Comparison between 50 W tapered laser arrays and tapered single emitters

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ABSTRACT

During the last few years high power diode laser arrays have become well established for direct material processing due to their high efficiency of more than 50 %. But standard broad-area waveguide designs are susceptible to modal instabilities and filamentations resulting in low beam qualities. The beam quality increases by more than a factor of four by using tapered laser arrays, but so far they suffer from lower efficiencies. Therefore tapered lasers are mainly used today as single emitters in external resonator configurations. With increased output power and lifetime, they will be much more attractive for material processing and for pumping of fiber amplifiers.

High efficiency tapered mini bars emitting at a wavelength of 980 nm are developed, and in order to qualify the bars, the characteristics of single emitters and mini bars from the same wafer have been compared. The mini bars have a width of 6 mm with 12 emitters. The ridge waveguide tapered lasers consist of a 500 µm long ridge and a 2000 µm long tapered section.

The results show very similar behavior of the electro-optical characteristics and the beam quality for single emitters and bars. Due to different junction temperatures, different slope efficiencies were measured: 0.8 W/A for passively cooled mini bars and 1.0 W/A for actively cooled mini-bars and single emitters. The threshold current of 0.7 A per emitter is the same for single emitters and emitter arrays. Output powers of more than 50 W in continuous wave mode for a mini bar with standard packaging demonstrates the increased power of tapered laser bars.

Keywords: high brightness, high power tapered lasers bars, single emitters, tapered laser, material processing

1. INTRODUCTION

High power diode lasers have become more and more attractive for direct material processing and not only as pump source for solid state lasers. Due to further development of beam shaping[1] and beam combining techniques such as wavelength- and polarization-multiplexing[2], diode laser modules with high power and low beam parameter product (BPP) have been developed. The beam parameter product (BPP) is the product of the radius of the beam waste and the opening angle, which is proportional to M^2. A lower BPP is better then a larger.

$$BPP = \theta_F \cdot \frac{d}{2}$$

The common applications for these modules are in the medical field and the welding and soldering of plastics. Even thin metal sheets can be cut[3]. With the development of new high brightness diode lasers more applications can be addressed, such as cutting of metals and pumping of fiber amplifiers. (Fig. 1)

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High-Power Diode Laser Technology and Applications IV, edited by
Mark S. Zediker, Proc. of SPIE Vol. 6104, 61040G, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.646125

Standard broad-area lasers have modal instabilities and filamentation, which result in a low beam quality in lateral direction. The beam quality of laser arrays can be increased by more than a factor of four by using tapered lasers.

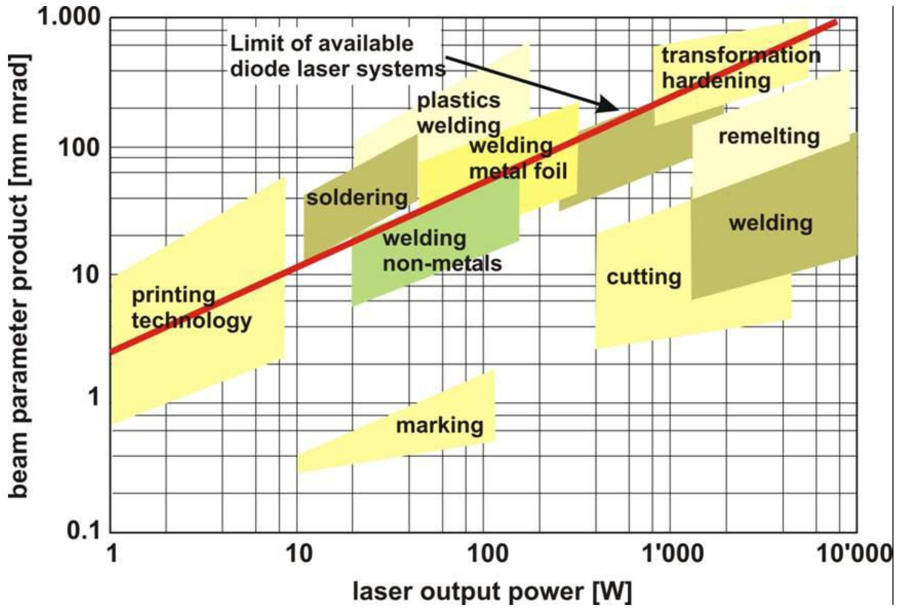

Fig.1: Application overview in dependency of beam parameter product and laser output power

2. TAPERED LASER STRUCTURE

The difference between broad-area lasers and tapered lasers is the lateral structure. The lateral structure of the tapered laser consists of a ridge and a tapered section. The ridge section is the starting point of the beam with high brightness due to the ridge waveguide structure. The tapered section amplifies this beam with low losses in beam quality. The lateral structure is shown in figure 2.

