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Abstract

At SPIE 2020 conference, we presented a blue diode laser that provides 200W output from a 200μm core diameter 0.22 NA fiber. Blue laser with high power and high brightness is the best choice for higher efficiency demanded by industrial processing. Based on 7 modules each provides 160W from a 105μm core diameter 0.22 NA fiber (NA 0.15/0.22 power ratio >93%), using fiber beam combining, 1000W output is achieved from a 330μm core diameter 0.22 NA fiber. And the aging test of 160 W unit modules was carried out. 1000W high brightness blue laser source is an ideal choice for processing (welding, 3D printing, etc) of non-ferrous metals, especially copper.

1. INTRODUCTION

Since invention of laser, many laser medium, from solid laser pumped by flash tube, RF excited CO2 laser to fiber laser, have been used. But limited by energy levels, their output wavelength are all above 1μm, thus have relative low photon energies. Although through harmonic wave transformation, they can output green light or even ultraviolet radiation, but high peak power density and nonlinear crystals are needed and continuous wave output with electro-optical effeciency over 20% can hardly be realized.

Having more selections on wavelength and pumped directly by electrical current, diode lasers have advantages of more wavelength selections, high electro-optical efficiency, continuous wave output and long service life. But currently most high power diode laser chips are wide stripe end emitting structure, thus can hardly achieve high brightness. Because of that, diode lasers, since their invention, are usually used as pump source for solid lasers and fiber lasers. Beam parameter product (BPP) is a key indicator to measure the focusability of a laser beam. A diffraction limited beam has a BPP=λ/π. That means shorter wavelengths corresponds to smaller BPP of diffraction limited beam and better focusability that enable the beam to be coupled in fibers of smaller diameter. At the same time, higher photon energy can increase the absorption of laser by material. Compared with infrared laser, absorption ratio of 450nm laser by common metals increase by 10-60%. This is especially true for high reflection metals like copper and gold. Increased absorption means better utilization of laser energy. And this may leads to a revolutionary progressions in material processing.

There have already been some kW-level blue diode laser products: Laserline based in Germany presents a blue diode laser based on spatial beam shaping of diode laser stack and provides 2000W from a 600μm NA 0.22 laser; NUBURU based in US presents a laser based on spatial beam combination of multiple single emitters and VBG dense spectral beam combination and provides 1500W from a 105μm NA 0.22 laser[1]. These companies also did welding and cladding experiments with high reflection materials like copper and aluminum. Experimental data shows that compared with infrared laser, high power blue lasers produce much less pore and splashing. And higher absorption obviously lowered requirement on laser power[2].

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2. OPTICAL DESIGN

To improve the reliability of kW-level diode laser system, fiber combiner is used to expand power. Considering a single blue laser chip provides only 5W, if only spatial beam combination and polarization beam combination are used, 200 single emitters need to be combined on light path. That's not good for production efficiency and product consistency. Also to reduce size and match existing automatic microlens collimation and fiber coupling system, COS mount is used instead of TO mount. Fig. 1 shows schematics of light path.

