

Two-dimensional beam shaping and homogenization of high power laser diode stack with rectangular waveguide

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Abstract In this paper, the research work of two-dimensional beam shaping and homogenization of high power laser diode (LD) stack by a rectangular waveguide is presented. Both the theoretical simulation and experiment results have shown that the diode stack beam can be shaped into a uniform square spot with a dimension of 10 mm × 10 mm and the non-uniformity less than 5% along both directions of slow axis and fast axis, the shaped beam has a uniform pumping depth over 10 mm, which is well to be used for a rectangular laser medium end pumping.

Keywords beam shaping, high power laser diode (LD) stack, laser end pumping

1 Introduction

Laser diode (LD) stack of the high-power lasers has been well applied in lots of fields like laser pumping, laser processing, and laser medicine [1], and laser pumping is one of its major applications. However, the LD stack consists of huge numbers of uncoupled waveguide lasers which has an output of poor beam quality which cannot be directly used to pump the laser material with transverse cross section uniformity. To improve the beam quality and the efficiency of a laser system, the output beam of the LD stack needs to be shaped and homogenized before it is used to pump the laser medium. Therefore, in this paper, the theoretical analysis and experiments of shaping and homogenization of the LD stack output beam will be presented.

To realize beam shaping and homogenization, three kinds of elements are usually taken into consideration: aperture, beam mapping and beam integrator [2]. Among those elements, the beam integrator is more reliable in

some cases, since the output of beam integrator is not strongly dependent on the distribution of input beam. Beam integration can be realized mainly in two ways: by micro-lens array and by waveguide [2]. The waveguide theory was proposed by Grojean et al. in 1980 [3] and then first studied in experiment by Joseph M. Geary in 1988 [4]. Either the core element of the system is a kaleidoscope [3–5] or pillar made by optical material [6–8], it shows an effect of beam shaping and homogenization on the intensity distribution of high power laser and LD stack. In 2012, Martin Laurenzis and his coworkers have reported the beam shaping of LD stack based on waveguide theory which is applied in laser illumination [9,10], in their paper, two methods were used to shape laser beam, the first one is to use a wedge type waveguide to shape LD stack laser beam, the wedge waveguide will produce an enlarged output divergence angle and small focus depth, this type of shaped beam although can be used to pump thin disk medium, but cannot be used to pump the rectangular laser medium which need the larger focus depth; the second one is to use a small aperture waveguide to shape a solid state laser beam, the laser beam is a single spot beam and has small divergence angle and better beam quality compared with the LD stack lasers. In 2014, Lutz and his colleagues have published a LD stack beam shaping results by using a waveguide as homogenizer [11], in their paper, a 100 mm focal length cylindrical lens was used to focus the LD stack output beam for the slow axis into a waveguide with aperture size of 1.5 mm × 2 mm, which indicates that the used LD stack beam has a divergence less than 1.2°. For most of the commercial LD stack laser for solid state laser pumping, the divergence angle in slow axis is over 10°, which is too large for the small aperture waveguide to shape, therefore the shaping and homogenizer for LD stack beam with larger divergence angle needs to be studied and discussed.

The study of one-dimensional beam shaping and homogenization of LD beam based on waveguide theory has been reported [12]. In this paper, the further application

of the waveguide theory for the two-dimensional beam shaping and homogenization of large divergence angle LD beam will be presented. Results obtained in the studies can be used to pump the rectangular laser medium, and the technique can be extended to shape and homogenize the larger aperture beam for high energy laser pumping.

2 Experiment setup

A LD stack of 10 LD bars with the power up to 5 kW at the wavelength of 940 nm is considered as the laser source. The bar beam along the fast axis (FA) is collimated by micro-lens and has a divergence angle along the FA (α_f) of 0.48° , and the bar beam along the slow axis (SA) has a divergence angle along the SA (α_s) of 10° . The shaping optical system consists of 6 optical cylindrical lenses and a waveguide, 3 optical cylindrical lenses are used for the FA direction beam shaping and 3 optical cylindrical lenses are used for the SA direction beam shaping. The experiment setup is shown in Fig. 1.

