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High brightness 100 W – 50 µm delivery blue laser diode module

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ABSTRACT

Blue laser diodes are emerging as the next revolution in laser material processing, especially for high reflective materials, such as copper and gold. The paper presents the most recent evolution of a family of medium-high power and high brightness devices specifically conceived for micro-machining applications. The modules make use of a proprietary architecture based on the combination of commercial laser diodes in TO9 package. The diodes are first organized in rows staggered along the fast axis, then the rows are multiplexed along the fast axis; finally, wavelength and polarization multiplexing are exploited to achieve up to 100 W of power into a 50 µm/0.22NA fiber.

Keywords: Blue laser diodes, Laser processing of copper, Laser processing of gold, High-brightness laser diodes, High power laser diodes

1. INTRODUCTION

The quest for higher power and brightness laser diode modules so far has been driven mainly by devices emitting in the 900–1000 nm range, which are typically used as pump sources for fiber and solid-state lasers for material processing, although the latest advancements in chip technology have paved the way also to new industrial applications for direct-diode configurations, especially for laser cladding and for welding of metal sheets.[1–3]

Industrial material processing is today largely dominated by kilowatt fiber lasers emitting in the 1000–1100 nm range, which are known to be the golden standard technology for cutting, welding and brazing many metals, such as iron, steel and titanium. Conversely, these lasers are very inefficient in processing highly-reflective and highly conductive materials (HRMs), such as copper and gold. Indeed, effective processing of HRMs would require shorter laser wavelengths, with blue (i.e., around 450 nm) being the ideal choice because of its high absorption (for example close to 70% for copper and gold as compared to about 5% at 1000 nm) combined with the availability of GaN-based chips directly emitting at these wavelength without requiring additional frequency conversion components. However, while chips emitting at 9xx nm have maximum power in the order of 10–15 W, the high power blue emitters today are able to deliver only about 3–5 W. This means that, in order to reach the hundreds of watts required for industrial processing, many more diodes are to be combined; in turn this poses important challenges in implementing the multiplexing approaches to preserve the highest possible beam quality, as brilliance still represents a key figure of merit like in any high-power laser application.

The interest in laser processing of HRMs is rapidly growing, fueled mainly by emerging applications such as electrode welding of battery packs for electrical vehicles and additive manufacturing from copper metal powders.[4] To the best of our knowledge, considering only data taken from publicly available datasheets, the state of the art in fiber coupled high-power blue laser modules is given by some sources based on single emitters capable of delivering about 60 W and 100 W in a 100 µm/0.2 NA fiber (SLD and Shimadzu, respectively) or about 200 W in a 200 µm/0.2 NA fiber (Nuburu) or by devices based on bars capable of delivering up to 1500 W in a 600 µm/0.2 NA fiber (Laserline).

Leveraging on previously demonstrated[5, 6] capabilities to design and assemble high-power and high-brilliance fiber coupled laser diodes emitting at 9xx nm, this papers report on a new blue laser module prototype based on single emitters that allows achieving 100 W in a 50 µm/0.22 NA fiber by exploiting a combination of different

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multiplexing approaches. First, the single emitting blue diodes are spatially combined in rows and wavelength stabilized; then, some rows emitting at slightly different wavelengths are spectrally combined. Finally, the two of such spectrally combined beams are combined in polarization.

2. MODULE DESIGN AND REALIZATION

The developed blue laser module is based on the combination of single emitter diodes in TO9 package. The layout has been designed using a proprietary multi-emitter simulation tool, combined with commercial ray tracing software. Computing the NA filling and the focused spot size, the optimal number of spatially stacked single emitters to best fill a 50 µm / 0.22 NA fiber has been determined. As it can be seen in Fig. 1, up to seven single emitters can be stacked along the fast axis. This means that, considering the maximum emitted power by each emitter, the polarization multiplexing, and the expected coupling loss, to achieve 100 W, spectral multiplexing with three wavelengths is required.