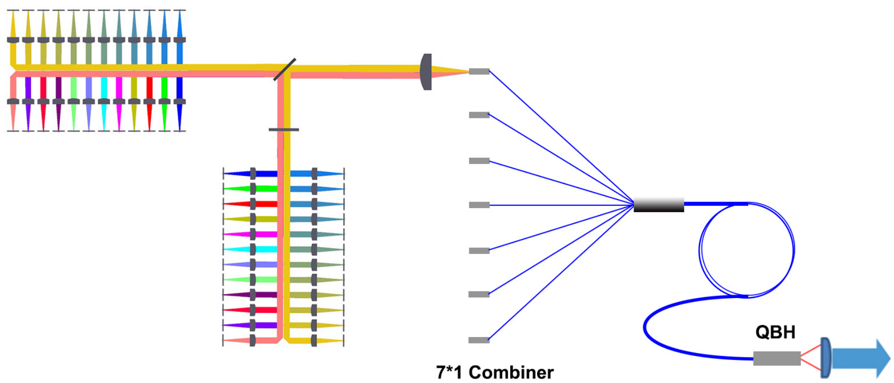


Figure 1. Beam combination structure

A module for fiber combination contains several sub units. Since cavity surface of blue diode laser chip has high requirement on cleanness and and are sensitive to some chemical compounds (like organosiloxane compounds), each sub unit is sealed with protective atmosphere inside. This measure effectively ensures the longtime reliability of light source. Fig. 2 shows schematics of light path in a module for fiber combination and photo of the sub unit.

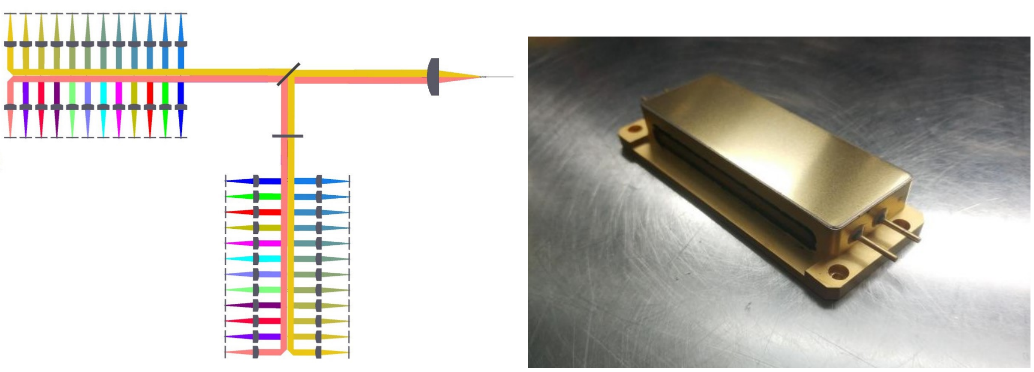


Figure 2. Schematics of light path and submodule

Compact light path design of sub unit shortens optical path length and increases ratio of energy within 0.15/0.22 NA in fiber coupling. The ratio directly decides the coupling loss while 7 105μm fibers are tapered and fusion spliced with a 330μm fiber. The ratio of energy within 0.15/0.22NA is an important optimization indicator in optical design. Based on the fast axis and slow axis BPP of 0.4mm*mrad and 2.2mm*mrad of the blue diode laser chip, beam spots after spatial beam combination are simulated. Firstly, 12 emitters are spatial beam combined in fast axis to form a column of beams. Then, 2 columns are spatial beam combined in slow axis. After that, polarization beam combination is applied to couple160W into a 105μm fiber in a module. Energy ratio of 0.15/0.22NA is measured to be 93%. Fig. 3 shows simulated arrangement of beam spots and measured energy ratio.