The optical shaping system was designed and simulated by Zemax. The model of LD stack in Zemax was taken based on Ref. [13], the waveguide has the size of 10 mm height \times 10 mm width \times 100 mm length, which is made of silica and coated 940 nm high-transmission coating on the entrance and exit surface of the waveguide. The lenses, also made of silica and coated with 940 nm high-transmission coating, were chosen based on α_f and α_s of the LD stack and make sure that the light will experience total reflection within the waveguide along the SA. The Ray tracing diagram is shown in Fig. 2.

Because the 10 bars are piled in the stack, spacing 1.7 mm between each other, the output beam distribution of the stack is periodical lines along the FA. For FA, Since the beam has the divergence angle α_f along the FA direction, although it is quite small, the beam from each bar will overlap after propagating a certain distance, the intensity

distribution of the beam from the stack can be uniform along the FA, but often the overlapped uniform beam size will not be the size needed. And the size of beam along SA will be too big after the beam propagating a certain distance. Therefore, the shaping principle of the large aperture waveguide for FA and SA is to design the proper geometric parameters to make the bar beams propagating in the waveguide and overlap at the exit of waveguide to obtain the hat-top intensity distribution and meanwhile maintaining the shaped beam size as the size of the waveguide dimension, which is needed for an optical system to image a size for laser medium end pumping. Behind the waveguide, an optical system consisting of three lenses is used to image the hat-top beam intensity distribution to the required target plane.

3 Theoretical simulation results

For the purpose of the analysis and discussion convenience, some definition of the parameters used in simulation and experiment results are made as following:

First of all, the FA of LD stack is defined to be coincided with the y -axis and SA is coincided with the x -axis mentioned in the paper.

Second, the definition of non-homogeneity η in this paper is shown as follows:

$$\eta = 1 - \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}},$$

where I_{\max} and I_{\min} are the maximum and minimum intensity in the flat top area of the distribution.

Third, for a laser medium end pumping, a length of uniform pumping along the pumping beam propagation direction in the laser medium should be required. Therefore, a parameter of pumping depth should be defined for the shaped beam, which is the distance between the front target plane and the rear target plane with specified