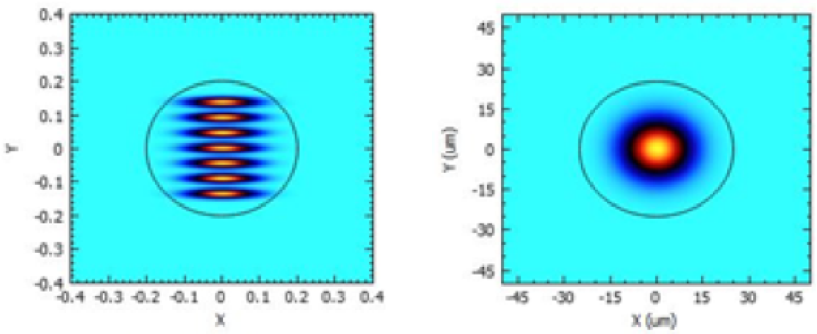

Figure 1. Optical simulation for optimal filling into a 50 µm / 0.22 NA fiber (left) and focused spot size (right).

In order to exploit a dense spectral multiplexing, rows composed of seven emitters each have been wavelength stabilized at 440 nm, 444 nm, 448 nm through Volume Holographic Gratings (VHGs) positioned at the output of each stack. Spectral multiplexing employs dichroic mirrors placed as in the scheme of Fig. 2. The power (and the number of emitters) is then doubled by polarization combining employing a Polarization Beam Combiner (PBC). Finally, the beam is focused in the fiber through a telescope lens system.

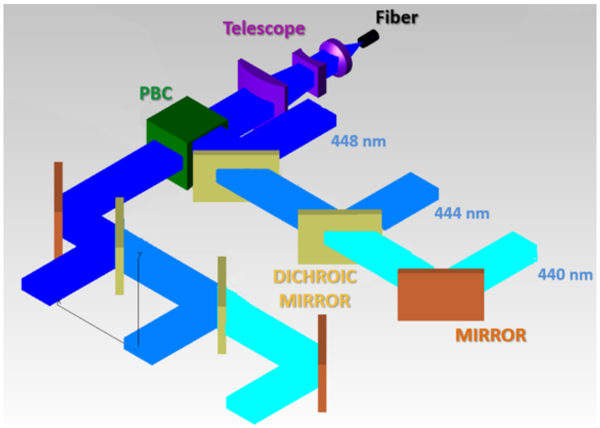

Figure 2. Scheme of the module optical architecture.

Using commercially available diodes emitting 3.5 W and assuming an overall 30% loss, the proposed solution is capable of providing 100 W of coupled power into a 50 nm / 0.22 NA fiber, for a brilliance of about 330 GW/(sr m^2).

The tolerance for a non-perfect parallelism of the beams has also been evaluated, finding ±0.02° for a rotation along the fast axis and ±0.03° along the slow axis. In the situation shown in Fig. 3, the losses are around 10%

for the non-perfect parallelism, which means 10 W in the cladding. However, this value can be lowered with a more precise alignment.

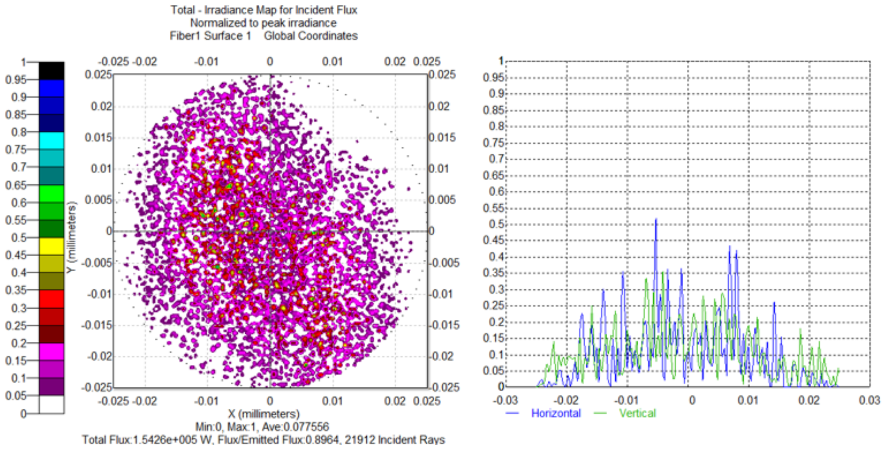

Figure 3. Tolerance analysis: focusing of non-parallel beams within the limits.

