High brightness laser output with single-fiber-coupled laser diode array

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In order to get high efficiency and high brightness laser output with single fiber coupled laser diode array, two laser diode array bars which have 40-W continuous wave (CW) output power at 980-nm wavelength are used in the experiment. The laser diode bars are collimated by two pieces of cylindrical micro lenses in the fast axis direction, and in the slow axis direction step mirrors are used to divide the beams of light to shape the output beam symmetrically. A piece of polarizing beam splitter cube is used to combine the two shaped beams. The focused output beam is coupled into a multimode fiber. More than 55-W output power is obtained from the fiber with core diameter of 400 μm and numerical aperture of 0.22, the total coupling efficiency is about 70% and the brightness is up to 10^9 level.

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Laser diode arrays have many advantages such as high efficiency, small size, low weight, high lifetimes, high reliability, and low prices, which made these devices very popular in medical treatment, material processing and industrial processing, especially in pumped solid-state laser materials and fiber lasers[1,2]. But the emission of high power laser diode arrays is asymmetry and has micro size. The light beam has big divergence angle. These disadvantages made the laser diode arrays cannot be used in end-pumped solid-state laser and fiber laser directly. So it is necessary that the light beam must be shaped or be coupled in a fiber, and the technology of fiber coupling has become an important research direction in diode laser field. An advanced technology was used in this paper to shape the beam of laser diode array, and two 40-W laser diode beams were combined to one light beam by a piece of polarizing beam splitter cube. It was coupled in a fiber whose core diameter is 400 μm and the numerical aperture is 0.22 in the end. In brightness the device got a high level, and the result is approving.

The main parameters in fiber coupled output laser are fiber core diameter and numerical aperture[3]. To couple a fixed power laser diode array into a fiber the two parameters are determinant to the output beam brightness. According to simple deducing, the brightness L_{fiber} is given by

$$L_{\text{fiber}} = \frac{P}{\text{d}S \cdot \text{d}W} = \frac{P}{4\pi^2 (d/2)^2 \sin^2[(\arcsin\ \text{NA})/2]}, \quad (1)$$

where NA is the numerical aperture of the fiber, d is the fiber core diameter, and P is the output power from the fiber. According to the expression to get high brightness output, two methods can be used in the experiment which are reducing the numerical aperture and the core diameter of the fiber or increasing the output power, but reducing the numerical aperture and the core diameter of the fiber is in conflict with increasing the output power. Using small core diameter and low numerical aperture must affect the coupling efficiency and minish the output power. So first the laser diode array emission should be shaped, and then the shaped beam should be focused to a smaller size than the fiber diameter; several laser diode bars can be used to combine a single light beam to improve the output power.

In high power diode laser the height of the active layer in vertical direction of p-n junction is very small ($d \approx 1$ μm), so the diffraction effect is strong and the divergence angle is big, the full-width at half-maximum (FWHM) is about $30° - 40°$ (NA is about $0.26 - 0.34$). This direction is called fast axis in fiber coupling. In parallel direction of p-n junction the width of the active layer is bigger ($\omega \approx 150$ μm), so the diffraction effect is little and the divergence angle is small. The FWHM is only about $6° - 12°$. This direction is called slow axis. These make the diode laser emission be very asymmetry and the facula is like an ellipse (see Fig. 1).

The facula in fast axis direction must be collimated first[4]. In this paper a standard micro lens of LIMO in Germany is used to collimate the beam of light in fast and slow axis directions respectively. The micro lens uses the non-spherical optic surface to compress the beam of the fast axis and the slow axis in different degrees. By collimation the divergence angle in fast axis direction is shortened to about 1°, and in slow axis direction it is changed to about 3°. The beam quality can also be improved by micro optical components. The so-called

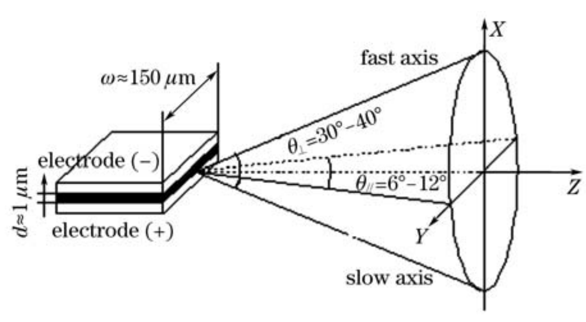

Fig. 1. Schematic diagram of single emission of the laser diode bar.

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stepped mirror symmetrizes the laser emission of a high power diode laser by two reflections dividing the slow axis into 15 subunits. The principle is shown in Fig. 2.

The light of the diode laser that is collimated by the micro lens hits a first stepped mirror that reflects the light upwards and displaces it in the fast axis direction. A second stepped mirror shifts the emitting areas in the slow axis direction resulting in a rectangular emitting area but with different divergences in both axis[5]. The shaped facula is shown in Fig. 3. In the experiment, in order to reduce the affection of polarized reflection the mental Cu is used to make the stepped mirror by minute machining.