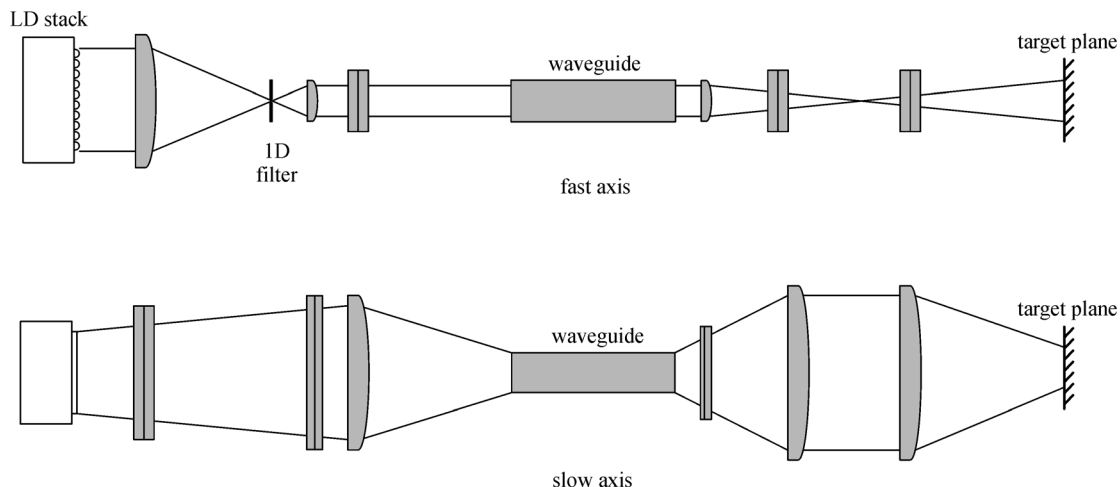


Fig. 1 Schematic of the setup of the beam optical shaping system

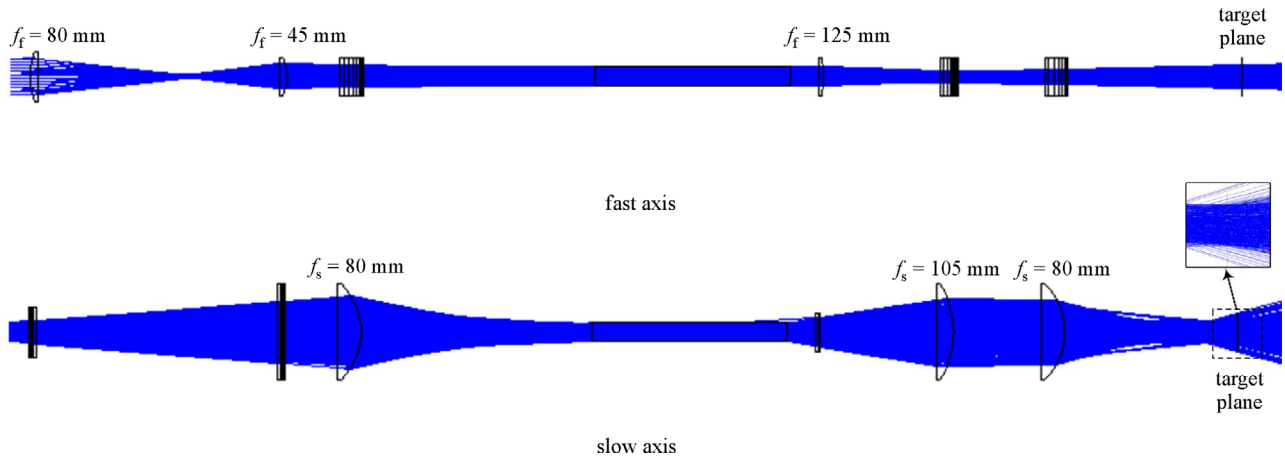


Fig. 2 Ray tracing diagram

transverse intensity distribution non-uniformity.

In this paper, the required transverse intensity non-uniformity of the shaped beam is set to be less than 5%. Based on the required non-uniformity of less than 5%, the pumping length is the distance between the front target position and the rear target position with the transverse intensity distribution non-uniformity less than 5%.

The simulations of the optical shaping and homogenization of LD stack with 10 bars as shown in Fig. 3 were carried out with the help of Ray tracing in Zemax, the results of which are shown as follows.

The calculated transverse intensity distribution of the shaped beam at the target plane is shown in Fig. 4. It can be seen that the non-uniformity of the transverse intensity distribution of the shaped beam is less than 5%.

Also, the transverse intensity distribution of the shaped beam at the front and rear target position is shown in Figs. 5 and 6.