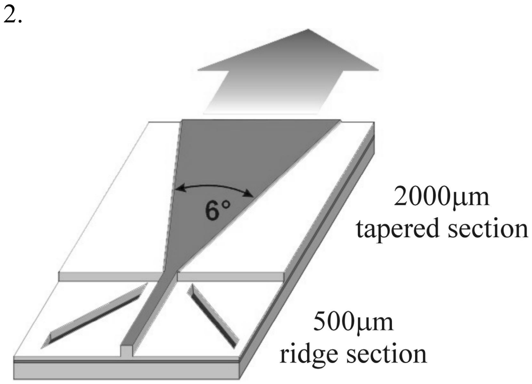

Fig.2: Lateral structure of tapered laser

In this case the developed tapered laser with high efficiency and high output power have a 500 µm long ridge and a 2000 µm long tapered section. The taper angle is 6°, which results in an approximately 210 µm wide output facet. Single emitters and 6mm wide mini bars of this type of tapered lasers have been processed. The mini bar is a array of 12 2.5 mm long emitters with a pitch of 500 µm. The single emitters are packaged onto modified c-mounts and the mini bars onto micro-channel heat sinks and passively cooled copper mounts. In all cases a standard process with soft solder is used.

3. ELECTRO OPTICAL CHARACTERISTICS

In the following the electro optical characteristics of single emitters and mini bars are investigated in continuous mode (CW). The bars packaged onto passively cooled heat sinks have due a lower slope efficiency to worse thermal conditions. Figure 3 shows a typical P-I-characteristics of such tapered lasers. The wall-plug efficiency for the single emitter is above 50 % and around 45 % for the mini bars. In order to get comparable data between single emitters and bars, the output power and the current is divided by the numbers of emitters. This means, that the output power of the mini-bar is divided by 12, so that an average power and current per emitter is given. All measurements are done in continuous wave mode (cw) and at a heat sink temperature of 20°C.