In order to improve the output power two 40-W laser diode arrays are used in the experiment, and the beams are shaped and rearranged by the above described techniques first. Polarizing beam splitter cube can divide an unpolarized light beam into two polarized light beams with different polarization states. The light splitting theory is that the vertically polarized light can transmit directly and the horizontally polarized light only can reflect from one side of the cube. The principle is shown in Fig. 4. The light from laser diode bar is often vertically polarized state. So we can change the state of one beam of laser diode bar by a piece of $\lambda/2$ retardation sheet and incident from one side of the cube. Another beam of laser diode array transmits from the next side to the first beam directly. So the two beams are combined to one beam. The principle of the light path is shown in Fig. 4.

The beam of the two laser diode arrays after the series changing must be coupled into a fiber. Proper compressing and converging system should be designed[6]. In this paper a piece of aspheric lens and a piece of spherical mirror were used. The aspheric lens compresses the light in the fast axis direction, and the spherical mirror focuses all the beams systematically. The distance between the aspheric lens and the spherical mirror is very important

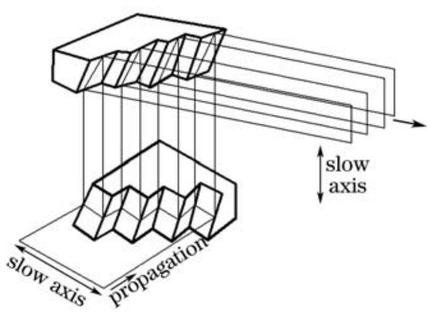

Fig. 2. Scheme of stepped mirror used for symmetrization.

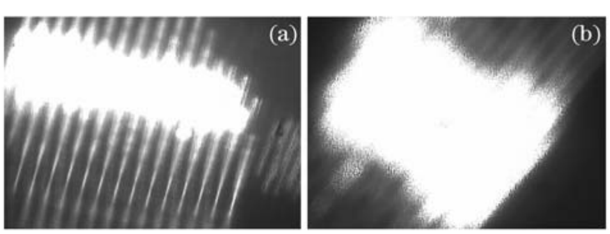

Fig. 3. Facular after stepped mirror in different distances of (a) 30 and (b) 80 mm.

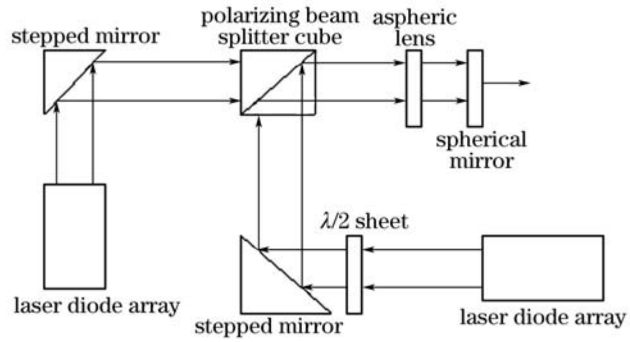

Fig. 4. Principle of the light path.

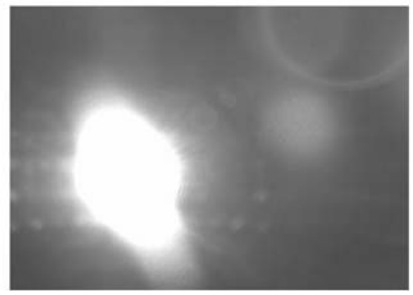

Fig. 5. Focused facular of the system.

to the system. It is necessary to adjust the distance accurately to get good result. In the experiment, the position of spherical mirror is located firstly by adjusting the output power from the fiber. The fiber is connected with an SMA905 linker. Change the aspheric lens position, watch the output power in the power meter, and locate it when the power is the biggest. The focused facular is about 250×400 (μm) as shown in Fig. 5. The output power of the system from a fiber with 400-μm core diameter and 0.22 numerical apertures is about 56 W at 45-A current (each laser diode array is 40 W at 45-A current). The coupling efficiency is about 70%, and according to Eq. (1), one can obtain

$$
\begin{aligned}
& L_{\text{fiber}} \\
&= \frac{P}{4\pi^2 (d/2)^2 \sin^2[(\arcsin\ \text{NA})/2]} \\
&= \frac{56}{4 \times 3.14^2 \times (400 \times 10^{-6}/2)^2 \sin^2[(\arcsin 0.22)/2]} \\
&= 2.9 \times 10^9,
\end{aligned}
$$

the brightness is up to 10^9 level. The result is satisfied.

In order to improve the brightness of the light coupled into a fiber from laser diode array, two 40-W laser diodes were adopted in the experiment. After a series changing to the light beams, it was coupled into a fiber which core diameter is 400 μm and the numerical aperture is 0.22. A device with 56-W output power from a single fiber was explored successfully. The obtained coupling efficiency is about 70%, and the brightness is 10^9 level.

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