Fiber optic coupling of high power laser diode array

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An optical fiber bundle array coupling module with high output power is proposed. The device integrates the coupling technique of the high power laser diode array (LDA) and the flat end-surfaces of fiber array. This module can efficiently couple the output laser of the LDA into the 19-fiber array through the flat-end surface. The fibers are ordinally fixed precisely on the V-grooves, and the fiber array has the same arrange period with the semiconductor laser units of LDA. A cylindrical fiber lens is fixed at the front of the LDA, which will greatly reduce the divergence of the laser beam and assure the laser beam to totally pass through into the end surface of fibers. High output power of 33.2 W of the fiber optic coupling of LDA is achieved, and maximal coupling efficiency is 84%.

OCIS codes: 140.3510, 060.2310.

High power laser diode arrays (LDA) have expanded their roles in many fields because of their small volume, easy handling, long working life, and high electro-optical efficiencies. Nowadays, they are widely applied in medical treatment, material processing, solid-state laser end-pumping, industry and aerospace and etc.

As we know that LDA are difficult for direct use in most fields because of their far-field character[1]. The cross section of the beam is elliptical. The beam divergence angle is about $20° - 40°$ in the direction perpendicular to the junction. But in the direction parallel to the junction, it is about $6° - 10°$. So it is necessary to improve the beam quality of the LDA, and the main way is to couple the light from LDA into optical fiber[2].

In this fiber coupled device, we use an inexpensive cylindrical lens to collimate the emission of an LDA in fast axis, and the fiber array can receive the entire laser beam of LDA. Finally, a fiber optic coupled LDA module with output power of 33.2 W is obtained.

For the stripe-emitting facet, the high power LDA has poor space propagation characteristics. In the direction perpendicular to the plane of p-n junction (fast axis), the divergence angle is quite large and up to 40°. The height of the emitters is approximately 1 μm, and in the direction parallel to the junction (slow axis), the divergence angle is less than 10°. Most high power LDA are realized as 10-mm-wide semiconductor bars that are mounted on a heat sink and deliver 20 W to 40 W continuous wave optical power[3]. There are distinct emission regions, each typically 150 μm wide in the slow axis, and every period of emission is 500 μm, and the amount of emitter is 19. Figure 1 is a scheme of a high power laser diode array.

Figure 2 is a schematic diagram of the coupling of laser diode (LD) to a flat-end fiber. In generally, the distance from the LD to the cylindrical lens is dependent on not only the radius and the index of refraction of the cylindrical lens, but also the divergence angle of the LD in fast axis and the numerical aperture of the multimode optical fiber[4].

The geometry of the structure is indicated in Fig. 3 together with an incident ray in fast axis direction. In the Fig. 3, r is the cylindrical lens radius and it is the radius of the flat-end fiber. d_1 is the vertical distance from the incidence point of LD beam and cylindrical lens to main optical axis. d_2 is the other vertical distance from the exit point of LD beam and cylindrical lens to main optical axis. L_1 is the distance from the LD to the cylindrical lens surface. L_3 is the distance from the back of cylindrical lens to the flat-end fiber. H is height of LD beam through the cylindrical lens in the L_3 point. With ray-tracing technique, H is given by

$$H = d_2 + [L_3 + r - r\cos(2\alpha_2 - \alpha_1)]\tan\alpha_4. \quad (1)$$

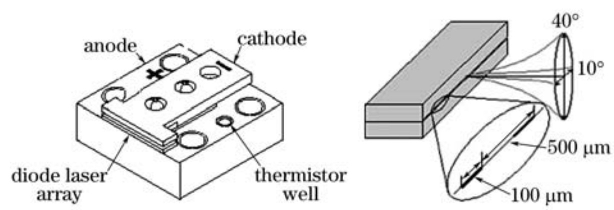

Fig. 1. Schematic diagram of LDA.

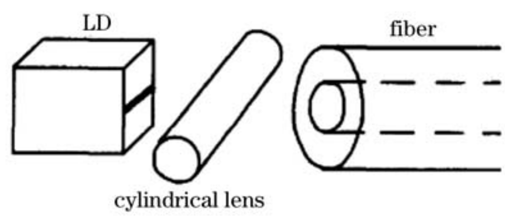

Fig. 2. Schematic diagram of the coupling of LD to a flat-end fiber.

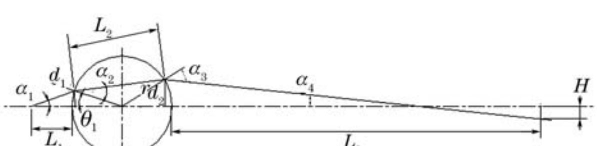

Fig. 3. Schematic diagram of coupling system space propagation in fast axis.

If we use a flat-end fiber with $\varphi = \arcsin 0.22 = 12.709$, $\phi = 200$ μm (φ is numerical aperture angle of the flat-end fiber, ϕ is the diameter of the flat-end fiber), only rays with $\alpha_{4(\max)} \leq \varphi$ will be accepted into the core of the fiber.

$$\alpha_4 = 2\arcsin\left[\frac{(L_1+r)\sin\alpha}{nr}\right] -2\arcsin\left[\frac{(L_1+r)\sin\alpha}{r}\right] + \alpha, \qquad (2)$$

where $n = 1.458$ is the index of refraction of the cylindrical lens, $r = 100$ μm, $\alpha = 20°$. We can get $L_1 \leq 109.667$ μm. And when $\alpha_4 = 0$, the rays will parallelly propagate, and $L_1 = 46.860$ μm.