From the above simulation results, it can be seen that the

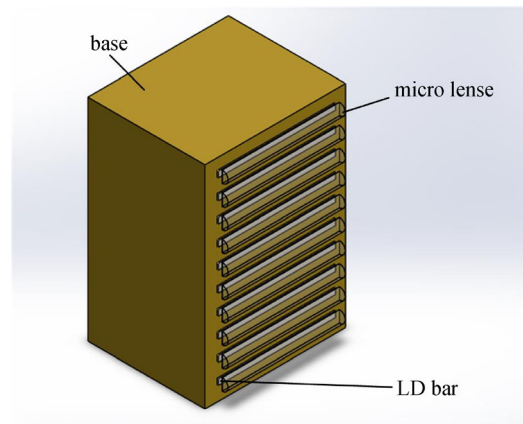
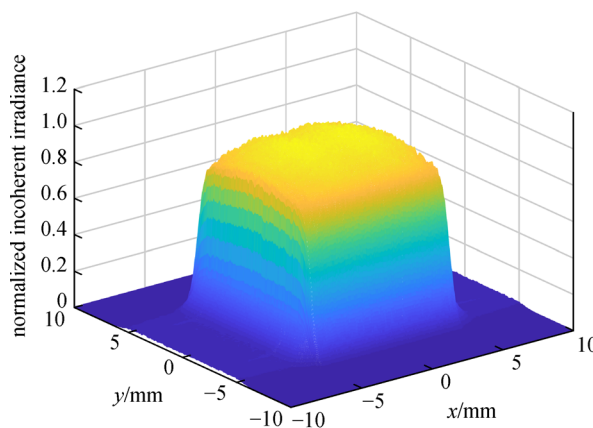
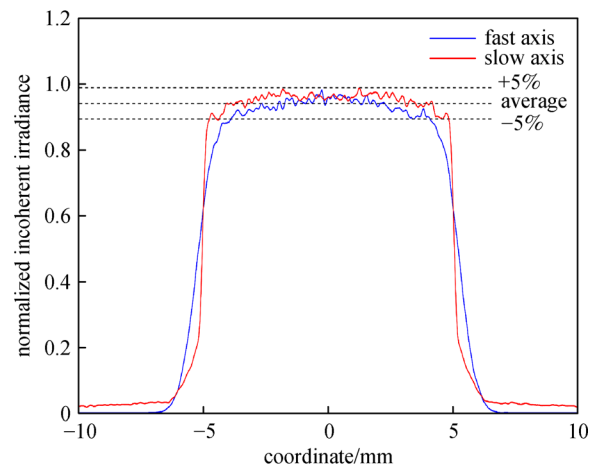


Fig. 3 LD stack with 10 bars

shaped beam has a pumping depth not less than 10 mm with the non-uniformity less than 5%.



(a)



(b)

Fig. 4 Simulation results at the target plane. (a) 3D intensity distribution of the shaped beam of the beam cross section; (b) intensity distribution of the shaped beam cross section

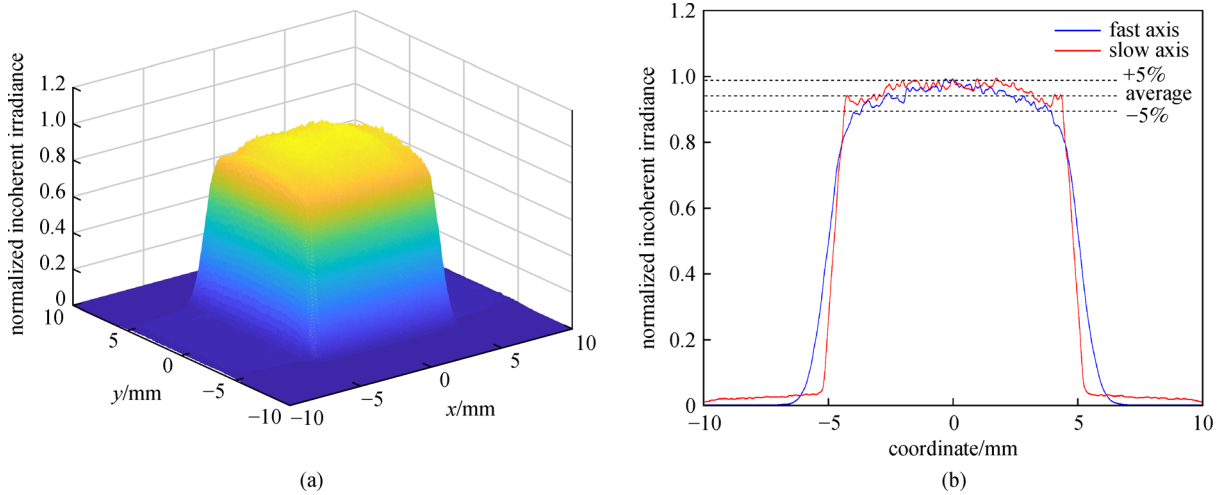


Fig. 5 Transverse intensity distribution at the front target position of 5 mm from target position. (a) 3D intensity distribution at the front target position of 5 mm from target position; (b) intensity distribution at the front target position 5 mm from target position

