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High brightness KW-class direct diode laser

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ABSTRACT

With certain emitter beam quality and BPP allowed by fiber, we have derived a spatial beam combination structure that approaches the BPP limit of the fiber. Using the spatial beam combination structure and polarization beam combination, BWT has achieved 1.1KW output from a fiber (one end coated) with NA 0.22 and core diameter of 200μm. The electro-optical efficiency is nearly 47%. Multiple emitters with wavelength of 976nm are packaged in a module with size of 600 $\times$350$\times$80mm^3.

Keywords: Diode laser, spatial beam combination, margin arrangement, fiber coupling

1. INTRODUCTION

Although the power improvement of single mode single fiber laser is limited by the transversal mode instability(TMI)[1] and the Stimulated Raman Scattering(SRS), 10kW single mode output has been achieved with tandem pumping [2]. With the in-depth study on mechanism of TMI and photon darkening of active optical fiber and new structure (such as photonic crystal fiber ,PCF)and new material of application of optical fiber, the fiber laser power will reach a new level, then the pump source's brightness is the main obstacle to enhance the power of fiber laser. In this paper, we studied the improvement of pump source's brightness. Beams from multiple emitters are spatially combined and polarization combined. An output power of 1.1KW is achieved from a 200μm core 0.22 NA fiber, and a brightness of 24.7 MW/cm^2-sr is reached. A previous study introduced a 1000W fiber coupled diode laser based on spatial beam combined bars [3], but the 225μm core fiber provided a limited brightness. Pump source of higher brightness improves optical-optical efficiency in fiber lasers, and its beam can be guided with fiber combiner and coupled into active fiber of smaller clad diameter. Smaller clad diameter enables smaller bend radius, which in turn further increases loss of higher order modes and helps development of high efficiency single mode single fiber laser.

2. SIMULATION AND DESIGN

Limited by development of semiconductor material and related engineering technology, the brightness enhancement of semiconductor laser chips is slow. The highest brightness level is 4.3W/mm*mrad[4] at present. However, due to intellectual property issues, the manufacturing technology of high brightness chips is not popular. Therefore, the way to improve the brightness of diode pump source is to increase the number of chips through spatial combination arrangement, and make full use of the normalized frequency of fiber to reach the limit of fiber reception. By studying the correlation between BPP (beam parameter product)of diode laser single emitters, normalized frequency of fiber and BPP of spatial combined beam, BWT has deduced a spatial arrangement structure, which we call it margin arrangement. As shown in Figure 1 below, the margin arrangement maximally utilizes the space in the solid corner corresponding to the fiber NA, which compacts multiple single emitters and meets the basic condition of fiber coupling [5]. Quantitative relationships that relates BPP of spatial combined beam and BPP of fiber needs to be strictly complied in a margin arrangement structure. For example, with emitter of BPP=4mm*mrad, core diameter of 200μm and NA 0.22, allowed number of diode lasers versus variable CSF is shown in Fig. 1. Also shown in Fig. 1 is the arrangement of beams. CSF:the ratio between width of collimated beam in slow axis and height of collimated beam in fast axis.

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It can be seen from Fig. 1, that with certain BPP of emitter and normalized frequency of fiber, allowed number of emitters is related to CSF, and there is a maximum allowed number. The spatial arrangement of the limit values reflects the connection between multiple single emitters and optical fiber on geometric figures, that is, multiple inscribed rectangles, which are just the arrangement of multiple single rectangles in conventional space arrangement. In the numerical operation process, our physical model takes into account the divergence of beams and the spatial dark gap between adjacent emitters, which enables us to accurately predict the worst results in the actual situation.