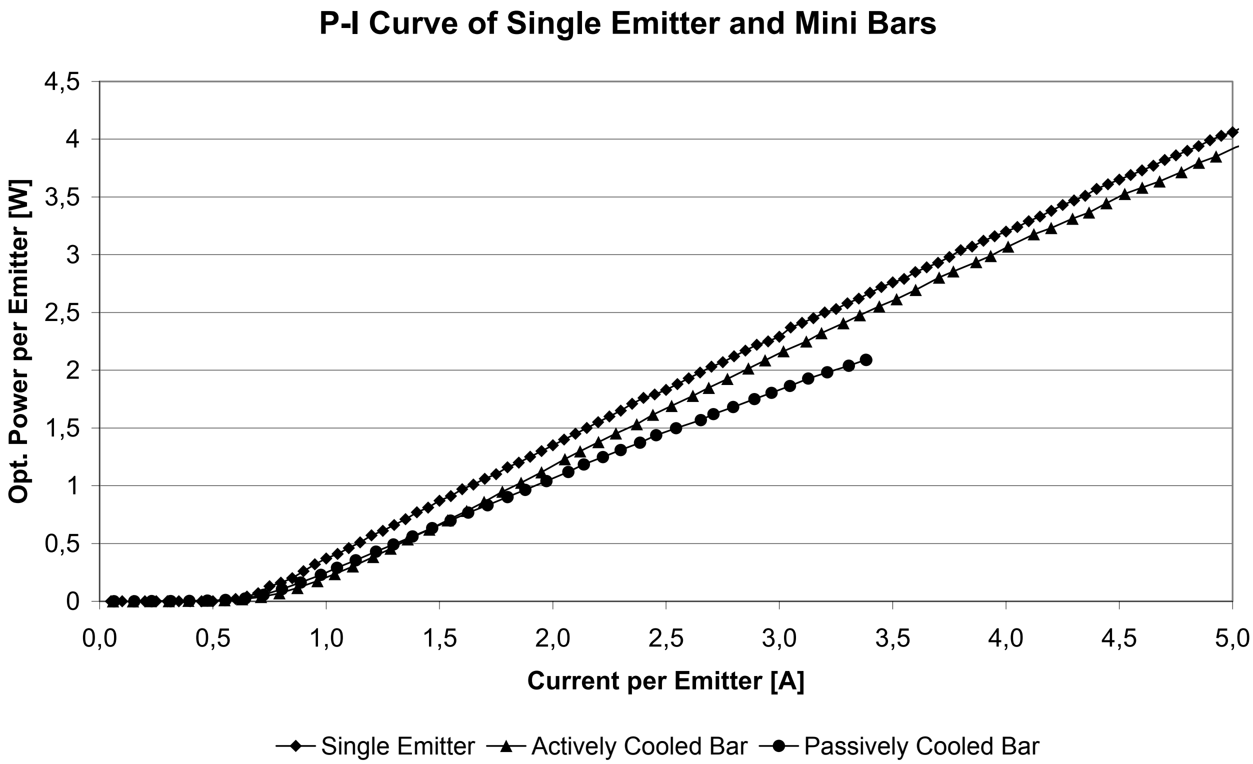

Fig.3: P-I curve of different tapered lasers in continuous wave mode (cw) and 20 °C heat sink temperature.

An overview of the characteristic values are given in table 1. There is a 4 nm difference in the peak wavelength between the single emitter and the actively cooled heat sink, which corresponds to a temperature increase of more than 12 K. The higher average operating temperature of the mini bar has no great effect on the threshold and slope efficiency. This means, that the structure is temperature stable and that all emitters of the bars have nearly the same good characteristics (homogeneous).

	single emitter	activly cooled mini bar	passivly cooled mini bar
Threshold [A]	0,6	8,81 (0,73)	8,29 (0,69)
Slope Efficiency [W/A]	0,99	0.98	0,80
max. wall-plug efficiency [%]	50	46	46
peak wavelength [nm]	962,2	966,4	969,3

Table 1: Characteristic values of tapered lasers measured in continuous wave mode with 20°C heat sink temperature. The values in parentheses for the mini bars are the by emitter values.

