

Anamorphic beam concentrator for linear laser-diode bar

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Abstract: An anamorphic beam concentrator for linear laser-diode (LD) bar is presented. It consists of a tapered SiO₂-rod with skewed and curved surface. The principle and applicability of this device are numerically investigated by ZEMAX and experimentally illustrated for the specific example of the linear LD bar. Results show that a relative symmetrical output beam spot is produced at the output facet of the rod and the intensity and spatial fluctuations in the input beam are compensated at distance of 20cm from the output facet.

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1. Introduce

Laser beam shaping has many applications in different fields, including material processing, imaging, optical inspection and metrology, optical communication and laser pumping of high power solid-state lasers and fiber lasers. Generalized laser beam shaping techniques commonly use diffractive optical elements with complicated phase functions [1-6] or micro-optic-element groups [7-9]. However, these laser beam shaping systems are difficult to adjust and cost much to fabricate. As the high-power solid-state lasers and fiber lasers become more and more important in military, deep space laser communication system and laser machining, the anamorphic beam shaping of the high-power pump sources such as linear and stack LD bar attract more and more interests. A simple, cheap and compact package high-power laser system can be realized by using a non-imaging optics concentrator scheme such as the lens duct [10, 11] and the gradient-index rod [12, 13]. However, the lens duct and gradient-index rod cannot provide an anamorphic, adiabatic shaping, so there is no coupling between the two transverse directions (viz. fast axis and slow axis) of the LD bar, which causes that the brightness cannot be transferred between them and an output beam with uniform intensity and angular distributions cannot be produced [14]. Therefore, a simple anamorphic shaping optical element for concentration of linear LD bar is present in this paper. It consists of a tapered SiO_2 -rod with skewed and curved surface, hence enabling coupling between the horizontal and vertical directions of the guided LD beam. Because it not only achieves an anamorphic transformation, but also produces different optical magnification and minification along mutually perpendicular radii just like an anamorphic lens, we call it anamorphic beam concentrator.

2. Principle and Fabrication

In our technique, the beam shaping is achieved with a tapered SiO_2 -rod with skewed and curved surface. Its input facet is a rectangular cross section with 1:10 aspect ratio, which is match to the output facet of the linear LD bar. And the output facet is a rhombic cross section. The design is presented in Fig. 1.

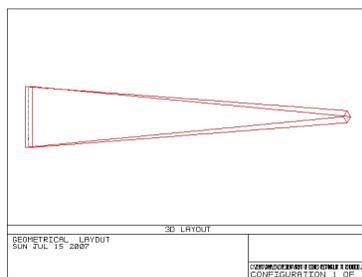


Fig. 1. Geometrical layout of the tapered SiO_2 -rod with skewed and curved surface.

The four structural parameters (the area of input facet, the area of output facet, the taper angle and the length of the rod) of the device are optimized by the ZEMAX. The areas of input and output facets are $1.2 \times 12 \text{ mm}^2$ and $2 \times 2 \text{ mm}^2$ respectively. And the total length of the tapered SiO_2 -rod with the taper angle of 14.2 mrad is 30 cm . The shape of a guide beam is changed and concentrated by tapering the shape of this SiO_2 -rod along its longitudinal axis slowly. If the transformation of taper is slow enough, the term adiabatic can be used and then

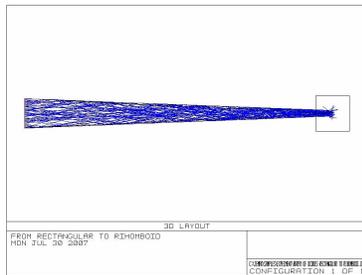


Fig. 3. Ray tracing of the LD bar, which is shaped and concentrated by the tapered SiO₂-rod.

A diffuse screen is placed immediately at the output facet of the SiO₂-rod, and the intensity images are recorded with a digital camera in Figs. 4 and 5. Because an equipartition occurs between different directions of the linear LD bar, resulting in coupling between fast axis and slow axis, the input laser beam with high aspect ratio of 1:10 is concentrated into a rhombic beam spot with side length of 2mm and the most of light intensity is concentrated into an elliptical beam with aspect ratio of 1:2. Because the receiving screen is placed immediately at the output facet, the size of the beam image in Fig. 5 is equal to the size of the output facet (2×2mm²) of the SiO₂-rod.

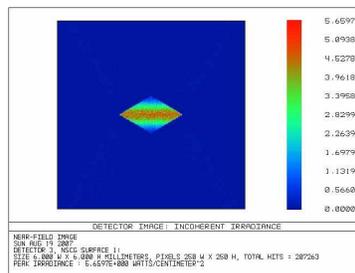


Fig. 4. Intensity image simulated by ZEMAX at the output facet of the device.

