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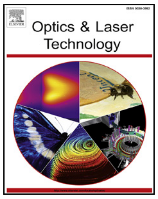

Full length article

Beam shaping design for fiber-coupled laser-diode system based on a building block trapezoid prism

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HIGHLIGHTS

- A building block prism was designed to compress the beam width of the diode.
- Beam shaping can be achieve independent of the refractive index of the material.
- The system in this paper for fiber coupling was simple and short in optical path.

ARTICLE INFO

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ABSTRACT

For the fiber-coupled laser diodes, the high brightness and miniaturization have always been our goals to pursuit. An effective method of achieving a high power and high brightness fiber-coupled laser-diode system has been put forward by ZEMAX software simulation. We designed a simple beam shaping system to improve the beam symmetry and narrow the line width with a trapezoid prism and a set of parallelogram plates. Using this technique, a laser-diode stack consisted of eight bars was coupled into a fiber with a core diameter of 200 μm and a numerical aperture of 0.22. The simulation results demonstrated that the output power can reach 272 W with equalizing brightness of 7.48 MW/(cm^2·sr), and the optical-optical efficiency was 85%.

1. Introductions

As semiconductor lasers have played an important role in fiber or solid laser pumping, material processing, medicine fields, it is very significative to develop efficient fiber- coupled module for diode lasers [1–5]. Laser diode stacks are assembled vertically by several laser diode bars with pitches of 1.8 mm. For a bar, the light emitting region is 1 μm in the fast axis with 30–60° divergence angle. In the slow axis, the divergence angle is 6–10° with a broad emitting width [1–4]. At present, there are two types of laser diode bars in the commercial markets: cm-bar and mini-bar. For the cm-bar, the emitting area width in the slow axis is about 1 cm and contains 19 light emitting units. For mini-bar, the slow axis width and the luminescent units are 5 mm and 5 units, respectively [3,4]. Since the lightless areas between each emitter and large mismatch of the beam quality between both axes, it is difficult to achieve effective coupling. So a compact and high-efficiency beam shaping technique is vital for the diode stacks fiber coupling system.

Because the slow axis direction beam is much wider than the fast axis direction, the main ideology of the beam shaping is to rearrange the collimated beam. In general, this is carried out by prism stacks to cut and rearrange the beam to a symmetrical beam quality, such as the double-cutting beam shaping technique proposed by Huang in 2013 [2]. Another beam shaping method for instance parallelogram plates and a prism array was proposed by Yu et al in 2015 [3]. In the same year, a beam shaping system is put forward based on a right-angle prism array and a distributed cylinder-lens by them [4]. In 2012, Ghasemi and Lafouti achieved beam shaping by using a V-stack mirror and polarization beam combining elements [6]. After such beam shaping method, the beam quality of the fast and slow axes reach a relatively symmetry status, and the beam quality can be improved effectively. However, this previous method needs too much number of prisms.

In this paper, we simulated a fiber coupling system by using a build-up trapezoid prism which consists of parallel plates to narrow the beam width of the fast axis, and the subsequent parallelogram plates were proposed to improve the beam quality. Compared with the traditional beam shaping technique, the proposed beam shaping method in this paper has the advantages of structure simply and assembling easily. Due to we can compress the beam width along the fast axis with the build-up trapezoid prism, which can be treated as an integrated prism,

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Table 1
The Parameters of Mini-bars.

Parameter	Numerical Value
Bar width	5 mm
Center wavelength	980 nm
Out power	320 W
Number of emitter	5
Emitter width	100 μm
Pitch of emitter	1000 μm
Fast axis divergence	40°
Slow axis divergence	8°

the number of prisms we used can be decreased and the light path was shortened. Another advantage of the system is that we can achieve beam shaping independent of the refractive index of the material. Based on the technique, eight mini-bars could be coupled into a 200 μm/NA 0.22 fiber. The results verity that the beam shaping technique we proposed is compact and effective for the laser-diode module.

2. Light source design and beam shaping technique

The beam quality of the laser diode is ordinarily appraised by the beam parameter product (BPP), which is defined as Eq. (1) [7–9],

$$\mathrm{BPP}\frac{1}{4}*\theta*W \tag{1}$$

where θ is the far-field divergence angle of the beam, and W is the beam waist diameter. As the BPP value becomes smaller, the beam quality will be improved. Therefore, it is vital to reduce the divergence angle and beam width of semiconductor lasers. Mini-bar is the best choice for the effective fiber coupling as a result of the beam quality along the slow axis is better than that of cm-bar and it is also feasible to achieve the relatively high power for fiber coupling compared with the single emitters.

In this paper, we adopted a laser-diode stack consisted of 8 mini-bars as the source that each mini-bar contains five emitters, the parameters of the stack we used are shown in Table 1. The mini-bar is soldered in a heat sink with 1.8 mm pitch [3], and the stack we designed is assembled with 8 mini-bars in the fast axis. To couple the beam into a fiber, it is necessary to reduce the divergence angle in both axes to improve the beam quality. Aspheric micro-cylindrical lenses with the effective focal length (EFL) equal to 0.5 mm were adopted to collimate the laser beam in the fast axis to 2.62 mrad, as it is shown in Fig. 1. In the slow axis, we need cylindrical microlens array to collimate the laser beam, each cylindrical lens corresponds to each emitter of the mini-bar. We adopted the cylindrical microlens array of the EFL is 8 mm to reduce the residual divergence angle to 13.96 mrad as shown in Fig. 2.