Since the single emitters are almost fully TE polarized, in the developed architecture the advantage of pure S polarization has been exploited in the design of the dichroic mirrors. This allowed having only 4 nm spacing between two consecutive multiplexed wavelengths. Fig. 4 reports the simulated response of the designed dichroic mirrors: as it can be seen, the transition is very steep due to the presence of S polarization only.

The assembly of the prototype module has been made by using an ad-hoc automatic assembly line that exploits artificial intelligence approaches to optimize the positioning and alignment of the optics while minimizing the required time.[7,8] The final layout is composed of 3 blades: each of the lowest two implements the beam stacking with the three wavelengths for a single polarization, while the topmost one the polarization combining and the focusing through the telescope system.

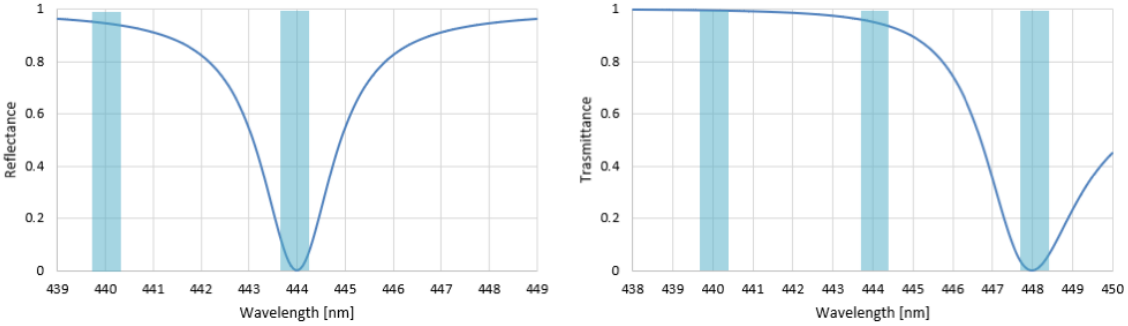

Figure 4. Dichroic mirrors simulated response. On the left, the first dichroic mirror, which transmits one wavelength and reflects the other. On the right, the second dichroic mirror, which transmits two of the three wavelengths.

3. EXPERIMENTAL RESULTS

The spectra of an emitter are shown in Fig. 5, comparing the same diode without/with the VHG stabilization. The picture on the left shows that well above the threshold the peak emission at 445 nm without VHG shifts at 444 nm when a VHG at 444 nm is used, with shrinking of the FWHM below 1 nm (as measured considering using quite a poor resolution spectrometer). The effectiveness of the wavelength locking has also been verified for low driving currents: in the picture on the right of Fig. 5 it is shown that while the laser diode is operating below the threshold, inserting the VHG makes the emitter lase because of the increased feedback.

Fig. 6 reports the measured power, before and after coupling with the delivery fiber, for the assembled prototype. The goal of 100 W coupled in the delivery fiber is attained, with coupling losses of about 8%. The overall losses are about 30%, as expected.

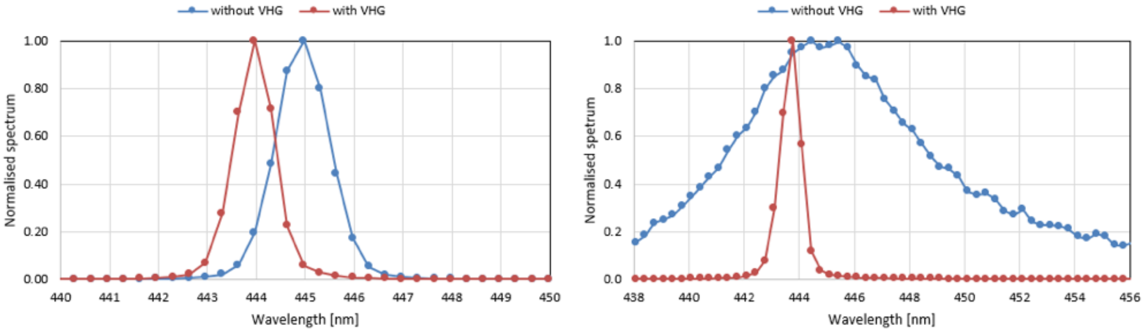

Figure 5. On the left: typical measured spectrum of a single emitter before (blue curve) and after stabilization (red curve); on the right: similar case, but for single emitter below threshold without the VHG.

