Manufacturing and Reliability Analysis of High Brightness Blue Light Semiconductor Laser

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Abstract

The blue semiconductor laser with a wavelength range of 450nm has developed rapidly in recent years. For high-reflective and high-thermal conductive materials represented by copper, gold and high-strength aluminum, the absorption rate of blue laser is 5-10 times than infrared lasers. Blue laser can achieve high-quality and consistent welding results, stable melt pools and no spatter. With the development of blue semiconductor laser technology, there is a growing demand for higher brightness and reliability.

Based on the practical application background, we have designed and implemented a stable high-brightness blue laser. Through BPP theory and ZEMAX simulation calculation, 48pcs TO-packaged 5.5W blue lasers are coupled into a 105μm core diameter 0.22NA fiber using polarization and optical fiber coupling technology. More than 250W output power is obtained with coupling efficiency exceeds 90% and electro-optical efficiency exceeds 35%. The high brightness blue laser has passed various reliability tests including accelerated aging for 7000 hours, 85℃ high temperature storage, -40℃ low temperature storage, -20℃~70℃ temperature cycling test, vibration and mechanical shock test. The stable high-brightness blue laser find significant applications in medical, 3D printing and welding.

Keywords: blue laser, high brightness, high reliability, fiber coupling

1.Introduction

Under the development trend of light-weighting, new demands have been placed on material processing in applications such as new energy vehicles, 3C electronics, and aerospace. Traditional iron-based materials face more challenges in terms of mechanical, electrical, thermal, and chemical properties. Copper, aluminum, titanium, gold and other nonferrous metals and their composite materials are being increasingly used. New materials and application pose new demands and challenges for laser processing.

The excellent electrical conductivity, thermal conductivity and cost advantages of copper make it widely used in the manufacture of electronic products and power batteries, and precise and reliable copper processing solutions face higher requirements.Since copper absorption rate of blue laser is much higher than that of infrared laser, it can effectively solve the problems of splashes, pores, internal defects that occur during infrared laser welding, enabling precision and high-quality processing. In recent years, more and more research on blue laser has been published[1], and the research on the failure mechanism of blue light chips has been continuously deepened[2,3],with the breakthroughs in high-power blue semiconductor laser technology,

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blue laser considered as one of the core tools for next-generation advanced intelligent manufacturing.

The development of high-power blue lasers has driven the development of copper-based 3D printing technology. Using blue lasers as the processing light source can greatly reduce laser reflection during processing, and the improved energy utilization rate is accompanied by faster processing speeds and higher processing quality.This article focuses on presenting a stable high-brightness to meet such requirements.

2.Optical and Mechanical Design

To obtain a relatively ideal coupling efficiency, the optical parameter need to satisfy the following relationship[4]:

$$d_{in} < d_{core}$$

$$\theta_{in} < \theta_{max} = 2arcsin(NA)$$

$$BPP_{laser} = mBPP_f + nBPP_S < BPP_F = \frac{d_{core} \cdot NA}{2}$$

d_{in} is the spot diameter of the incident beam, θ_{in} is the full angle of the far-field divergence angle of the incident beam, d_{core} is the diameter of the fiber core, θ_{max} is the full angle of the maximum incidence angle of the fiber, NA is the numerical aperture of the fiber, BPP_{laser} is the BPP of the laser beam, BPP_f is the fast axis direction BPP of the laser chip, BPP_S is the slow axis direction BPP of the laser chip, BPP_F is the BPP of optical fiber, *m,n* are the number of chips stacked on the fast and slow axis.

Base on the BPP (beam parameter product) theory, we designed to stack 12 blue light spots along the fast axis direction, and stack two rows of spots along the slow axis direction, resulting in a total of 24 spots for spatial beam alignment. Then 48pcs TO-packaged blue lasers are coupled into a 105μm core diameter fiber based on polarization combination.

First, we use the aspheric lens to collimate the output beam of TO-packaged blue laser, due to the emission characteristics of the semiconductor chip, there is a significant BPP difference between the fast and slow axis directions. After collimation with the aspheric lens, the spot size in the fast axis direction is too large, and there is a large residual divergence angle in the slow axis direction, which is not conducive to subsequent coupling. Therefore, it is necessary to perform secondary beam shaping. We choose to use cylindrical lens groups based on the Galileo telescope structure.

The beam energy distribution on the fast axis direction is close to a Gaussian distribution, with less energy on the periphery. In order to fully utilize the BPP of the fiber, we use cylindrical lens groups to expand the slow axis beam by 5 times and reduce the fast axis beam by 6.75 times. Then, we use an aspheric focusing lens to couple the fast and slow axis beams into the fiber simultaneously.The optical design simulation is shown in Figure 1.

