Beam shaping concepts for kW-Class CW and QCW diode lasers

Andreas Unger*, Willhelm Fassbender, Holger Müntz, Bernd Köhler, Jens Biesenbach

DILAS Diodenlaser GmbH, Galileo-Galilei-Str. 10, 55129 Mainz-Hechtsheim, Germany

ABSTRACT

In modern diode lasers beam shaping of the highly asymmetric laser beam, which exits the front facet of the semiconductor laser material, is a crucial step towards cost efficient high brightness laser modules which in turn can be further combined towards kW-class diode lasers and can be efficiently fiber coupled. In order to scale up the power of a single laser module in an economic way, high fill factor laser bars are employed. The increased power density from such a laser bar requires improved cooling technologies. On the other hand the increased fill factor of the bar makes advanced beam shaping necessary to be able to achieve small focal spot sizes and couple the laser module efficiently into optical fibers. Finally, to be able to mass produce the laser modules, it is desirable to design the module in a way that allows automated packaging and optics alignment.

In this talk, the beam shaping concepts developed at DILAS for high fill factor bars are presented. Starting from optical simulation and choice of optical elements the laser modules incorporating these bars are presented. The concepts developed enable very compact laser modules of up to 2kW of power at a single wavelength with beam qualities of less than 40mm x mrad. Optionally these modules can be wavelength stabilized via external feedback. The packaging technology developed enables the automated alignment of the optics and cooling is DI-water free. Based on the same concepts very compact free space and fiber coupled QCW packages are presented as well.

.

KEYWORDS: Industrial Laser, High-Power Diode Laser, High-Brightness, Fiber Coupling, Materials Processing, Scalable, Modular,

1 INTRODUCTION

The market for kw-class industrial lasers can coarsely be divided into low beam quality and high beam quality applications. High beam quality applications are laser sheet metal cutting which needs beam qualities less than 10 mm mrad and laser welding with 20 to 30 mm mrad. While the latter can be addressed with currently available direct diode lasers the former is still largely the domain of fiber lasers and CO2-lasers although there are concepts for direct diode lasers available. Besides these applications there are numerous applications which do not require high beam qualities but can be addressed with lasers that have more than 40mm mrad beam qualities and output powers up to 10kW. Examples of this applications include laser brazing, hardening, cladding or heat treatment.

In the past module concepts for pumping and direct applications were developed based on the T-bar concept[1-5]. This concept employs low fill factor bars to achieve high beam quality with maximized power conversion efficiency and minimized optics cost at the same time. The low fill factor enables 200µm fiber coupling with only simple collimation and focusing optics. The minimum number of optical elements together with the adapted bar structure accounts for an efficient and economic high beam quality laser source. When going to higher fill factors and laser bar powers beam quality decreases which necessitates beam transformation optics that impose some efficiency penalty and cost increase per bar, however overall cost per power can substantially decrease. When high beam quality is not needed for a specific application it can therefore be advantageous to employ high fill factor bars. The question arises what is the optimum fill factor for a given beam quality and application. In between the design targets beam quality, cost and efficiency an optimum trade-off has to be found. For very high powers in the range of several kWs and low beam quality (>40mm mrad) we developed new laser modules based on 50% fill factor bars as an answer to this question. These modules deliver up to 2kW of output power at a single wavelength which can be coupled to optical fibers with a beam quality of >40mm mrad. The aim of this paper is to report this developments.

* a.unger@dilas.de, tel. +49 (0)6131 9226 459; fax +49 (0)6131 9226 257; www.dilas.de

The paper is structured as follows: First the development of the modules is shown. Second measurements of the actual performance of the developed modules are presented. Briefly integrated systems which employ the new modules are described and finally a summary and conclusion is presented.

2 DESIGN OF LASER MODULES BASED ON 50% FILL FACTOR BARS

In this section the development of the laser modules based on 50% fill factor bars is shown. The section is divided in 3 subsections. At first the beam shaping of a single bar is shown. Then the development of a new cooler for up to 5 of these bars is reported and finally the setup of the module is shown.

