Basic Concept of Tailored Bars

Results, applications and potential power scaling
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Direct diode lasers are, in principle, more efficient and smaller than classic solid-state lasers. But the combination of multiple beams from hundreds of individual emitters requires beam shaping and lensing at the expense of efficiency. At the costs for the micro-optical elements and alignment, the efforts for super-imposing of individual emitters with different techniques, assumption of the economic superiority over solid-state laser sources is not so readily apparent – so far.

The heart of our concept is a tailored diode laser bar, whose epitaxial and lateral structure is designed such, that only standard fast- and slow-axis collimation lenses, in combination with appropriate focusing optics, are required to couple the beam into a fiber with a core diameter of 200 µm and a numerical aperture of NA 0.22. The ease with which the output of tailored diode laser bars can be shaped optically makes the concept inexpensive compared to more traditional beam twisting and step mirror concepts.

Another main design aspect of the modular concept is the automation of the production steps that enable a stable and cost-efficient manufacturing process. In Dilas’ automated production lines, the bars are inspected, automatically mounted to heat sinks with in-situ position monitoring, tested and sorted depending on e.g. wavelength and performance parameters. Multiple bars are mounted on a single base plate, similar to an electronic circuit board. With integrated beam shaping that is realized by automated alignment of the micro-optics, all the individual beams of the tailored bars are then focused into the delivery fiber.

The optical output power and the beam qualities are scaled from 300 W at 10 mm·mrad as a high-brightness beam, 1200 W at 20 mm·mrad in a single wavelength for high-power fiber laser pumping and up to 4.5 kW with 25 mm·mrad using multiple wavelengths for direct diode applications.

Tailored bars for high-brightness fiber-coupled diode lasers

The tailored bar concept combines the advantage of laser diode bars, such as simultaneous multiple emitter mounting and lensing, with the advantage of single emitters, such as beam shaping, improved cooling and higher power per emitter. This leads to unparalleled brightness for fiber-coupled laser diodes, which can be used as a pump for fiber lasers or for direct diode laser materials processing applications.

The tailored bar is a diode laser bar, with its number of emitters, emitter size, and pitch chosen in a way that the desired beam quality in the slow-axis can be reached and utilized with simple optics. The next step in the modular concept is to arrange a number of tailored bars on a single base plate in combination with the fast-axis and slow-axis collimation for each bar. Optical beam shaping is used to generate an optical stack by overlaying the beams from the different bars. All optical components are mounted automatically with active alignment procedures to ensure high consistency and to minimize pointing errors which is important for the beam quality with regard to fiber coupling or wavelength stabilization. The latter one is possible by using a single volume holographic grating (VHG) for the whole set of laser bars from one base plate, locking the wavelength to a fixed center wavelength with a narrow spectral width (< 0.5 nm FWHM).

The limiting factor in the brightness of fiber-coupled modules is still the beam quality in the slow-axis of the bars. For the standard tailored bar with five emitters of 100 µm each and 1000 µm pitch, beam qualities in the range of 20 mm·mrad are achievable. Current standard power levels are at 250 W at 200 µm fiber with NA 0.22 for a module based on a single base plate.

High-brightness approach for diode lasers

With its tailored bar platform, Dilas has shipped more than 30,000 units of pump
modules for kW+ class fiber laser pumping. Combining several base plates with polarization and spatial multiplexing technologies, a whole series of standard, single wavelength based modules is produced for a variety of applications. The multiplexed modules with 2, 4 and 8 plates inside result in a series of products which can generate up to

- 250 W in 200 µm Ø, NA 0.2 fiber
- 400 W in 200 µm Ø, NA 0.2 fiber
- 800 W in 200 µm Ø, NA 0.2 fiber
- 1500 W in 300 µm Ø, NA 0.2 fiber
- 2000 W in 400 µm Ø, NA 0.2 fiber

Such modules are still single wavelength (976 nm or 915 nm) and can be used for end-pumping fiber lasers, as well as for materials processing such as thin sheet metal welding and additive manufacturing, for example.

In addition to the series of standard modules, a visible red module has been realized at 638 nm, producing 40 W in 400 µm Ø, NA 0.2 for display and projection application. The visible module is in principle also scalable with two and more plates, and first customers have already received modules at 638 nm with 80 W in 400 µm Ø, NA 0.2.

For airborne applications the tailored bar concept has already been realized with up to 330 W in 200 µm Ø, NA 0.2 fiber, at a weight of only 300 g (< 1 kg/kW). In this application, the tailored bar concept, including optical beam shaping has been proven to be ruggedized for harsh treatment such as shock and vibrations. Further work has achieved an even better weight-to-power ratio, with a tailored bar based module concept producing 650 W in 225 µm Ø, NA 0.2 fiber with only 0.65 kg/kW.

Industry requirements for a lot of welding applications ask for up to 4 kW. Scaling power by simple wavelength multiplexing would be straightforward, but still be bulky. Here, the approach to get to high-brightness combined with small footprint is to use a compact electro-optical building block which is stackable for power scalability and still compact to allow preservation of the beam quality due to short optical beam path. This is achieved by starting with a modified base plate which will generate 145 W at moderate current of 40 A with an efficiency of > 60 %. It can be equipped with a variety of wavelengths and is cooled with industrial (non-DI-) water.