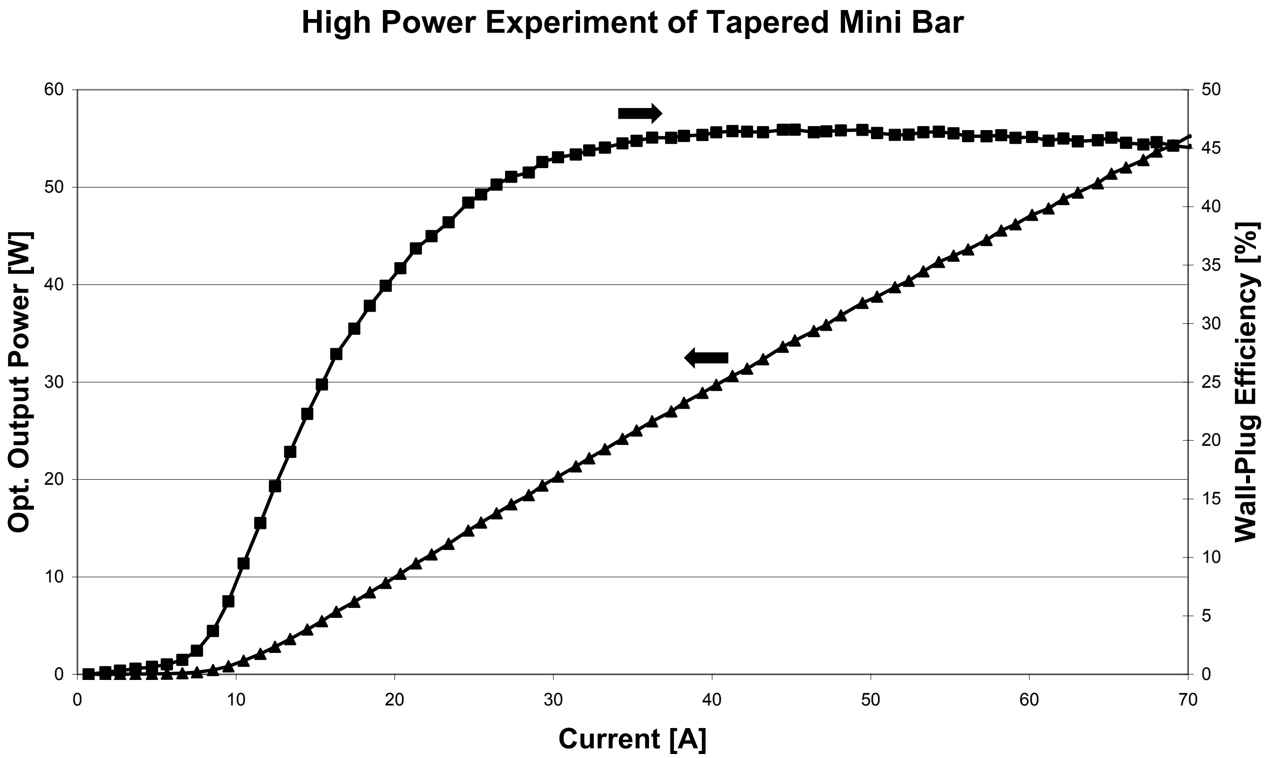

Fig.4: P-I curve of a actively cooled mini bar in continuous wave mode

55W optical output power at a driving current of 70A could be achieved with a 6mm wide mini bar on an actively cooled heat sink (figure 4). This corresponds to an output power of 4,6W per emitter at a current of 5,8A per emitter. The maximum efficiency is 46% at a current of 45A with an output power of nearly 35W.
30W at 40A seems to be a good operation condition for actively cooled bars in cw operation and 20W at 32A for passively cooled bars.
With this condition lifetime tests with a few samples in constant current mode have been made. The estimated lifetime is calculated with a linear fit starting after a 100 h burn-in. The end of lifetime is reached, when the output power has decreased by 20%. So far the tests run only between 500 or 1000 hours, and will be continued.

	current per emitter	heat sink temperature	estimated lifetime	range
passively cooled mini bars	2,6 A	20 °C	2500 h	1.500 - 3500 h
actively cooled mini bars	3,3 A	20 °C	1600 h	700 - 2400 h
single emitters	3,5 A	50 °C	17500 h	>24.000 h or less than 2.500 h

Table 2: Estimated lifetime for the different tapered lasers. .

The estimated lifetime between single emitter and bars are different. It is obvious, that the emitter can be divided in two groups with poor and good reliability. A reason for the failure can be the mechanical stress, which occurs due to the large chip size with a cavity length of 2.5mm. Perhaps expansion matched heat sinks and a more advanced packaging process will solve this problem. The failures and defect mechanism of these emitters will be investigated further.

4. LASER BEAM CHARACTERISTICS

Tapered lasers are designed to have a low beam propagation factor M² in fast-axis and also in slow-axis direction.

$$M^2 = \frac{r_{waste} \cdot \Theta \cdot \pi}{\lambda} > 1$$

The beam quality factor is the product of the waste radius (r_{waste}) and the far field half divergence angle (Θ), divided by the wavelength. A M² of 1 is only diffraction limited and the best value you can get (Gaussion beam).
Unfortunately the tapered structure leads to astigmatism effects, which means, that the beam source is different for the slow-axis and fast-axis direction. The virtual lateral direction (slow-axis direction source seems to be located inside the semiconductor, where the source of the fast-axis direction (transversal) coincides with the emission facet (Figure 5). A typical astigmatism is in the range of 600µm.