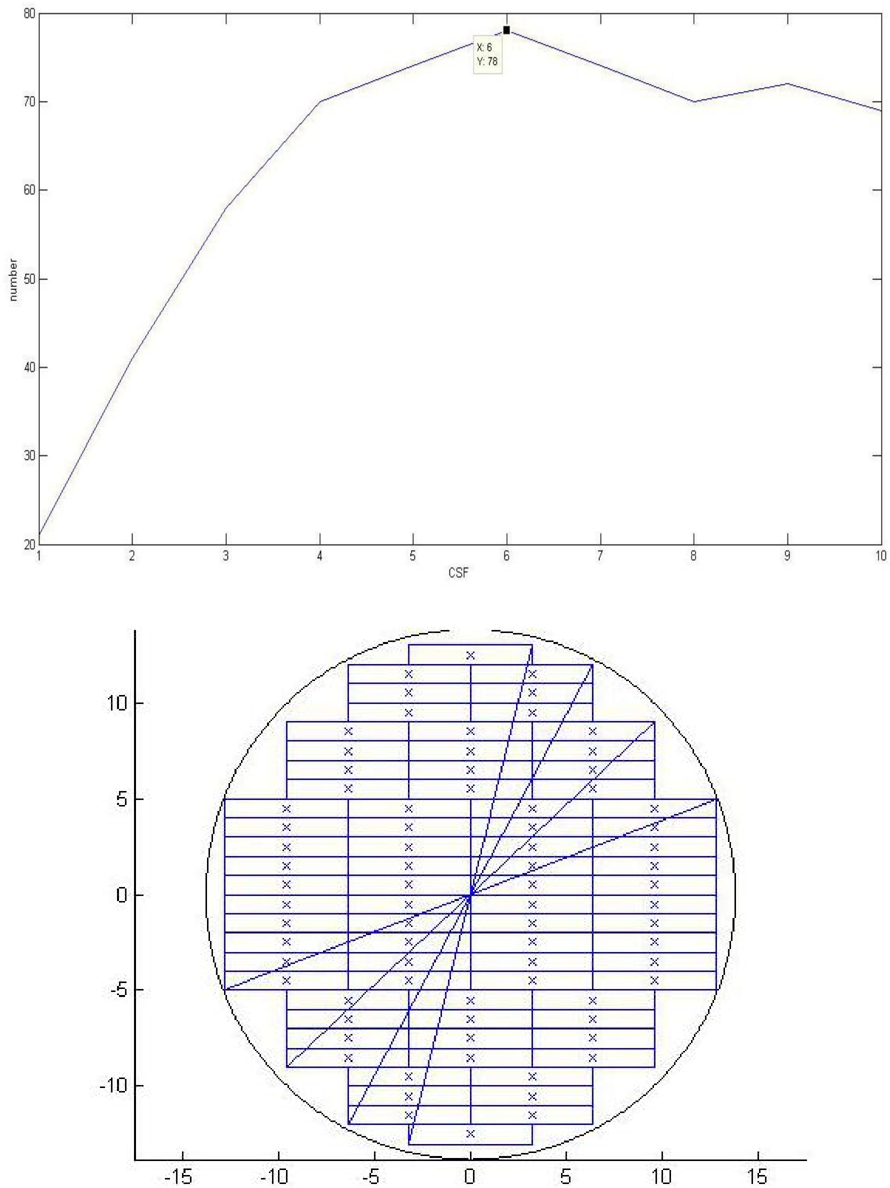

Figure 1. Margin arrangement.

Similarly, for a given initial parameter (such as single emitter BPP, fiber core diameter, NA and other parameters), we have solved the optical parameters based on the coupling condition of fiber: the focal length of coupling lens and fast and slow axis collimating lens[5], as shown in Fig. 2.

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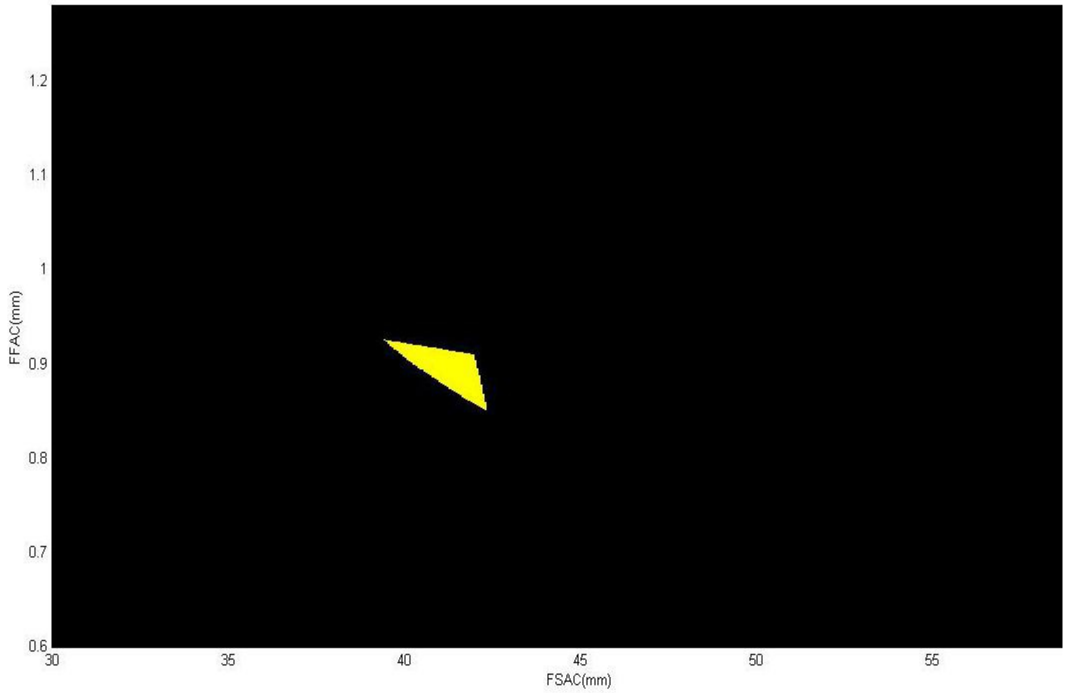

Figure 2. Numerical calculation.

