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Research on fiber coupling technology of kilowatt laser diode by single emitters

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Abstract. This paper proposes a program that combine the laser of single-emitters by using fiber combiner, what's more, we designed and developed a multiple single emitters diode laser module of full optical fiber. We used ZEMAX software to simulate and optimize the influence of fiber coupling efficiency by the location of cylindrical lens and fiber, finally, we developed 8W fiber coupling single emitter diode laser, the wavelength is 915nm, fiber diameter is 105/125μm, NA0.15. This article also carried on the theoretical research of N×1 fiber combiner, and based on Vytran GPX glass processing system, we fabricated the 19×1fiber combiner by TFB technique, combined 19 105/125μm, NA0.15 fibers to a 400/440μm, NA0.22 fiber, has realized 150W laser output, with fiber combining efficiency more than 96%. In the end, 8*400um fibers are synthesized through a fiber taper. The output laser power after fiber taper reached 1453W, with the focus spot size is 2.25mm*1.1mm and power density reached $6\times10^4 W/cm^2$.

1 Introduction

Diode laser mainly includes single emitter, bar and vertically stacked. For kilowatt-class diode lasers, the main research method currently is to use bar or vertical stack to combine and focus then coupling into the optical fiber [1-3].

There is an inevitable disadvantage in the way of coupling the bar and the vertical stacked array beam into the optical fiber: due to the limited light receiving area, the optical density at the optical end surface is extremely high, which is easy to cause damage to the optical fiber end surface, and because the receiving area of the optical fiber end surface is too small, the coupling efficiency is decreased sharply due to the slight deviation of the position.

Aiming at the problem of optical fiber end-face damage in the field of high-power diode laser fiber coupling and the decrease of coupling efficiency caused by optical fiber position deviation, a method of combining single-emitters diode laser with fiber optic combiner is proposed, and the all-fiber multi-single-emitters diode laser module is designed and developed.

2 Theory of laser fiber coupling and fiber combiner

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2.1 Theory of laser fiber coupling

There are two kinds of fiber coupling theories: mode field coupling theory and geometrical coupling theory. For diode laser, because of its complex beam, it is difficult to accurately solve the mode-field distribution, so the geometric optical coupling theory is generally adopted. According to the theory of geometrical coupling, two conditions are needed to be satisfied when the beam is coupled into the fiber: the incident diameter of the beam must be smaller than the core diameter of the fiber; the beam must meet the total reflection condition during transmission [4-6]. In figure 1, the laser beam coupling condition can be expressed as equation (1) and (2):

$$D_{in} < D_{core} \tag{1}$$

$$\frac{\theta_{in}}{2} < \arcsin(NA) \tag{2}$$

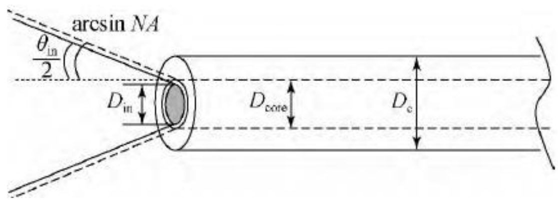

Fig. 1. Fiber coupling conditions for lasers.

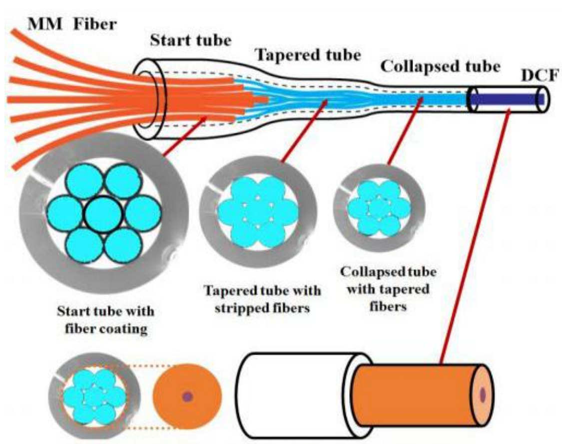

Fig. 2. N×1 fiber beam structure diagram.

2.2 Theory of NX1 optical fiber combiner

Based on the tapered fiber coupling theory, N×1 fiber combiner is fabricated by using Quartz sleeve, and put multiple input optical fiber on Quartz sleeve, which are fused into a matched fiber after taper drawing. The structure diagram is shown in figure 2.

The development of optical fiber combiner mainly includes two principles: the principle of brightness conservation and the principle of numerical aperture matching. Only by satisfying these conditions can it be possible to produce a fiber combiner with high beam combining efficiency.

In this paper, a 19×1 fiber combiner is fabricated by using two kinds of optical fibers: the core diameter of input fiber is 105 /125 μ m, NA0.15; the core diameter of the output fiber is 400 / 440μ m, NA0.22. The theoretical value of the maximum taper ratio is 1.5, while the actual taper ratio is 1.6. theoretically, it seems that the actual taper ratio is too large. In fact, the beam quality of the single-emitters diode laser selected is better than the beam quality allowed by the optical fiber, and based on this consideration, even if the actual taper ratio of the optical fiber is slightly larger than its theoretical maximum, a fiber combiner with high beam combining efficiency can still be obtained.