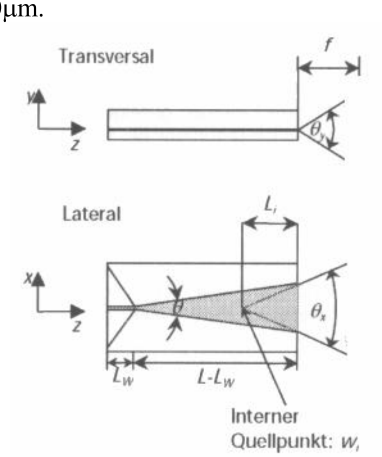

Fig.5: Transversal and lateral source of a tapered laser structure

In order to measure the beam profile optic imaging is needed. For the measurements of the M² of a mini bar two set-ups are used. The first set-up is a telecentric optic (Fig. 6) using an imaging aspect of 1:1, to image the beam source of the slow-axis outside the semiconductor. Then the beam profile can be measured with a commercial beam analyzer (beam scope).

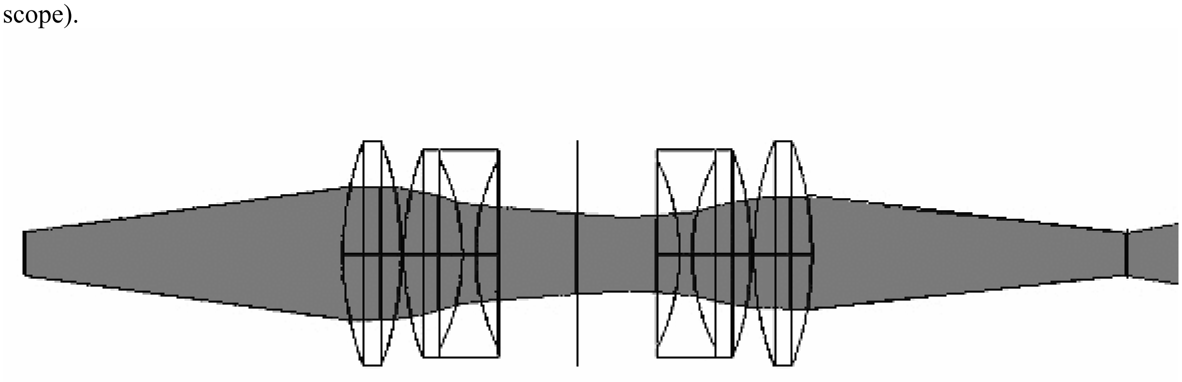

Fig. 6: Telecentric optic for measuring the beam profile in slow axis.

The second set-up consist of a pair of cylindrical lenses to image the beam waste.
A slit is used, in order to measure the beam profile of only one emitter. For the bars a central and an edge emitter is chosen, in order to see, if there is a difference due to the different thermal and mechanical stress situation.

The values of M^2 have been derived using two different methods: method 1 ($1/e^2$) cuts the measured beam profiles at level $1/e^2$ and uses these widths for calculating M^2. Method 2(integrated) uses an integral calculation method taking into account side lobes with heights even below $1/e^2$. Normally the integrated method leads to higher values of M^2.
A misalignment of the focus, resulting in a not sharp image and aberrations due to a non centrical throughput of the optics, can reduce the measured M^2 by several factors. The slit, a pair of prismen, need about 30mm of space in front of the laser bar, so that only lenses with long focal length could be used. The available lenses at the moment were not wide enough, so that the lenses were also apertures, which reduces the beam quality factor. The better measurements could be done with the telecentric optic, but due to alignment problems only a few measurements have been made until now. The set-up will now be optimized in order to measure higher numbers of emitters with better alignment possibilities and better reliability.
In figure 7 a typical measurement of the beam waste can be seen. The measured beam propagation factors is about 6, but the real factor will be better. The measurements are all taken with the non optimized set-up.

