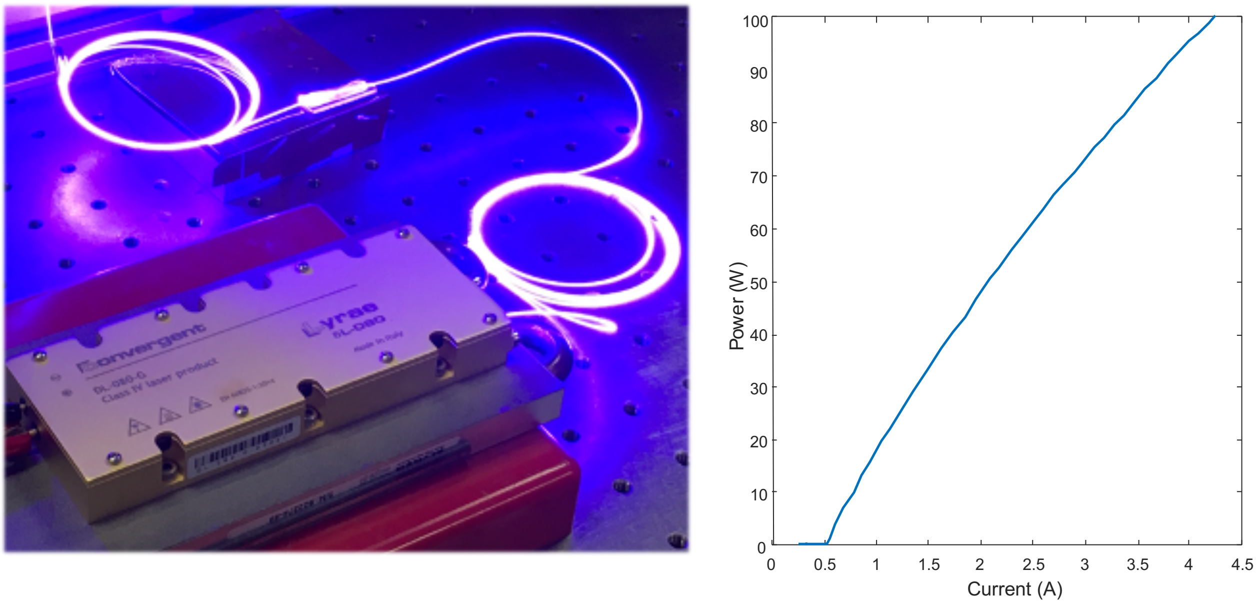

Figure 3: (*left*) the 100W module, under the power test; (*right*) the power / current characteristics, showing the output power in excess of 100 W

The Figure 4 shows the beam quality emitted by the laser module: the figure reports the measured Far Field at different bias current, confirming the estimated Numerical Aperture of 0.15 (filled by 95 % of emitted power), in good agreement with the simulated data. A performance comparison of the blue multi-emitter laser family is summarized in Table 1, demonstrating the unmatched low SWaP and high brightness achieved by the compact laser source family.

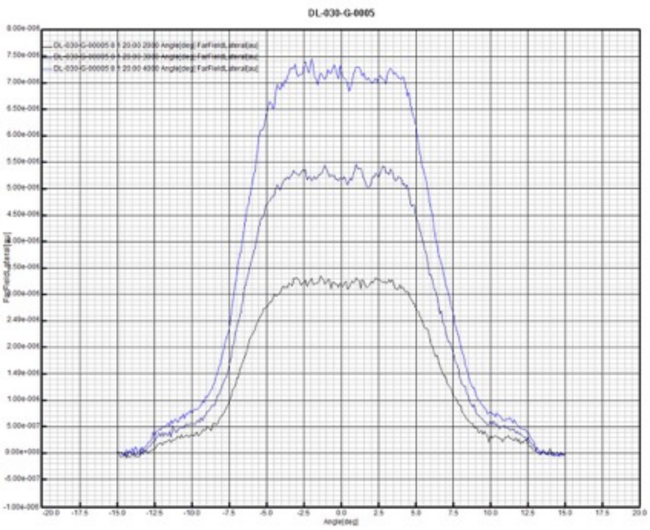

Figure 4: Far Field emitted by the module at 2, 3 and 4 A of bias current; a 0.15 N.A. at max power (filled by 95 % of emitted power) has been evaluated from the far field measurement

PN	450nm Wavelength Source Family						
	Package	*Size (mm x mm x mm)*	*Output power (W)*	*Fiber core/cladding (μm)*	*NA*	*BPP (mm mrad)*	*Brightness ($W/\mu m^2$ ster)*
DL-030-E	s-series	53 x 107.5 x 14.5	30	50/125	0.18	4.5	0.15
DL-040-G	s-series	53 x 107.5 x 14.5	40	114/125	0.15	8.6	0.07
DL-100-G	d-series	53 x 138 x 14.6	100	114/125	0.15	8.6	0.14

Table 1: overall characteristics of the blue multi-emitter laser family

4. CONCLUSIONS

A family of blue laser multi-emitter modules has been developed, relying on a Convergent Photonics proprietary architecture of spatial and polarization multiplexing, using the same platform and assembly lines of similar 9xx nm modules.

This proprietary technology leads to high emitted power, together with unprecedented low SWaP (Size Weight and Power consumption) and high brightness, perfect for a cost reduction over high volume productions. Present realization demonstrated power in excess of 100 W on 114 um core fiber, by an extremely compact (53 mm x 138 mm x 14.6 mm) laser source.

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