3 The system design

Aiming at the problem of optical fiber end-face damage in the field of high-power diode laser fiber coupling and the decrease of coupling efficiency caused by optical fiber position deviation, a method of combining single-emitters diode laser with fiber optic combiner is proposed, and the all-fiber multi-single-emitters diode laser module is designed and developed. Its structure is shown in figure 3. Of course, the arrangement of its output optical fiber can be adjusted according to actual requirements.

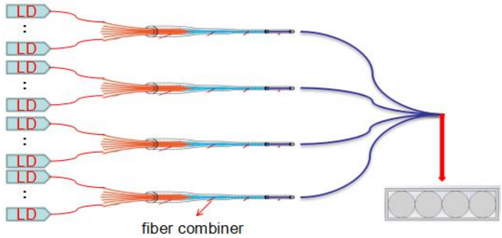

Fig. 3. Fiber laser module of single emitters.

In this structure, a 19x1 fiber combiner is used to combine multi-emitter diode lasers. The advantage of this structure is that it avoids the above problems. In addition, the use of single-emitters diode laser beams also has great advantages over bars or vertical stacks.

3.1 Fiber-coupled single-emitters diode laser

As is known , diode laser has a great weakness, that is, its beam-divergence angle in the fast and slow axis direction is quite different, the beam-divergence angle in the fast axis direction is much larger than the beam-divergence angle in the slow axis direction, thus leading to the diode laser beam quality is relatively poor.

The beam-divergence angle of the single-emitters diode laser in the fast axis direction is large and can not meet the numerical aperture of the power-transmitting fiber, so the divergence angle in the fast axis direction needs to be compressed for higher coupling efficiency . In this paper, a 125 μm diameter cylindrical lens is proposed to compress the beam-divergence angle in the fast axis direction.

3.2 19 x 1 fiber combiner

In this paper, a 19×1 optical fiber combiner was fabricated by quartz sleeve method. According to the related literature, the efficiency of the fiber combiner prepared by this method is 0. 27 dB [6]. Based on the Vytran GPX optical fiber processing platform, we will develop a 19x1 optical fiber combiner. The heating way of the platform is graphite filament heating. The development process includes the following steps: fiber group bundle, fiber bundle taper, fiber bundle cutting, fiber fusion and packaging.

Firstly, the optical fibers are grouped, and the optical fibers are closely arranged in a regular hexagon, so that the optical fibers can be better fused with the transmission optical fibers after the optical fiber bundles are fused and tapered. The fiber bundle is then inserted into a quartz sleeve that is pre - tapered and sized to match the fiber bundle. The quartz sleeve not only functions as a group bundle but also as part of the bundle itself. After the completion of the group bundle, the most critical part is fiber bundle taper. The fiber bundle is placed in a special optical fiber fixture, adjust the length of the drawer, taper speed and taper ratio and other parameters to ensure that the drawing of the qualified size and the structure of fusion taper area. After the taper is finished, the taper is cut from the taper waist position by using a cutting knife, and the end face is ground after cutting. The welding is then performed with an optical fiber that matches it. After the welding is completed, it shall be packaged to protect and dissipate heat.

3.3 The focus system

In this paper, using two modules, eight fiber bundles are bundled together, and the ends of the bundles are arranged in a 2 × 4 array. In order to meet the needs of the use of laser processing need to focus the beam. In this paper, using ZEMAX software to simulate the focus of optical fiber exit beam, the model and simulation results shown in figure 4 and figure 5. After focusing with three lenses, the focal spot size is 2 mm*1 mm and the optical power density is 6x10^{4}W/cm^2, meeting the requirements of heat treatment and cladding of metal surfaces in the field of laser processing.

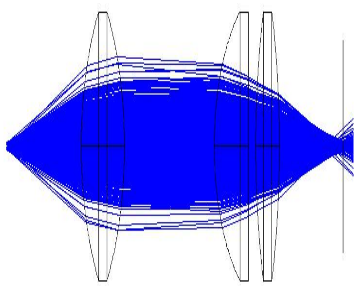

Fig. 4. Beam focusing system.

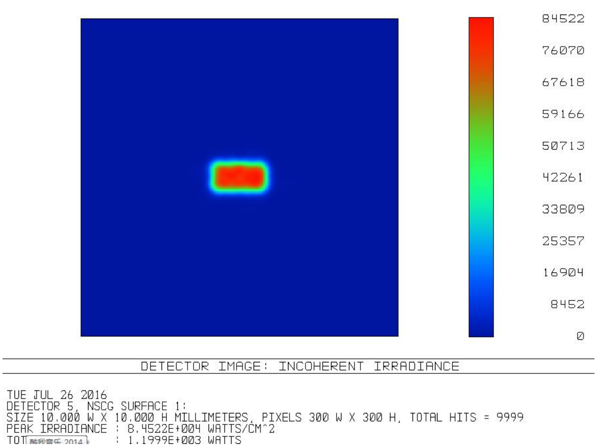

Fig. 5. Simulation results of beam focusing.