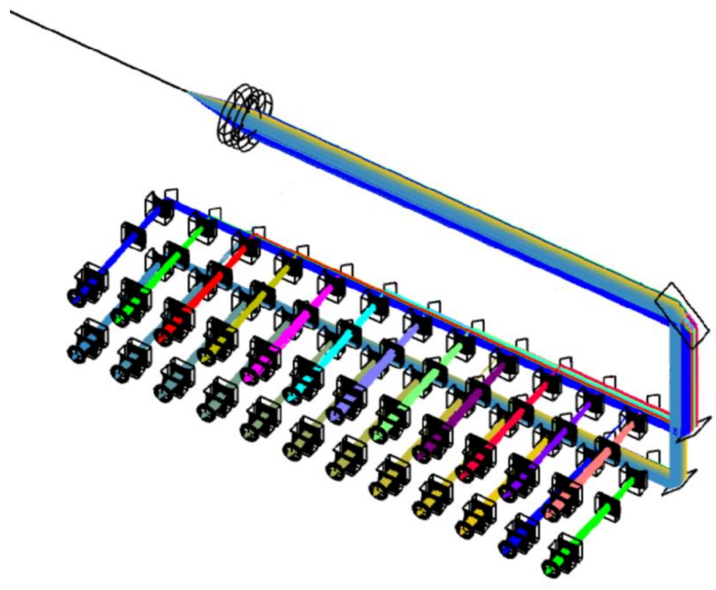

Figure 1. Schematic of optical design

Spatial beam alignment is shown in Figure 2(a), simulation focus spot size about 56μm*62μm at fiber incidence end face as shown in Figure 2(b).

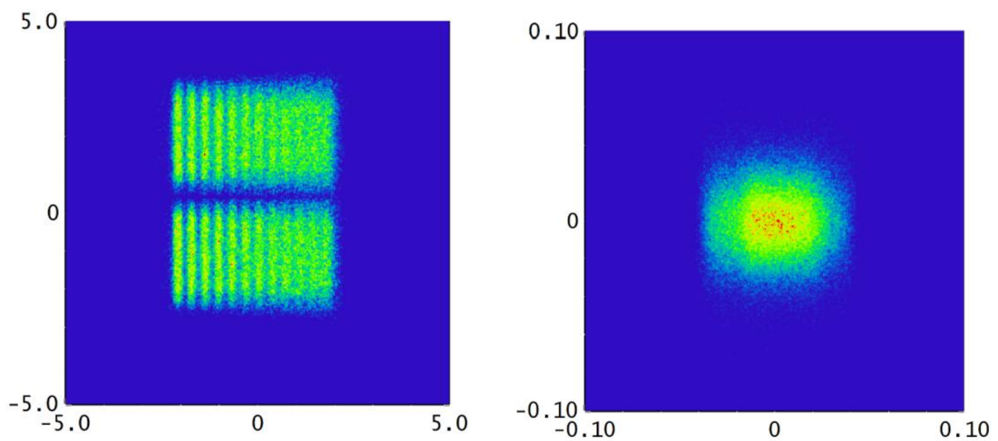

Figure 2. (a)Spatial beam alignment (b)Focus spot at fiber incidence end face

We design a composite material combination and water cooling heat dissipation scheme, which is shown in Figure 3. The overall package size is 217mm*159mm*103.6mm. The copper water-through module structures designed to ensure good heat dissipation, and the lightweight aluminum alloy frame design to ensure mechanical strength. Through design simulation, the optimal fixed positions and torque for different material combinations have been confirmed.High reliability fiber structure as shown in Figure 4, this design can ensure that the fiber can withstand high-power density blue light coupling and transmission.