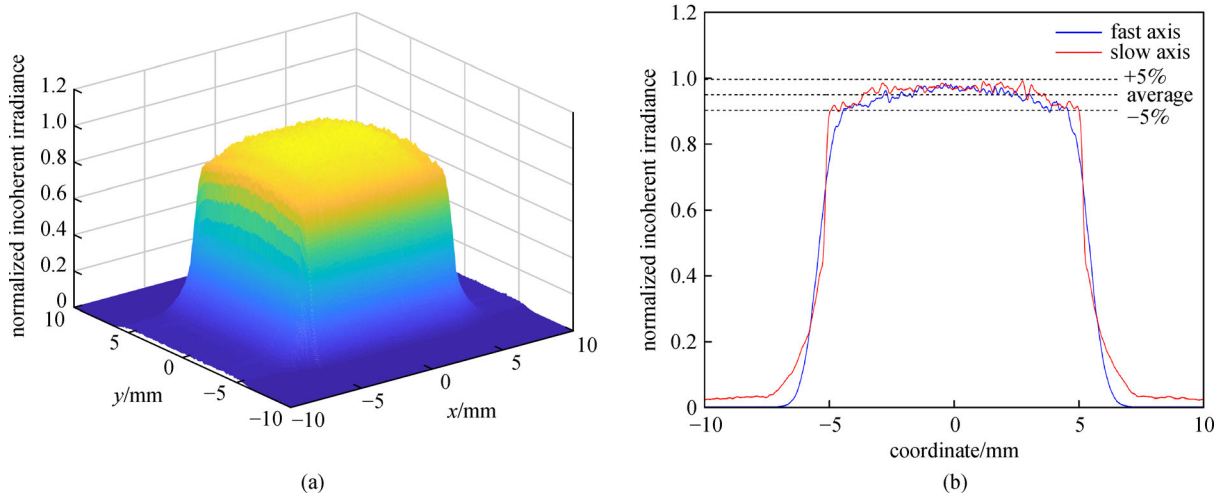


Fig. 6 Transverse intensity distribution at the rear target position of 5 mm from target position. (a) 3D Intensity distribution at the rear target position of 5 mm from target position; (b) intensity distribution at the rear target position 5 mm from target position

4 Experiment results

The laser source in experiment is a 10-bar LD stack fabricated by DILAS with output power up to 5 kW, each bar contains 66 emitters and the repetitive rate is 10 Hz. Its α_s is 10° and the α_f is 0.48° .

Theoretically, the output beam of each bars of the high-power LD Stack are parallel, but in practice, the output beam collimated by the micro-lens of each bars of the high power commercial LD Stack are often not parallel, which will have influence on the overlapped beam uniformity, therefore a 1D spatial filter as shown in Fig. 1 was used to filter the non-uniformity caused by the non-parallelism of the collimated bar beams. The result without the filter is shown in Fig. 7.

With the help of 1D filter, which is a slit along the SA in

the experiment, the non-uniformity of distribution on target plane can be reduced, the results are presented in Fig. 8.

From the experimental results shown in Fig. 8, it can be seen that the non-uniformity of the transverse distribution along the FA is less than 4.2% at the target plane, and the non-uniformity of the transverse distribution along the SA at the target plane is less than 4.9%, both of the non-uniformity is less than 5%. It is well matched with the theoretical simulation.

5 Conclusion

In this paper, an optical shaping system which is designed to shape the beam from LD stack to a uniform distribution square beam is proposed. The result obtained is $10 \text{ mm} \times$