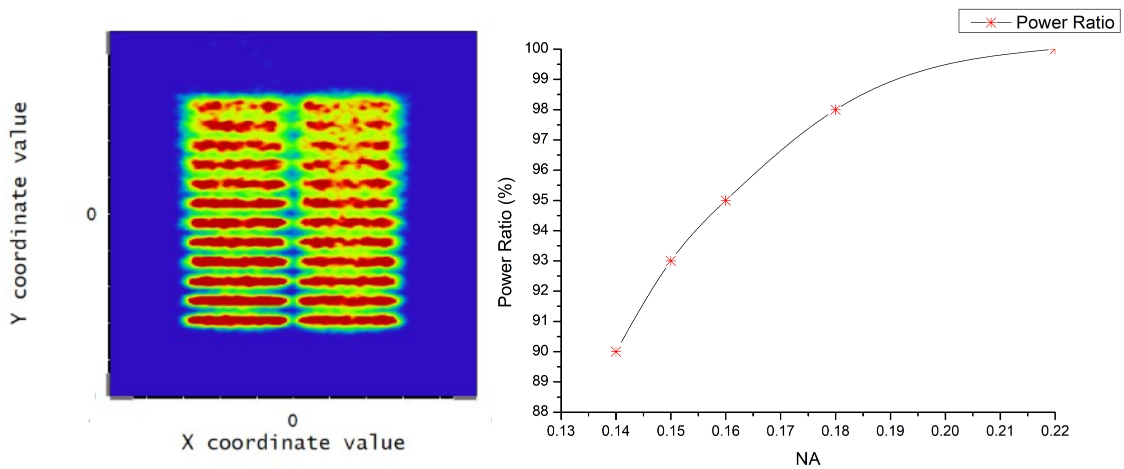
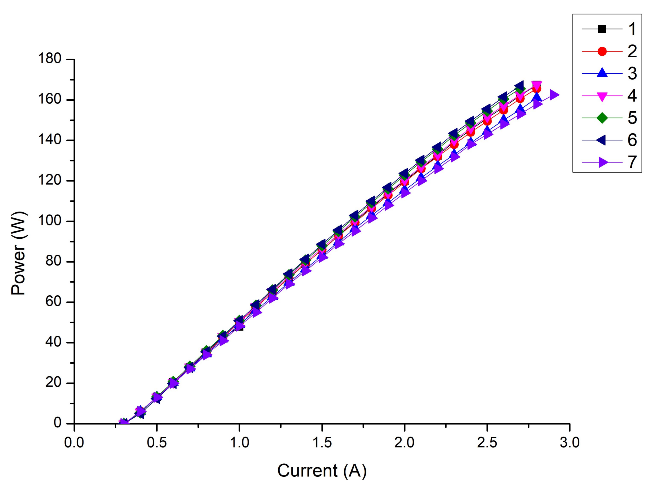


Figure 3. Arrangement of beam spots and ratio of energy within certain NA

3. TESTING OF MODULES AND BEAM COMBINATION

At least seven 160W modules are needed to obtain 1000W blue laser from a 330μm NA0.22 fiber. Power of 7 modules are measured and data is shown in Fig. 4. After 1000 hours of aging under the condition of 2.5A current and 20℃ water cooling, the power attenuation of the unit is less than 3%. Based on fiber tapering and fusion splicing, a 7*1 fiber combiner is produced. All fibers are common quartz fibers with relative short lengths. A combination efficiency of 90% is achieved. Fibers specialized for blue laser may improve combination efficiency in future studies. We manufactured power supply control system and QBH transmission fiber. Fig.5 shows measured power after beam combination.