In order to attain an efficient fiber-coupled system, the BPP of the laser diode beam in both axes should meet the requirements given in Eqs. (2)–(4):

$$\mathrm{BPP}_{\mathrm{Fast}} \leqslant \frac{\mathrm{BPP}_{\mathrm{Fiber}}}{\sqrt{2}} \tag{2}$$

$$\mathrm{BPP}_{\mathrm{Slow}} \leqslant \frac{\mathrm{BPP}_{\mathrm{Fiber}}}{\sqrt{2}} \tag{3}$$

$$\mathrm{BPP}_{\mathrm{Fiber}} = \frac{\mathrm{D}_{\mathrm{Fiber}}\times\mathrm{NA}}{2} \tag{4}$$

$\mathrm{BPP}_{\mathrm{Fast}}$ and $\mathrm{BPP}_{\mathrm{Slow}}$ are the BPP of laser beam in fast and slow axis direction respectively. $\mathrm{BPP}_{\mathrm{Fiber}}$ is the maximum beam parameter product that the fiber can hold. Due to the surface of fiber is round, the focus beam spot size must be $1/\sqrt{2}$ smaller than the diameter of the fiber core, and the BPP of the laser beam must be$1/\sqrt{2}$ less than the BPP of the fiber.

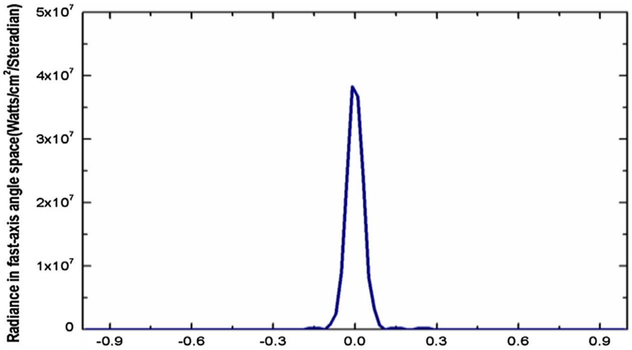

Fig. 1. The divergence angle after collimation in the fast axis.

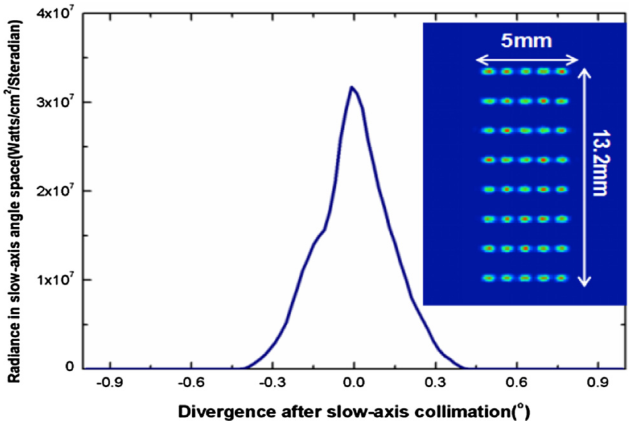

Fig. 2. The angle after collimation in the slow axis and the output spot after collimation of both axes.

3. Design and simulations results

Besides collimating the divergence of both axes, the other factor to improve the beam quality is to narrow the beam width. We proposed a beam shaping method based on a trapezoid prism which can fill the dead areas between bars to compress the beam width in the fast axis. The trapezoid prism looks like a building block made up with five quadrilateral prisms as shown in Fig. 3. We can narrow the beam width using only one prism assembled like this, which can effectively reduce the number of prisms used and make installation easier. The parallelogram prisms above correspond to the bevel of the small trapezoid prism at the bottom, and the two small quadrilateral prisms in the middle are perfectly fitted to the upper and lower sides. The five small quadrilateral prisms are completely glued together, and the refractive

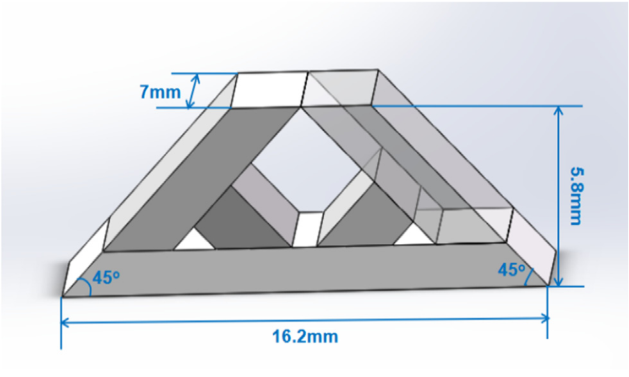

Fig. 3. The trapezoid prism built-up for compressing the beam width in the fast axis.