Beam shaping

The laser diode bars with 50% fill factor employed in the new modules have a beam parameter product (BPP) of about 260 mm mrad in the slow axis and are therefore not suited for coupling into fibers with 40-100mm mrad BPP. Since the fast axis is nearly diffraction limited, a beam twister can be employed to twist the single emitters of the bar so that the fast axis of the emitters is aligned in the horizontal plane. The resulting beam can be collimated in the slow axis with a simple cylindrical lens. With the correct focal length of the cylindrical length a beam results that is almost symmetric in the far field. Stacking of multiple beams in the vertical axis leads to a symmetric near field as well and a fully symmetric laser beam results that can be coupled to a fiber with a simple spherical or aspherical lens. Figure 1 shows a Zemax simulation of the beam transformation optics. The highly asymmetric far field which exits the laser bar facet (Figure 1 b) is transformed to an almost symmetric far field with a low divergence of about 8 mrad x 10 mrad. At the same time the near field (Figure 1 a) is transformed into a more symmetric one with a size of 10mm x 2.5mm.

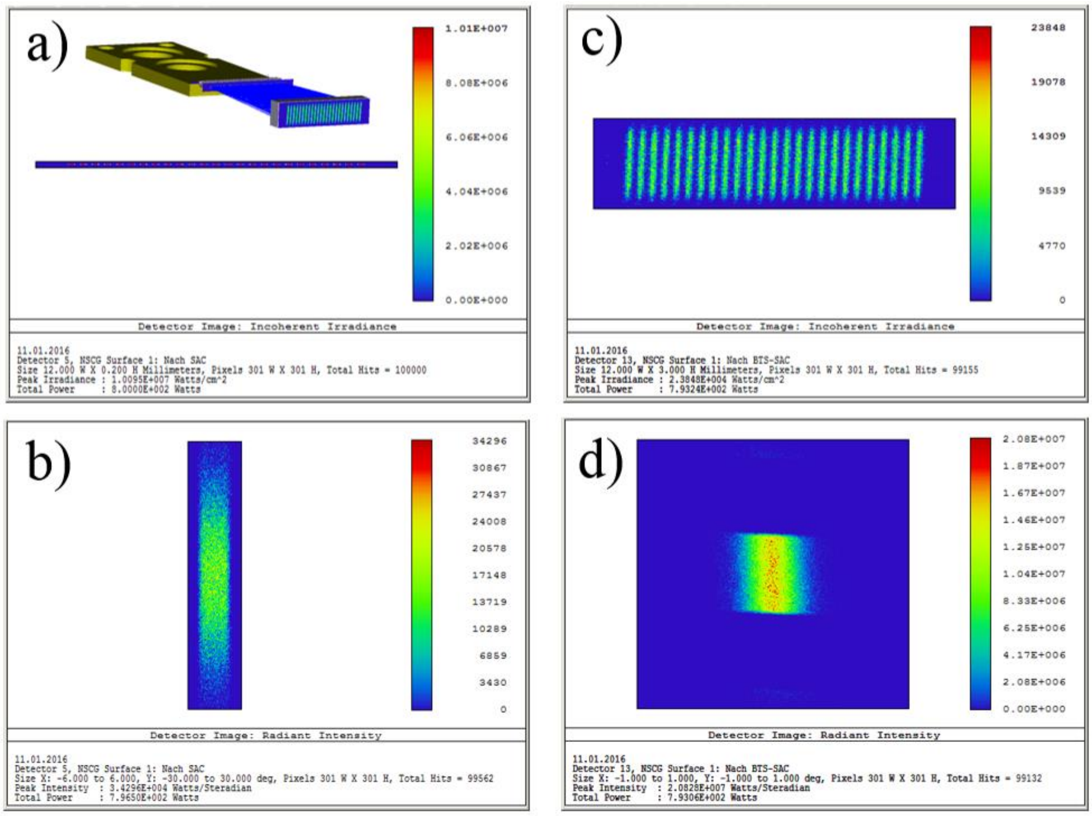

Fig. 1: a) Near field of the raw diode bar (inset: Zemax simulation of the transformation optics) b) far field of the raw diode bar. c) and d) near and far field of the transformed laser diode bar.