Figure 4 is the schematic diagram of coupling system space propagation in slow axis. In Fig. 4, L is the width of the LD in slow axis ($L = 10$ mm), A is an angle of refraction of LD ray into the cylindrical lens. H_1 is given by

$$H_1 = \frac{L}{2} + L_1 \tan 5° + 2r \tan A + L_3 \tan 5°. \qquad (3)$$

When $|H| \leq \sqrt{r^2 - H_1^2}$, the flat-end fiber can accept the entire laser beam of LDA.

Figure 5 is the schematic diagram of LD rays propagation in fast axis and slow axis. The horizontal ray is schematic diagram in the fast axis, and the vertical ray is schematic diagram in the slow axis.

From the above theoretical analysis, we can confirm that when the distance from LD to cylindrical lens is 40−80 μm, the LD beams will be entirely coupled to the flat-end fiber. At the same time, the distance from flat-end fiber to cylindrical lens is less than 233 μm. To get the higher coupling efficiency, this distance is limited to less than 180 μm.

The flat-end fiber array made of 19 fibers, which are the same fiber core diameter of 200 μm. Firstly, every fiber end is polished into a very smooth flat end through grinder equipment. Then these fibers are fixed precisely on the V-grooves, and confirmed every fiber flat-end is intact. The V-grooves have the same arrangement period with the emitter units of LDA. The period distance is 500 μm. Secondly, the fiber acts as the cylindrical lens, and the core of the fiber is 200 μm. This fiber lens is fixed at the front of the LDA; the distance from the lens to the LDA is about 50 μm, and thus the beam can entirely pass through into the flat-end fiber. The final is the most important coupling course, and the LDA with the fiber lens is fixed on the bottom of copper. Their underside is water-cooled, the working temperature is 25°, the threshold current of the LDA is 6.8 A, the working current is 42 A, and at the same time the power is 40 W. The flat-end fiber array is nippid through five-dimension adjuster equipment. Every flat-end fiber is accurately aimed at every emitter unit. The distance between the flat-end fiber and the LDA is important for the coupled efficiency, but other direction adjust also will be necessary to ensure the coupled efficiency. Every direction distance will impact the coupled efficiency. Every direction distance needs careful correction, until the highest output power is obtained. Then the 19 fibers are combined into a bundle of fiber, and the output laser beam is transmitted from the fiber array ends. Figure 6 is the schematic diagram of the bundle of 19 fibers. At last the highest output power after coupling is 33.2 W, and maximal coupling efficiency is 84%.

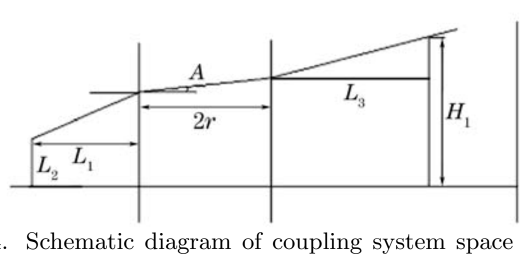

Fig. 4. Schematic diagram of coupling system space propagation in slow axis.

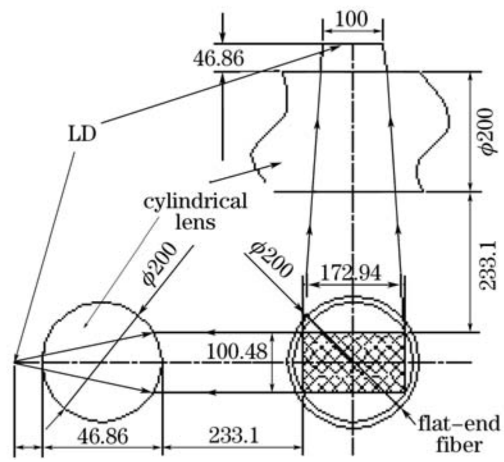

Fig. 5. Schematic diagram of LD rays plane propagation. The parameters are all in unit of microns.

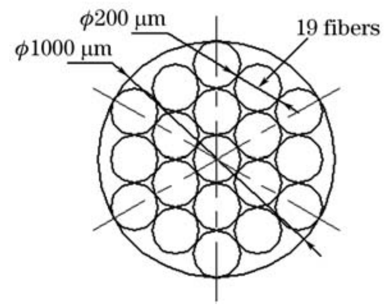

Fig. 6. Schematic diagram of the bundle of 19 fibers.

In conclusion, a high power the optical fiber bundle array coupling module is introduced, and 84% coupling efficiency is obtained. Further optimization is still necessary, mounting and collimating technology advance will make the fast axis beam more perfect. "Smile effect", which will decrease coupling efficiency, is an important factor according to the performance of LDA. Generally, "smile effect" less than 2 μm, is necessary. The flat-end fiber requires high quality anti-reflection coating to reduce reflection losses. Considering all the possible improvements, a higher coupling efficiency should be achievable.

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