3. PUMP PERFORMANCE

In order to achieve the margin arrangement in compact volume, a patent pending structure expands arrangement of emitters from 2 dimensions to 3 dimensions. Chips are distributed on both sides of multiple heat sinks with water cooler channels. This structure not only reduces difference between beam sizes caused by divergence over various optical paths, but also shortens average optical path, which is beneficial to the beam control and fiber coupling. However, it is still in a mechanism proving stage, so material and structure of heat sinks are not optimized. As Fig. 3 shows, the prototype has a size of 600*350*80mm^3. Fig. 4 shows the beam profile measured by CCD.

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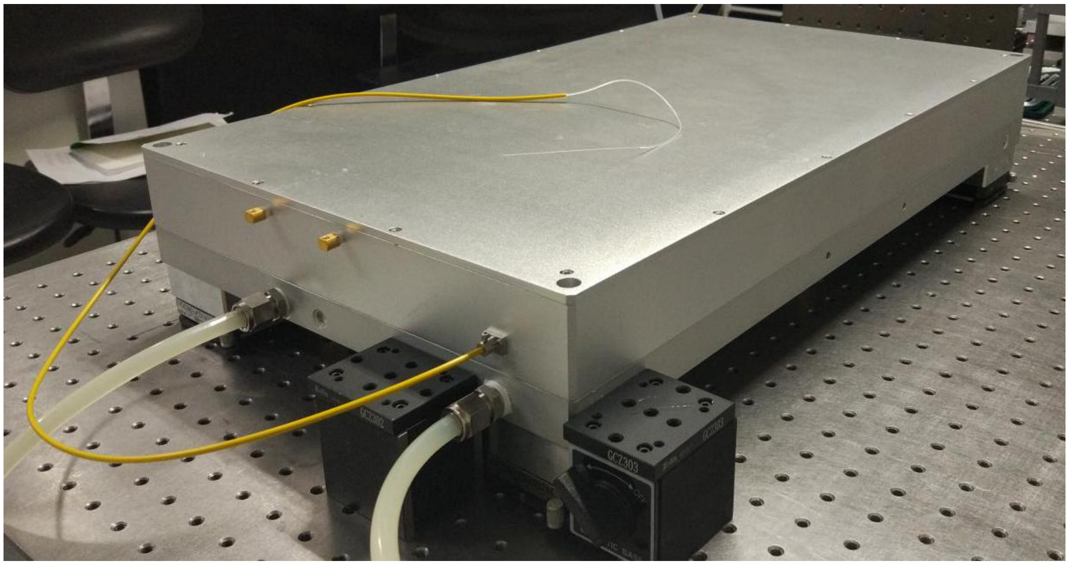

Figure 3. Prototype.

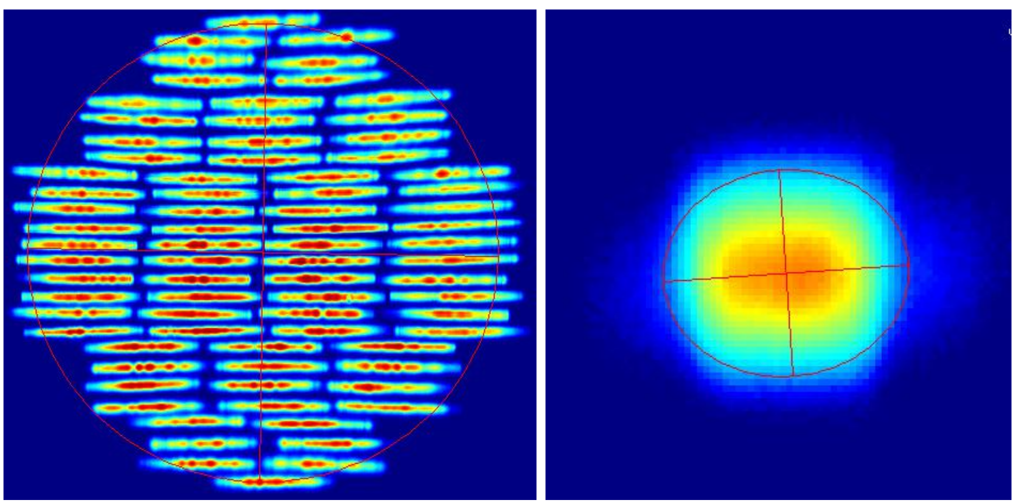

Figure 4. Profile of combined beams.