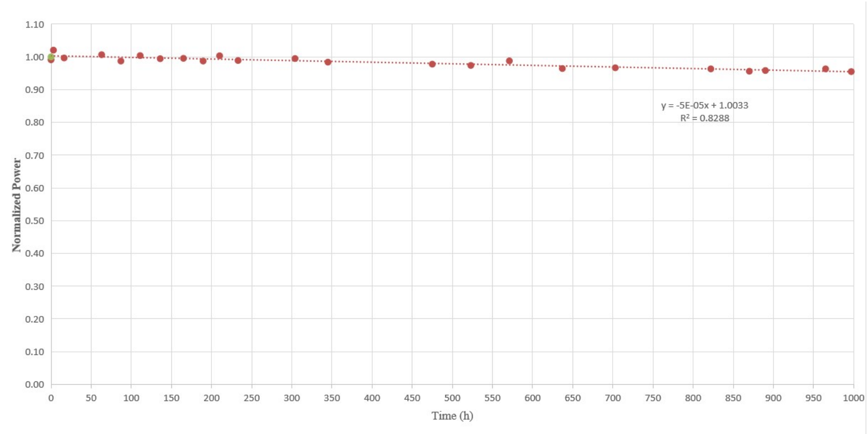


Figure 4. Power curve of 7 modules and aging test of one unit

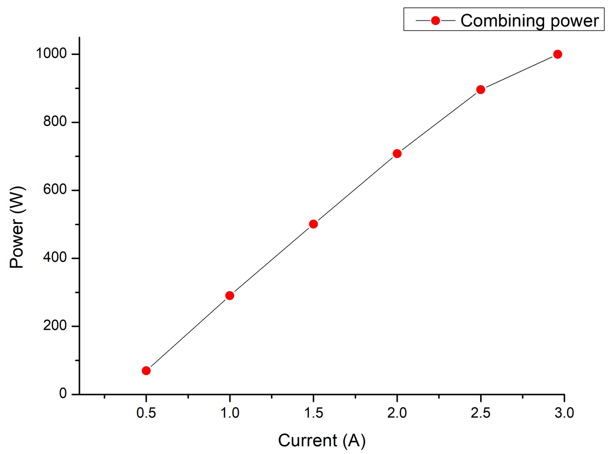


Figure 5. Power after beam combination

4. WELDING TESTS OF HIGH REFLECTION METALS

Fig. 6 shows photo of the blue laser system whose size(length×width×height) is 700×540×810mm^3. Copper and aluminum samples are welded to test the performance of the system. Collimating lens, focusing lens and protective lens are integrated in the welding system, but all lenses are not spherical aberration eliminated, which will have a negative impact on welding penetration. Spherical aberration eliminated lens group will be used as one of the optimization methods in the future. These lenses have antireflection coating that allows a transmission >99% for blue laser. With a magnification of 1.5x, a image of spot on end face of fiber is formed as the focus spot on work plane. Argon is used during welding process. Table 1 shows material, flow rate, welding speed, laser power, defocusing amount and corresponding phase diagram. No splashing is found in welding.

Figure 6. Blue laser system

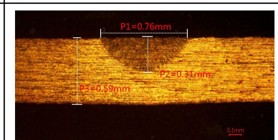
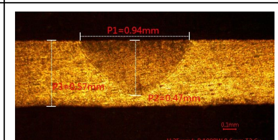
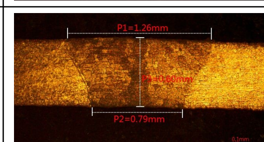
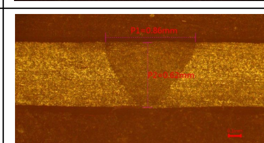
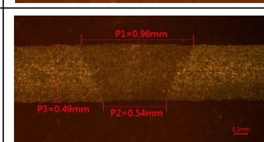
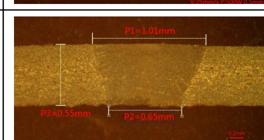
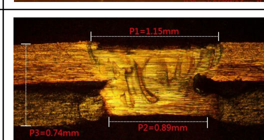
Material	Model number	Thick-ness (mm)	Laser power (W)	Focus spot (mm)	Welding speed (mm/s)	Argon flow rate (L/min)	Defocusing amount (mm)	Phase diagram
Copper	T2	0.6	1000	0.5	30	5	0	
Copper	T2	0.6	1000	0.5	25	5	0	
Copper	T2	0.6	1000	0.5	20	5	0	
Alumini-um	1060	0.5	500	0.5	30	5	0	
Alumini-um	1060	0.5	500	0.5	25	5	0	
Alumini-um	1060	0.5	500	0.5	20	5	0	
Copper& Alumini-um	T2 & 1060	0.3 & 0.3	1000	0.5	28	5	0	

Table 1. Welding parameters

5. CONCLUSION

Based on multiple blue single emitters, fiber coupled modules are made to provide 160W output from 105μm fibers. A 7*1 fiber combiner is used to obtain 1000W from a 330μm NA0.22 fiber. Welding of high reflection metals are tested. Test data shows that blue laser source is suitable for processing of high reflection metals, as copper and aluminum have important applications in many fields like battery of new-energy car and 3D printing of aerospace parts. It is believable that high brightness blue laser will have an important role in manufacturing of high-end equipment.

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