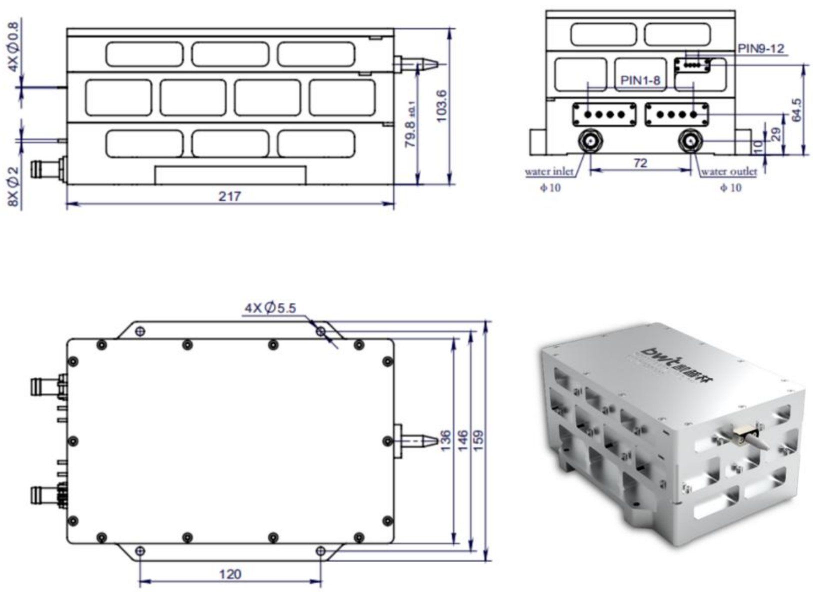

Figure 3. Mechanical design

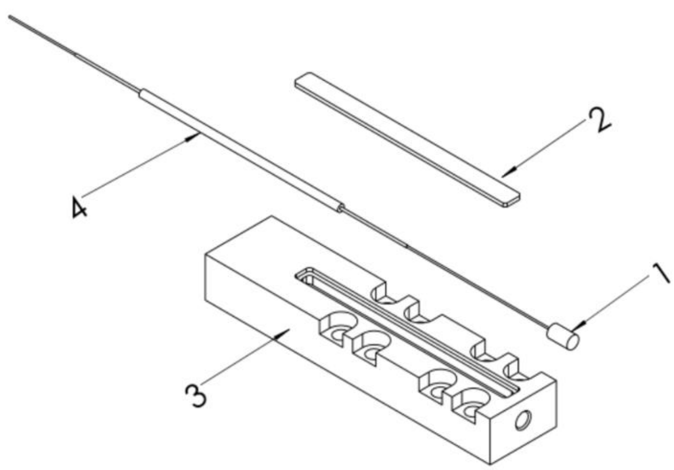

Figure 4. High reliability fiber structure
(1-1.8mm diameter fused silica end cap, 2-observation window, 3-mechanical structure, 4-105µm 0.22NA fiber)

3.Results and Reliability Test

At the water temperature of 20℃, 250W blue laser output power is obtained through a 105µm core diameter 0.22NA fiber, PIV data as shown in Figure 5. The central wavelength is 451.3nm. The coupling efficiency exceeds 90%, and the 0.17NA/0.22NA power ratio exceeds 90% for high brightness.

The high brightness blue laser has passed various reliability tests, including 85℃ high temperature storage, -40℃ low temperature storage, -20℃~70℃temperature cycling test, vibration and mechanical shock test, and 7000 hours accelerated aging test. Test results are shown in Figure 6.