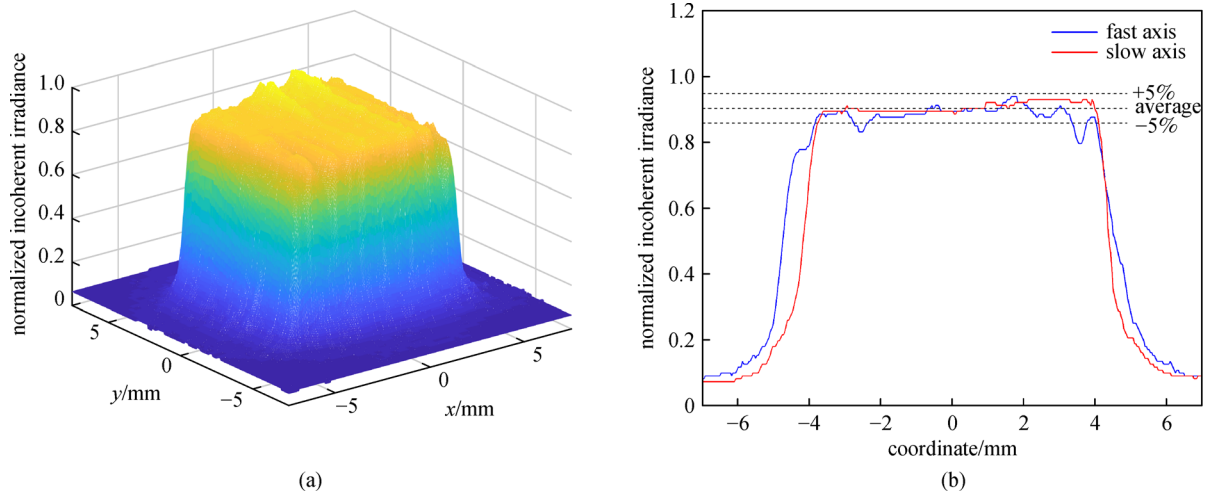


Fig. 7 Experiment results without 1D filter

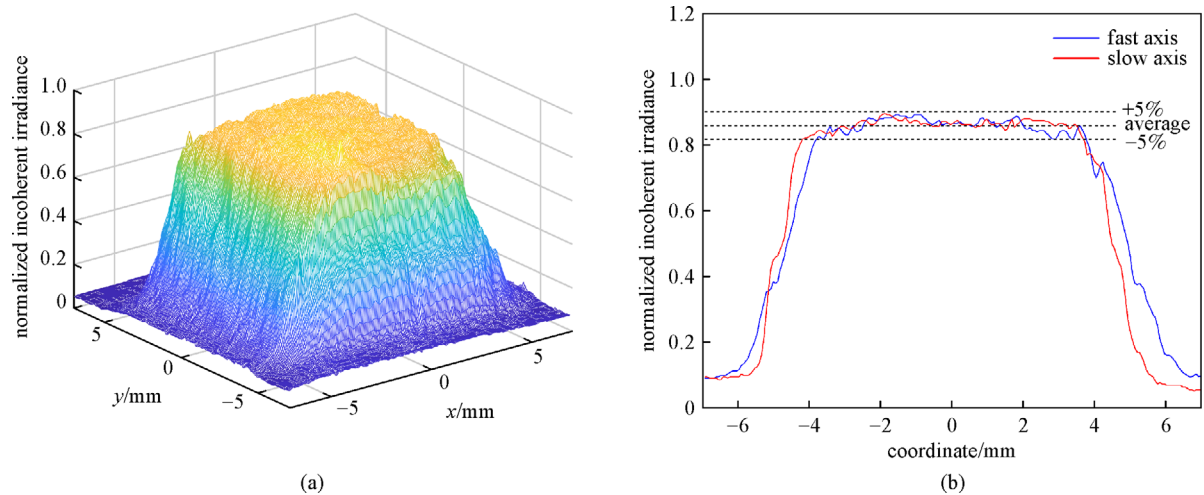


Fig. 8 Experiment results with 1D filter obtained at the target plane. (a) 3D transverse intensity distribution of the shaped beam at the target plane; (b) transverse intensity distribution

10 mm square uniform spot. The non-uniformity of the results of the system is less than 5% from both the simulation and experimental results, and the pumping depth of the shaped beam is not less than 10mm. The experiment results have shown that the non-uniformity is less than 5% for both SA and FA. The obtained shaped beam can be well used for end pumping of the rectangular laser medium.

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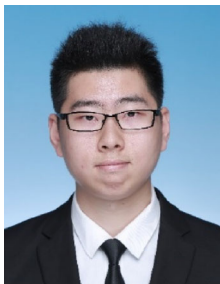
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