The concept shown in Fig. 3, starting with the modified base plate, aligned in an automated production process with four tailored bars (1λ) and both-axis collimation. In the final arrangement, eight plates are stacked to achieve a total of 32 both-axis collimated, tailored bars (2λ) in a two-dimensional arrangement. Using spatial and polarization multiplexing in an automated alignment procedure an optimized beam quality of < 25 mm·mrad for
a single-wavelength submodule is achieved.

Combining several submodules (Fig. 3 left) with different wavelengths (915, 940, 973, 1015 and 1057 nm), and using beam compression for the multiplexed beam, the light of all modules is coupled into 400 µm Ø fiber with NA 0.12, corresponding to 25 mm · mrad (Fig. 4). At moderate current level of 35 A, being close to the efficiency maximum, an output power of 4.1 kW is achieved with 48 % electro-optical efficiency. At a current of 40 A, the output power is 4.6 kW at 46 % electro-optical efficiency. Since the set-up is principally suitable for up to 50 A, there is still headroom for higher output power for the next generation tailored bars. With a laser system based on such an engine, metal welding can be performed as shown in Fig. 6.

High-quality laser welding not only allows optimized welding seams, but also reduces cost and time requirements for reworking of parts. Depending on the application, reworking may be completely eliminated. Assemblies and parts with metal thicknesses below 1 mm allow the use of diode lasers with power levels well below 1 kW, but for thick metal welding the above described laser engine can be used to enjoy the advantages of laser-based metal welding such as:

- high welding quality with little or no reworking
- no tool wear, due to contactless process
- highest reliability with a maximum degree of flexibility
- high welding speeds
- low cost of ownership – and investment costs

High-brightness diode lasers

For a long time, high-brightness applications, such as cutting or remote welding, were not accessible for semiconductor laser-based systems. For these applications, beam parameter products well below 20 mm · mrad are necessary. In terms of using fibers with NA of 0.2 for delivery and to maintain flexibility, this corresponds to fiber diameters of 100 µm Ø. With the introduction of tailored bars for fiber-coupled module manufacturing in an automated production line, Dilas has demonstrated that the tailored bar concept allows a simplified optical train, with highest coupling efficiencies and unparalleled consistency. The consistency and very small pointing error of the individual beams allows wavelength stabilization by using a single volume holographic grating (VHG) for a whole set of laser bars. As mentioned, the limiting factor in the brightness of fiber-coupled modules is still the beam quality in the slow-axis. By using only 50-µm-wide emitting structures instead of 100 µm as for the standard tailored bars, the brightness is improved and techniques have been demonstrated allowing > 320 W in a beam parameter product (BPP) of 10 mm · mrad (Fig. 7).

For further power scaling, polarization multiplexing and wavelength multiplexing can be adopted. As each of the automated manufactured tailored bar arrangements is linearly polarized, polarization multiplexing of two base plates (2 × 7 tailored bars) could be used as a first approach to power scaling. Another way to increase brightness is wavelength multiplexing. By using a number of very different wavelengths with 20 to 40 nm differences and applying dichroic mirrors for coupling would only allow the coupling of four to five different wavelengths in the high-efficiency semiconductor laser band at 900 to 1000 nm. To achieve higher brightness levels, more wavelengths are required; subsequently, a smaller channel spacing between the different wavelengths is needed, which also makes wavelength stabilization and spectral line narrowing necessary.

Our demonstrator is based on three different free-beam modules, each equipped with seven bars and each being wavelength-stabilized with VHG’s. The center wavelength of the gratings has been set at 972, 976 and 980 nm,

![Fig. 5 The 5A-wavelength-multiplexed, fiber-coupled engine (shown here inside a turn-key system), producing > 4 kW with 48 % electro-optical efficiency and beam parameter product of 25 mm · mrad.](image)

![Fig. 6 Welding curve for stainless steel (1.4301), also indicating the cross section of the welding seam at a speed of 2 m / min.](image)
The module has a beam quality of around 30 µm. Since internally the whole beam path of this dense wavelength multiplexing setup is linearly polarized, the route for 1 kW modules with 10 mm · mrad is pretty clear. The inclusion of more wavelengths, including 911, 915 and 920 nm, as well as 935, 940 and 945 nm, which are well-proven and based on established epitaxies, will allow multi-kW class diode laser systems to be built.

**Summary**

The tailored bar concept has been described and the achievable power and brightness levels have been discussed, together with its applications such as pumping of kW+ class fiber lasers or direct diode metal welding applications, as well as variants used in cinema projection or in airborne applications. Aspects of the power scaling for the tailored bar concepts have been discussed.

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**Company**

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DILAS manufactures high-power diode laser components and systems in a wide range of output powers and wavelengths. Products range from single bar components and multi-bar sub-assemblies to high-brightness fiber-coupled diode laser modules and complete turn-key high-power diode laser systems. Founded in 1994 in Mainz, Germany, DILAS is the recognized expert in high-power diode laser technology. Today, with over 340 employees in manufacturing and research / development facilities in Europe, North American, and Asia, DILAS’ products are an essential part of business for defense, display, and projection, laser pumping, medical, printing, scientific and materials processing markets.

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![Fig. 7 PI-Power curve and electro-optical efficiency of a fiber-coupled module (100 µm core, NA 0.2) based on dense wavelength multiplexing of three different wavelengths at 972 nm, 976 nm and 980 nm.](image-url)