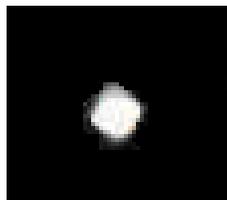


Fig. 5. (2.2MB) Movie of the intensity image recorded with a digital camera at the output facet.

Then the receiving screen is removed to the different distances (6cm, 10cm, 15cm and 20cm) from the output facet of the rod respectively, and the intensity distributions are recorded in Figs. 6 and 7. We expect that the light intensity will become uniform along with the increase of the radiation distance, provided that there are a “sufficient” number of reflections inside the rod. The simulated and experimental results of the output intensity distributions are showed in Figs. 6 and 7 respectively. In Fig. 6, the rhombic beam spot at the

output facet of the device transforms into a rectangular spot with aspect ratio of 1:4 gradually, meanwhile, the light intensity distribution becomes more and more homogeneous as the rays propagate. And in Fig. 7, the beam image sizes are $3.2 \times 1.6 \text{ mm}^2$, $4 \times 1.5 \text{ mm}^2$, $4.9 \times 1.2 \text{ mm}^2$ and $6 \times 1.1 \text{ mm}^2$ when the receiving screen is move to 6cm, 10cm, 15cm and 20cm respectively.

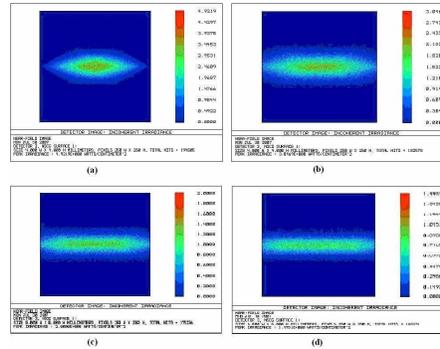


Fig. 6. Intensity distributions simulated by ZEMAX when the receiving screen is move to : (a) 6cm (b) 10cm (c) 15cm (d) 20cm.

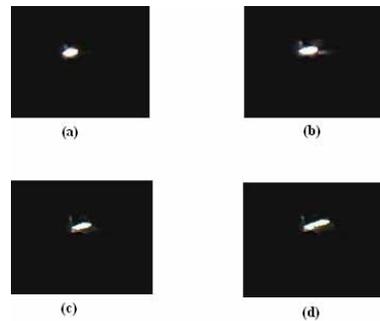


Fig. 7. Intensity images recorded with a digital camera experimentally when the receiving screen is move to: (a) 6cm (b) 10cm (c) 15cm (d) 20cm.

Figure 8 depicts the variations of the intensity distribution: when the receiving screen is moved from 6cm to 20cm, the peak irradiance of the output beam varies from 4.9219 W/cm^2 to 1.4931 W/cm^2 , meanwhile, the aspect ratio varies from 1:2 to 1:4 and a uniform intensity distribution is obtained. The reason for this kind of homogenization is that the SiO_2 -rod, having curved and slanted surface, achieves some coupling between the fast axis and slow axis directions of the linear LD bar, which compensates for intensity and spatial fluctuations in the input beam and produces a relative uniform and symmetrical output beam spot. The output power of the LD bar, the output power of the concentrator and the slope efficiency of the concentrator are showed in Fig. 9 together. The low efficiency ($< 40\%$) is caused by three kinds of loss of the incident power, which are reflection loss at the front and rear surface of the taper, scattering loss along the side surface of the taper and leakage loss of the refraction.

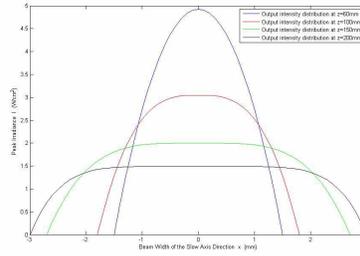


Fig. 8. Variation of the intensity distributions when the screen is moved from 6cm to 20cm

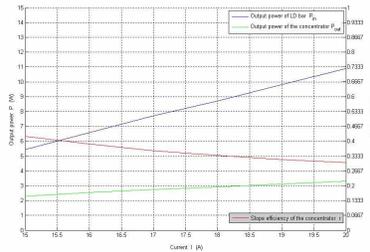


Fig. 9. Output power of the LD bar, P_{in} and the concentrator, P_{out} , and the slope efficiency of the concentrator η vs. the current I of the LD bar.

4. Conclusion

A tapered SiO_2 -rod with skewed and curved surface is proposed as an anamorphic beam concentrator for the linear LD bar. The geometrical shape and size of the SiO_2 -rod are designed and optimized. And the simulated and experimental results of the output intensity distribution at the output facet of the rod and four different distances from it are investigated. Because a mutual coupling between the fast and slow axis directions of the linear LD bar is achieved by the SiO_2 -rod with a curved and slanted surface, a relative symmetrical output beam spot with small aspect ratio of 1:2 is produced at the output facet of the rod and the intensity and a beam spot with uniform intensity distribution is obtained at a distance.