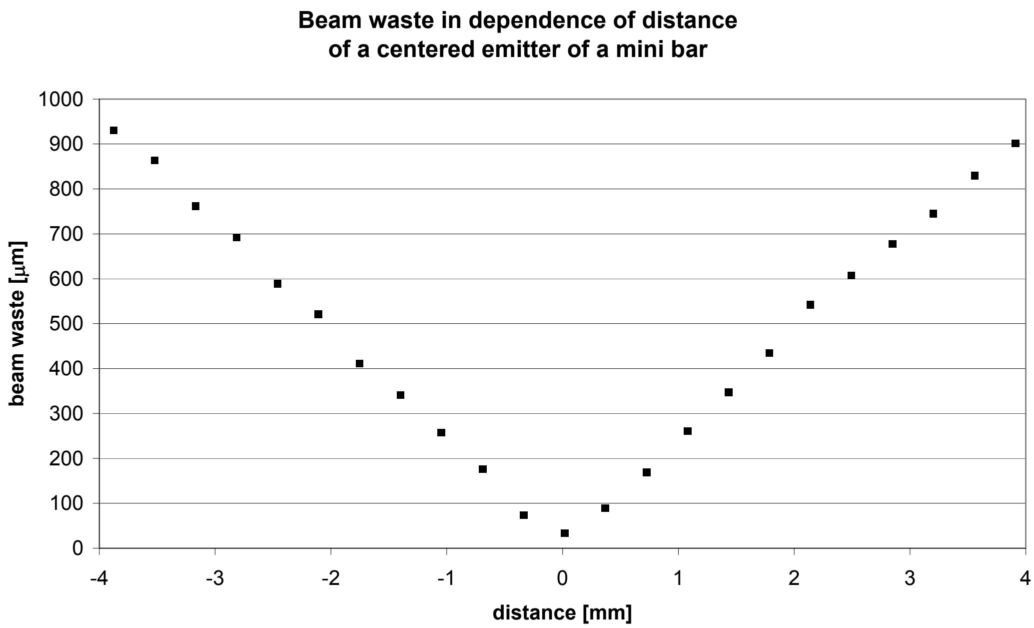

Fig.7: Beam waste of a centered emitter of a mini bar in cw-operation mode

The beam propagation factor for single emitter is measured similar to the second set-up for the mini bars. In this case the M^2 is also measured in dependence of the output power. The operating conditions are continuous wave with 20°C heat sink temperature.

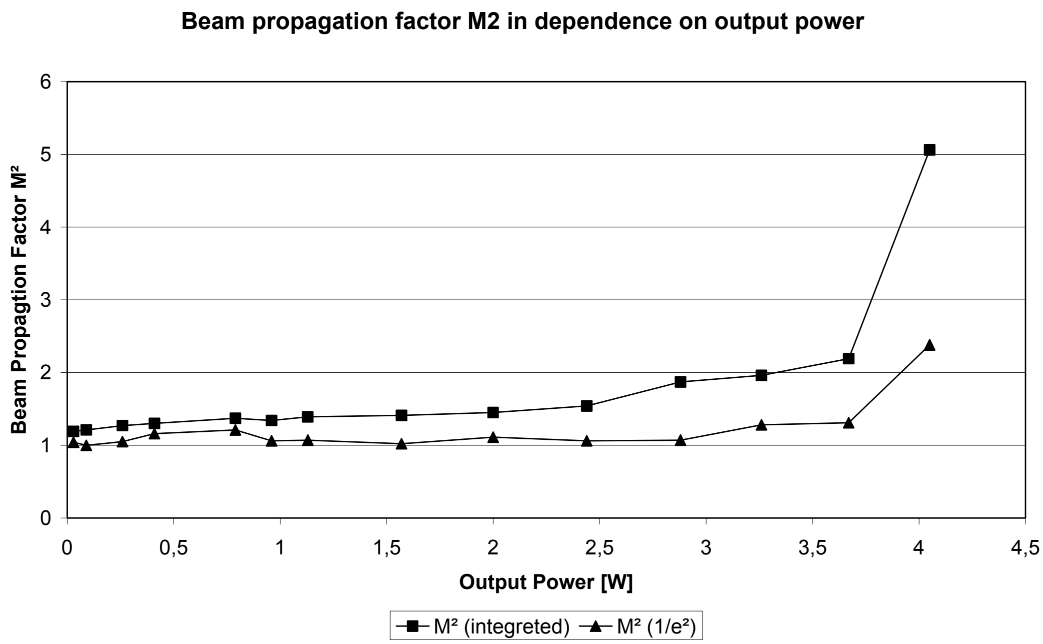

Fig.8: Beam propagation factor M² in dependence on output power of tapered single emitters

A nearly diffraction limited behavior ($M^2 < 1.8$) has been demonstrated up to output powers of 3.7 W for method (1/e²) resulting in a brightness around 300 MW/cm^2. Using the integral method for calculating M^2, nearly diffraction limited values of less than 1.8 have been observed up to output powers of 2.7 W. The brightness is around 180 MW/cm^2.