4 Experimental results and analysis

Based on the above analysis, a 8w fiber-coupled single emitter diode laser was developed. As shown in figure 6, the wavelength was 915 nm, the core diameter of the fiber was 105/125μm, NA=0.15.

According to the above-mentioned quartz sleeve method, a total of 19 optical fibers with a core diameter of 105/125μm, NA=0.15 are bundled, and the group bundle of optical fibers is tapered based on a Vytran GPX optical fiber processing platform. After tapered drawing is completed, the large core diameter fiber cutting knife CT-106 of Fujikura is used for cutting at the position of tapered waist and grinding. An optical fiber with a core diameter of 400/440μm is welded and encapsulaed by a self-designed tool. After testing, the coupling efficiency is basically maintained at more than 96 %.

After observing by the thermal imager, the loss of optical fiber combiner is mainly caused by light leakage at the fusion point of optical fiber bundle and fusion fiber. The leaked light not only reduces the coupling efficiency of the optical fiber combiner, but also causes the temperature rise of the optical fiber combiner, thus limiting the power increase of the optical fiber combiner.

A self-developed 8w fiber-coupled single emitter diode laser and an optical fiber combiner with coupling efficiency more than 96 % are combined, and the output beam of the optical fiber combiner is focused. The power and light spot is shown in figure. 6, 7 and 8, the output power is 1453w, the wavelength is 915 nm, and the spot size is 2.25 mm * 1.1 mm.

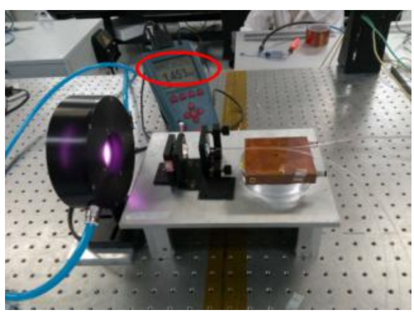

Fig. 6. Output power measurement of diode laser.

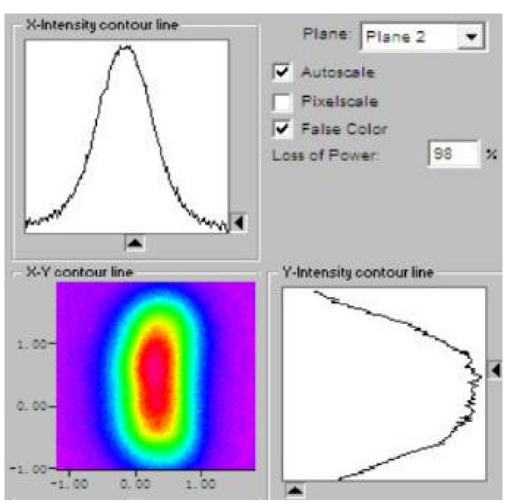

Fig. 7. Spot of diode laser.

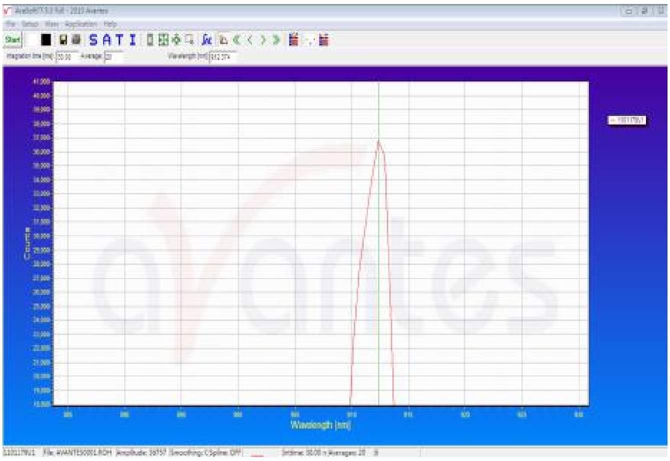

Fig. 8. laser diode spectra.

5 Conclusion

A method of combining single-emitters diode laser with fiber combiner is proposed, and the all-fiber multi- emitters diode laser module is designed and developed. The output power of 8w fiber-coupled single-emitters diode laser is combined by using two modules, that is, eight 19x1 fiber combiners with the beam combining efficiency more than 96 %. And eight output fibers are shaped and focused, The output power reaches 1453w, the spot size is 2.25mm*1.1mm, and the power density reaches 6x10^4w/ cm^2. Meet the requirements of metal laser cladding. Since the diode laser is integrated by a module, the spot size and laser power can be controlled by changing the number of modules to meet the requirements of laser processing.

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