Cooler design

For the employed diode bars a new cooler had to be developed as well. This cooler is designed to accommodate up to 5 diode bars horizontally in a row to deliver up to 1kW of output power which implies that it also has to remove up to 1kW of heat. Since it should be operated with non DI-water the cooling water has to be isolated from the electrical current path. Therefore the diodes bars are first soldered to an electrical isolating ceramic submount which is than soldered to the cooler. CFD and thermal simulation was used to design an internal cooling structure with minimized pressure drop and homogeneous temperature profile across the whole cooler to minimize spectral broadening trough temperature gradients along the diode bars. The outer layout follows closely the previously published macrocooler design[5] which enables fully automated alignment based on an existing production line.

Module design

Up to two coolers with up to 8 (2x4) or 10 (2x5) diode bars are stacked and the transformed bars are stacked optically along the slow axis with redirecting mirrors and polarization coupling giving an optical stack with 4 or 5 emitters in the slow axis. In the case of 8 bars this leads to a beam which is almost symmetric in the near and far field. Such a module is designed to be coupled to a 400µm NA0.2 fiber with a spherical lens leading to more than 1kW of fiber coupled power from a compact package. The module also contains electronics for temperature and power monitoring and CAN-bus communication in a laser system comprising multiple modules. The module and all of its current and cooling water connections are designed for plug and play application in a system.

3 PERFORMANCE MEASUREMENTS OF THE NEW MODULES

Performance of a single cooler

Figure 2 shows the output power and efficiency of a single cooler equipped with 5 bars and beam transformation optics. At 220A an output power of 1kW with an electro optical efficiency of 62% is reached.

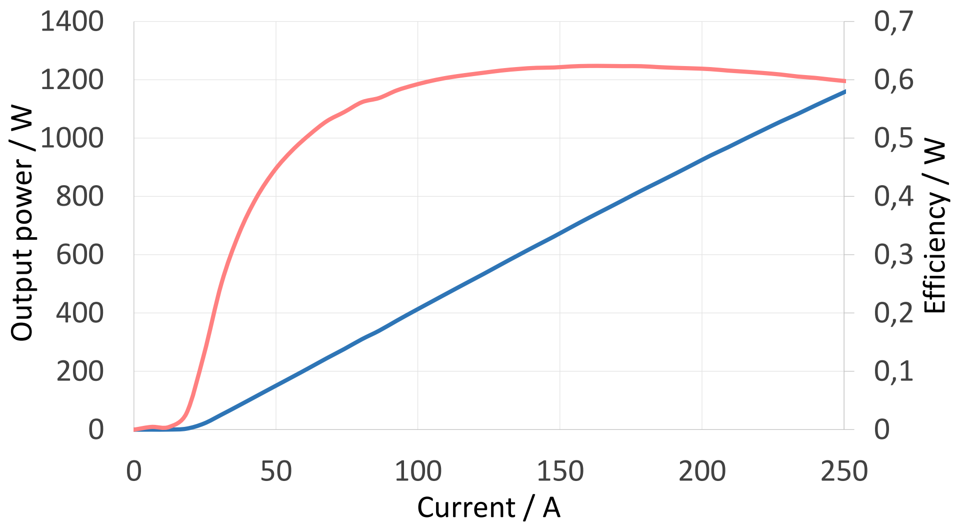

Fig. 2: Power and efficiency of the new cooler equipped with 5 bars with collimation and transformation optics.