The far field angles of the mini-bars were also measured. In fast-axis the full angel of 1/e² (95%) is approximately 70° and the full angel of 1/e² in slow axis is around 16°. (Figure 9)

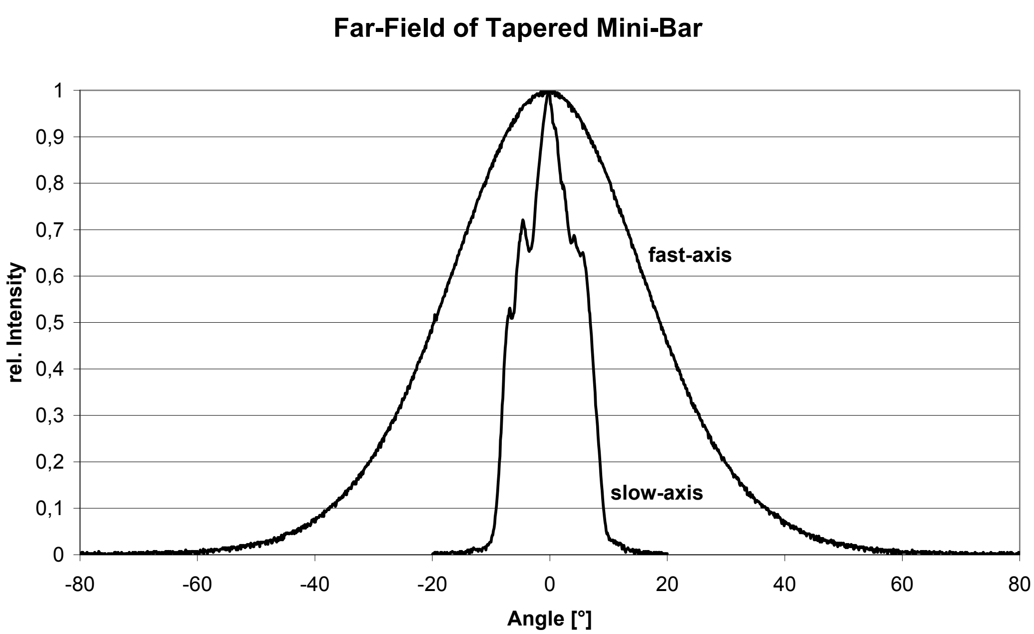

Fig.9: Far field angles of tapered mini-bar in slow- and fast-axis direction

5. CONCLUSION

A few years ago tapered diode lasers (single emitters) were only commercially available with output powers around 1 W and wall-plug efficiencies of less than 40% were typical values.
Now single emitters with nearly diffraction limited cw output powers of 3.5W are available. Even 5W in quasi continuous wave mode (qcw) at 6A are demonstrated. The wall-plug efficiency has risen up to over 50%.
Tapered laser mini bars with output powers of 30W at 40A cw are being manufactured. Due to the high wall-plug efficiency of more than 45%, the tapered mini bars can even operated on passively cooled heat sinks with output powers of 20W at 32A.
Output powers of 55W at 70A could be demonstrated, which is a record for tapered laser mini-bars.
The lifetime of the packaged mini-bars still needs some development. Due to the significant larger cavity length, higher mechanical stress occurs inside the semiconductor, which can explain the lower lifetime. An approach with advanced packaging technology onto expansion matching heat sink will be done, in order to reduce the mechanical stress and hopefully to increase the lifetime.
The measured beam quality factor of the emitters of a laser bar is around 6. In reality the M^2 will be better due to the alignment problems of the set-up. Further investigation of the homogeneity of the M^2 of the separate emitters of a bar will be done with an optimized set-up.

ACKNOWLEDGEMENT

The authors gratefully acknowledge support from the European Commission trough the IST projects WWW.BRIGHT.EU (IST-511722). (http://www.bright-eu.org)
Also the authors thank M. Haverkamp and T. Westphalen for the M^2 measurements of the mini bars.

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