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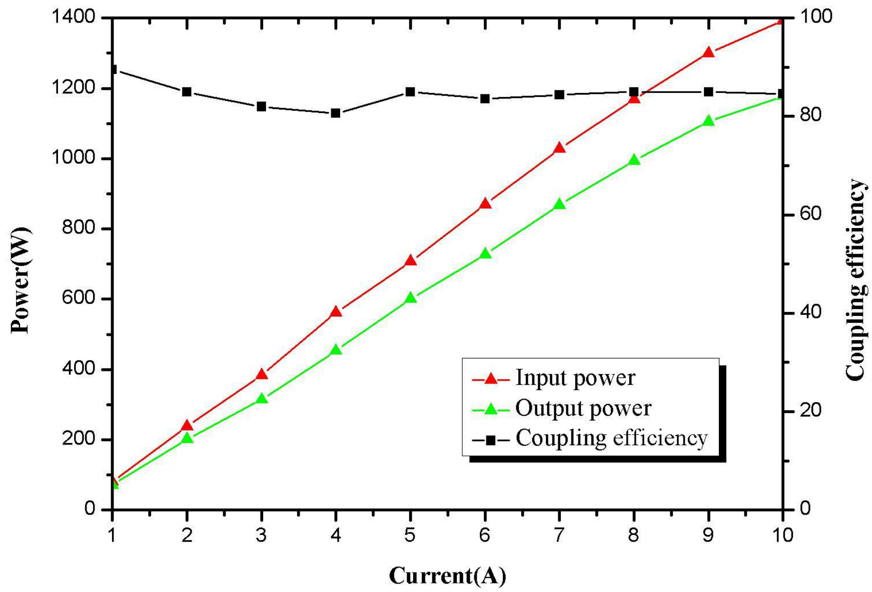

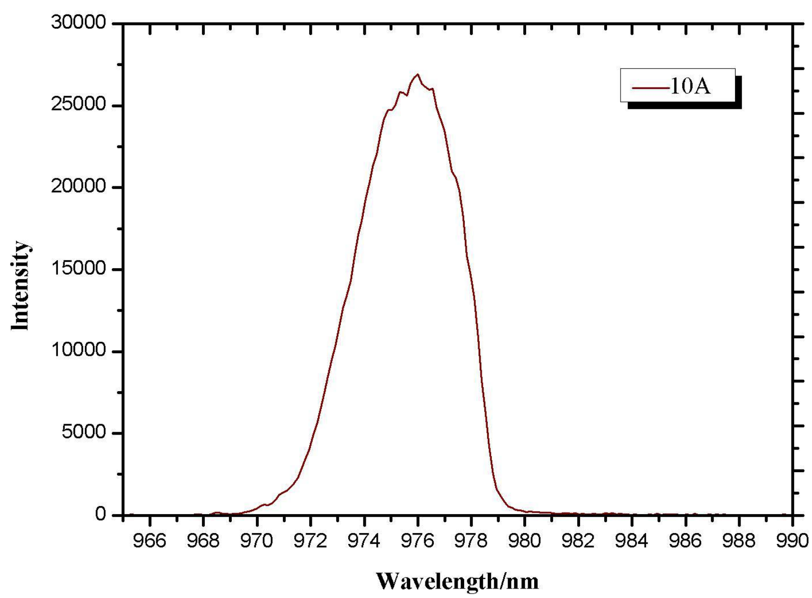

Figure 5. Coupling efficiency and spectrum.

Coupling efficiency and spectrum are also measured. During fiber coupling, part of power goes into clad. To reduce temperature (<50˚C) of fiber in operation, fiber coupling end uses a cladding mode stripping structure, and is packaged in a passive cooling heat sink. When the fiber with one end coated outputs 1178W, which amounts to 1227W in fiber, the highest temperature measured on the fiber is 41˚C, and spectrum as shown in Fig. 5.

4. SUMMARY

We developed a fiber-coupled pump-module emitting 1.1KW from a 200μm, 0.22NA fiber with one end coated. By improving engineering process, the electro-optical efficiency and power-to-weight ratio would be enhanced,and size can

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be reduced. 1kW of wavelength-locked can be obtained in the same dimensions. With increasing brightness of emitters, margin arrangement can further improve brightness of fiber coupled diode laser modules. High brightness diode lasers can be used as pump source of fiber lasers as well as be used direct processing like cutting thin metal sheet, welding and cladding. Combined with fiber combiner, the output power can be expanded to over 6kW, providing high economic efficient laser source for welding and cladding applications.

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