Performance of a kw-module

Figure 3. shows a caustic scan of a module equipped with 8 diode bars as described above. A BPP of 35mm mrad in the slow axis and 26 mm mrad in the fast axis was measured. Thus these modules are well suited to be coupled to a 400µm NA0.2 fiber. Spatial stacking of 4 modules leads to a beam which still can be coupled to a 1000µm NA0.2 fiber giving more than 4kW output power at a single wavelength into 100mm mrad.

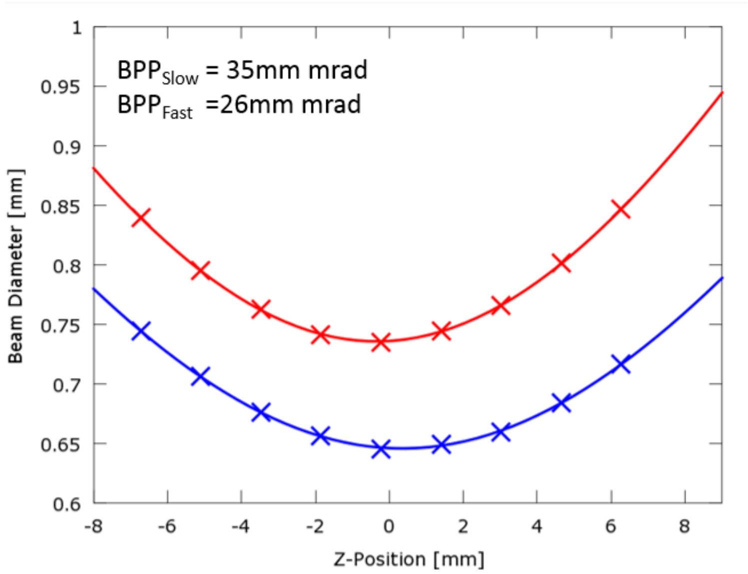

Fig. 3: Caustic scan of a module equipped with 8 bars (spatially stacked 4 emitter in the slow axis and polarization coupling).

Figure 4. shows the power and efficiency of modules equipped with 8 and 10 bars. Depending on the configuration a single module can deliver up to 2kW of output power. For a kW system an 8 bar module is used with 1kW of power from the fiber.

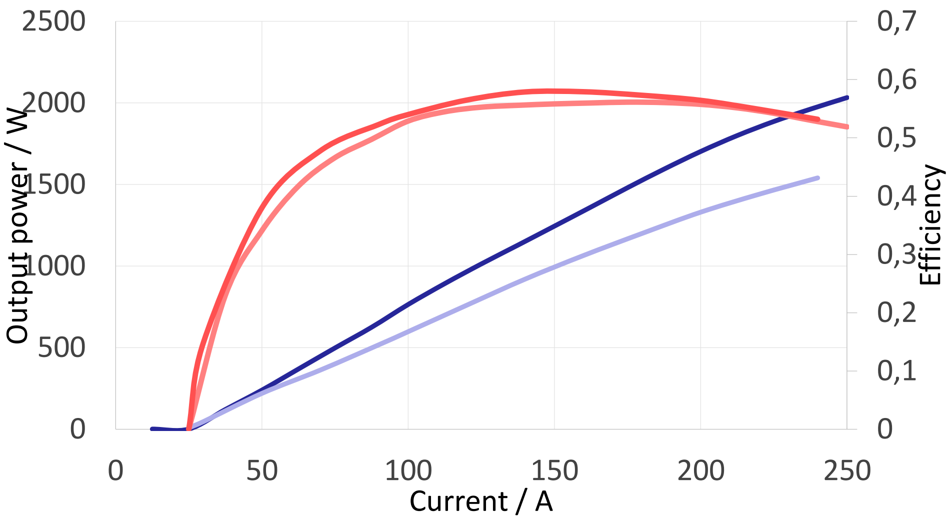

Fig. 4: Power and efficiency modules with 8 (light blue and red curves) and 10 bars (dark blue and red curves)

Performance of a system equipped with the new modules

Figure 5. shows the output power of a turnkey system equipped with 6 of the new modules which reaches 6kW of output power from a 1000µm NA0.2 fiber at 200A. The system uses spatial coupling of 3 modules and wavelength coupling at two wavelengths.