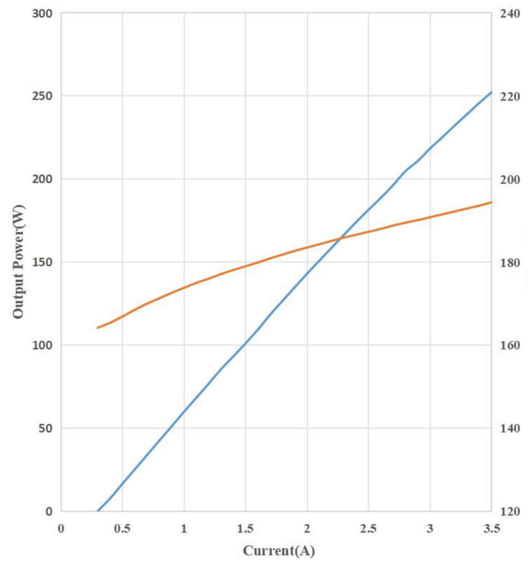

Figure 5. Power and voltage test data

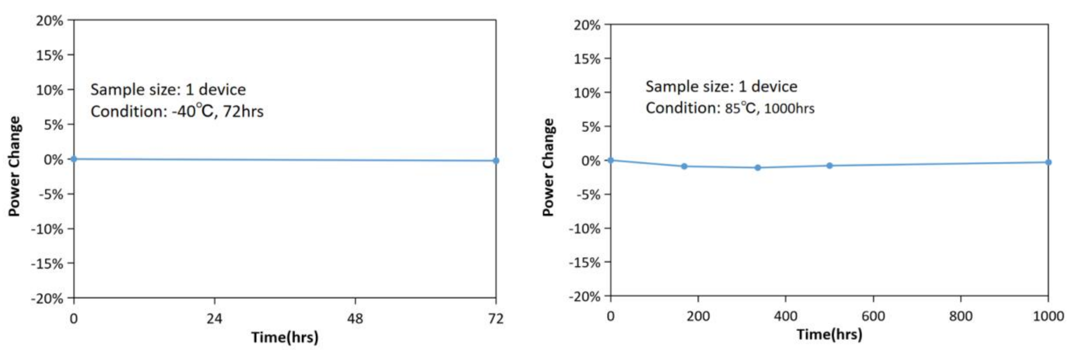

Figure 6. (a)Low temperature storage (b)High temperature storage

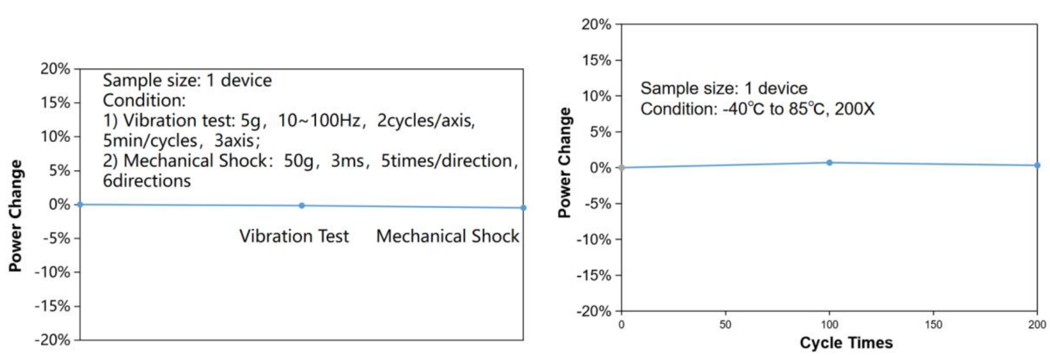

Figure 6. (c)Vibration and mechanical shock (d)Temperature cycling

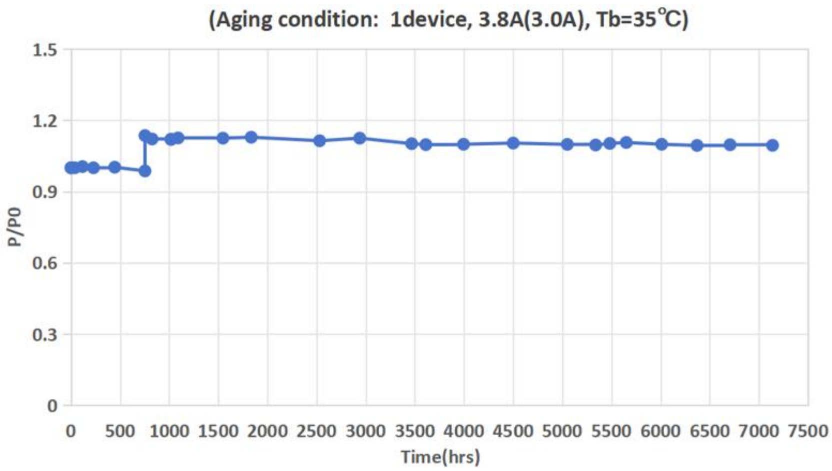

Figure 6. (e)Accelerated aging test

Base on 105μm high brightness blue laser module, through fiber combiner for module beam combination, we achieved 2kW blue laser output with a 600μm core diameter 0.22NA fiber, as shown in Figure 7.

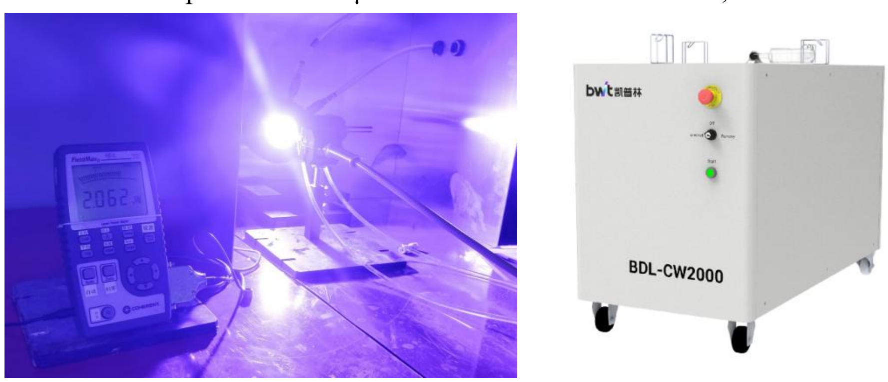

Figure 7. (a)2kW test data (b)2kW blue laser layout

4.Conclusion

With the rapid development of blue laser technology, blue laser demonstrate outstanding advantages in more and more applications. We implemented a high power and high brightness blue laser design, 250W output power is obtained through a 105μm core diameter 0.22NA fiber with 48pcs 5.5W TO-packaged blue laser chips. The coupling efficiency exceeds 90%, and the 0.17NA/0.22NA power ratio exceeds 90% for high brightness. 7000+ aging result shows stable and high reliable blue laser output, this design can ensure mass production capabilities and is an ideal light source choice for 3D copper powder printing, medical applications, and copper welding.

Reference

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