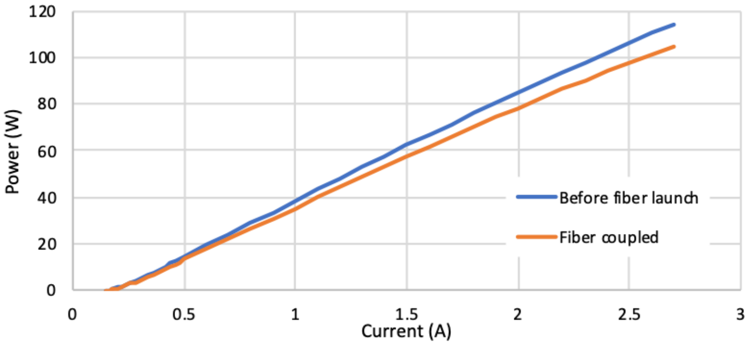

Figure 6. Final prototype output power against driving current, before and after the fiber coupling.

4. CONCLUSIONS

A prototype of a blue laser module capable of emitting 100 W in 50 µm/ 0.22 NA delivery fiber for a brightness is 330 GW/(sr m^2) has been designed, assembled and characterized.

The device has been built using a patented layout the exploits the combination of single emitters in TO9 package. Different levels of multiplexing (spatial, dense wavelength, and polarization multiplexing) have been used to maximize the number of emitters that can be coupled to the delivery fiber. This because the power emitted by current state-of-the-art commercial blue diodes is still much lower than the corresponding devices emitting at 9xx nm, hence much more chips are required to achieve the hundred of watts necessary for material processing applications.

The obtained results are in-line with expectations, although further tests to evaluate the long-term reliability are still on-going.

REFERENCES

[1] Laukart, A., Kohl, S., Fritsche, H., Grohe, A., Kruschke, B., and Schmidt, M., "Experimental and numerical investigations of laser beam welding with an ultra-high brightness direct-diode laser", Physics Procedia 83, 1397–1403 (2016).

[2] Costa Rodrigues, G., and Duflou, J.R., "Opportunities in laser cutting with direct diode laser configurations", CIRP Annals 66, 245–248 (2017).

[3] Kleine, K., and Balu, P., "High-power diode laser sources for materials processing", 2017 IEEE High Power Diode Lasers and Systems Conference (HPD) (2017)

[4] Asano, K., Tsukamoto, M., Funada, Y., Sakon, Y., Abe, N., Sato, Y., Higashino, R., Sengoku, M., and Yoshida, M., "Copper film formation on metal surfaces with 100 W blue direct diode laser system", Journal of Laser Applications 30 (2018).

[5] Yu, H., Riva, M., Rossi, G., Braglia, A., and Perrone, G., "High-power and brightness laser diode modules using new DBR chips", Proc. SPIE 10514, 105140 (2018).

[6] Yu H., Rossi, G., Braglia, A., and Perrone, G., "Development of a 300 W 105/0.15 fiber pigtailed diode module for additive manufacturing applications", Proc. SPIE 10086, 100860A (2017).

[7] Yu, H., Rossi, G., Braglia, A., and Perrone, G., "Investigation of collimating and focusing lenses impact on laser diode stack beam parameter product," Appl. Opt. 54, 10240–10248 (2015).

[8] Yu, H., Rossi, G., Braglia, A., and Perrone, G., "Application of Gaussian beam ray-equivalent model and back-propagation artificial neural network in laser diode fast axis collimator assembly," Appl. Opt. 55, 6530–6537 (2016).