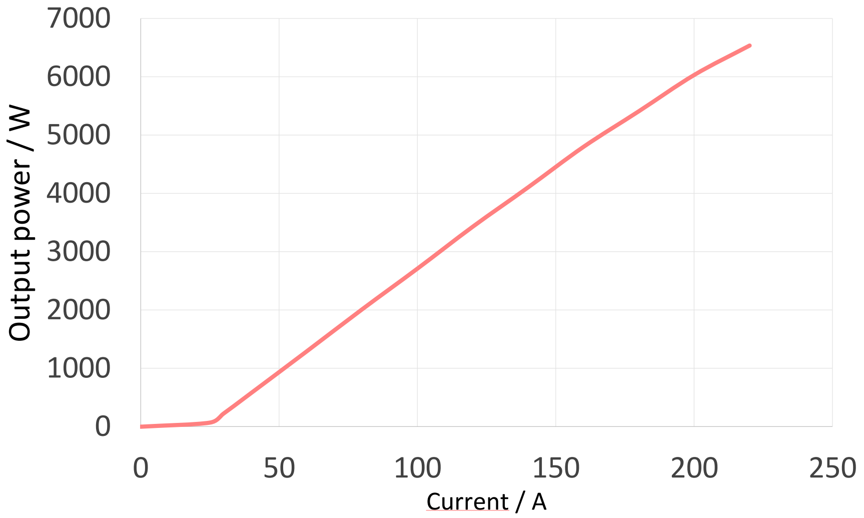

Fig. 5: Output power from a 1000µm NA0.2 fiber of a turnkey system equipped with 6 modules. The nominal power is 6kW and is reached at a current of 200A.

SUMMARY AND CONCLUSION

In this paper the development of new laser diode modules designed for kW systems was presented. The new modules employ 50% fill factor bars with beam shaping and feature a newly developed cooler with DI-water free cooling in a compact package which was designed for plug and play application into kW Systems with up to 8kW outpup power at a BPP of 100mm mrad or as a single module for coupling into 40 mm mrad fibers. While in this paper only CW applications were shown the concepts are also suitable for QCW stacks for medical and pumping applications. QCW modules with up to 2kW output power at several pumping and medical wavelengths are currently in development.

The new modules open up a path for efficient and economic kW systems with up to 4kW of power at a single wavelength. For scaling to higher powers wavelength coupling can be used. A turnkey system with 6kW of output power from a 1000µm NA 0.2 fiber, based on these modules was presented as well. This system employs six modules at two wavelengths and is especially designed for cladding, brazing and hardening applications.

REFERENCES

1. Wolf, P., Köhler, B., Rotter, K., et al., "High-power high-brightness and low-weight fiber coupled diode laser device," Proceedings of SPIE Vol. 7918, 79180O (2011)
2. Haag, M., Köhler, B., Biesenbach, J., et al., "Novel high-brightness fiber coupled diode laser device," Proceedings of SPIE Vol. 6456, 64560T (2007)
3. König, H., et al., "Scaling brilliance of high power laser diodes," Proceedings of SPIE Vol. 7583, 75830T (2010)
4. Köhler, B., Ahlert, S., Bayer, A., et al., "Scalable high-power and high-brightness fiber coupled diode laser devices", Proceedings of SPIE Vol. 8241, 824108 (2012)
5. Bayer, A., Köhler, B., Noeske, A, et al., "Scalable and modular diode laser architecture for fiber coupling that combines high-power, high-brightness and low weight", Proceeding of SPIE Vol. 8965, 89650J (2014)