Development of the High-Power Blue Laser Diode Module and its Laser System

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ABSTRACT With the goal of applying blue lasers to the metal processing, we have developed a high-power blue diode module in cooperation with Nichia Corporation. Nichia Corporation has made a blue laser diode (blue LD) which outputs the highest optical power in the world enclosed in a small-sized package and Furukawa Electric has modularized it based on the technology acquired in developing an infrared laser diode module (IR LDM) applied to fiber lasers. As a result, we have successfully developed the blue laser diode module (blue LDM) which generates an optical output power of 185 W in average through an optical fiber of approximately 100 µm in core diameter and has a high reliability with no decrease in the optical output power even after a continuous operation of 1,000 hours and exceeding.
We have built a Direct Diode Laser (DDL) by connecting the blue LDM mentioned above with a control circuit and a drive circuit and have successfully developed the Blue-IR Hybrid Laser System "BRACE" by combining it with an IR fiber laser.

1. INTRODUCTION

Most recently, momentum to regulate selling new gasoline vehicles has risen rapidly under the policies of various governments to prevent the global climate change and realize the sustainable society. Therefore, replacement to Electrified Vehicles (xEV) including Hybrid Electric Vehicles is more promoted from since. It is forecasted that 32% of vehicles will be replaced to xEV in the 2030s and 51% in the 2040s and this trend may be further accelerated. It is important to reduce the production cost and provide xEV at a lower price at similar level as that of today's gasoline vehicles to promote the widespread of xEV in the society. A lot of copper is used in motors, inverters and lithium-ion batteries which are core components for xEV. Processing copper such as welding motor magnet wires, welding bus bars or welding battery foil is highly required for each of them. We expect more demand for the laser processing, which can process copper free from contact, by higher speed, and in higher accuracy.

However, it is known that to process copper with an infrared fiber laser is difficult, which is already in the market by Furukawa Electric for laser processing.

We have formed a business alliance with Nichia Corporation and have developed a blue LDM targeting at the optical output power of 100 W or more through an optical fiber of approximately 100 µm in core diameter. As shown in a special paper "Development of High-Power Blue Laser Diodes" written by Dr. Nagahama, of Nichia Corporation, Nichia Corporation has developed a blue LD which generates the optical output power of 11.2 W, the world highest output among any blue LDs with one emitter and has also developed a small-sized package enclosing the blue LD: Side Lead Package (SLP). Furthermore, Furukawa Electric has developed the blue LDM equipped with this SLP by applying its design technologies and production technologies of the infrared laser diode module (IR-LDM) applied to the IR fiber lasers of Furukawa Electric.

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2. STRUCTURE OF HIGH-POWER BLUE LDM

The structure of an IR-LDM is shown in Figure 1[1)]. In this method, infrared laser diodes (IR-LDs) are arranged in a form of stairs and the optical output power of each IR-LD is input into an optical fiber through optical parts such as lenses and mirrors to reach higher output. As for the blue LDM, this part of the IR-LD is replaced with the SLP, and

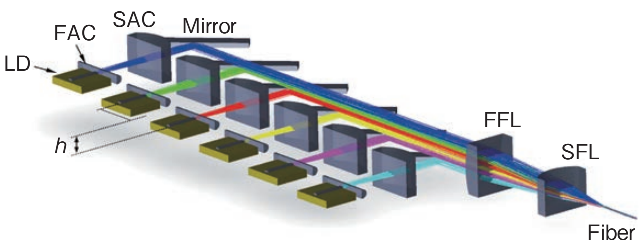

Figure 1 Structural drawing of IR-LDM.

optical parts and the structure are optimized to the SLP.

The temperature of our IR-LDM is controlled by cooling its package as a whole through an external heat sink. However, cooling through an external heat sink is insufficient for the blue LD, because the amount of the exhaust heat from the blue LD is as much as approximately double of that of our IR-LD as one of its characteristic properties. It is desirable for the blue LDM to cool each of its SLPs efficiently and uniformly to realize higher optical output power, more stable performance and higher reliability. For this purpose, as shown in Figure 2, we adopted such an integrated base plate with a water-cooling heat sink so that a water channel is formed along with the slope of stairs[2].

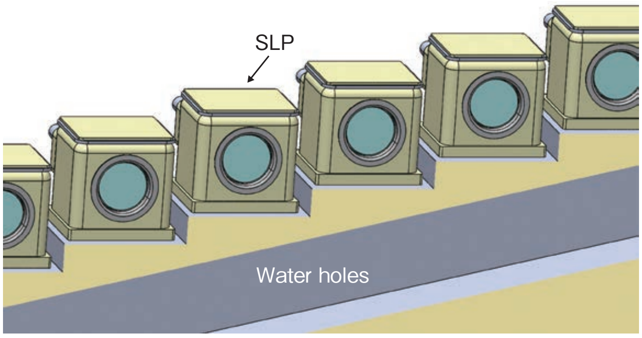

Figure 2 Structural drawing of cooling system for SLP.

3. CHARACTERISTICS OF THE HIGH-POWER BLUE LDM

Figure 3 shows typical characteristics of optical output power vs input current “L-I characteristics” and voltage vs current “V-I characteristics” of the designed high-output blue LDM and was made based on the technologies mentioned above. Setting the temperature of cooling water at 25°C, the measurement was carried out under the Continuous Wave (CW) driving. As a result, the fiber core of approximately 100 μm in diameter has achieved the optical output power of 185 W with a rated driving current of 8.5 A and 220 W with 10.5 A which was the end of life current. These are the highest-class optical output power density in the world output through a fiber core of approximately 100 μm in diameter. Further, the typical wave spectrum of the blue LDM is shown in Figure 4. The mean wavelength is approximately 462 nm and is almost same as that measured at SLP, which is indicating that the blue LDM is sufficiently cooled by the integrated base plate with a water-cooling heat sink.

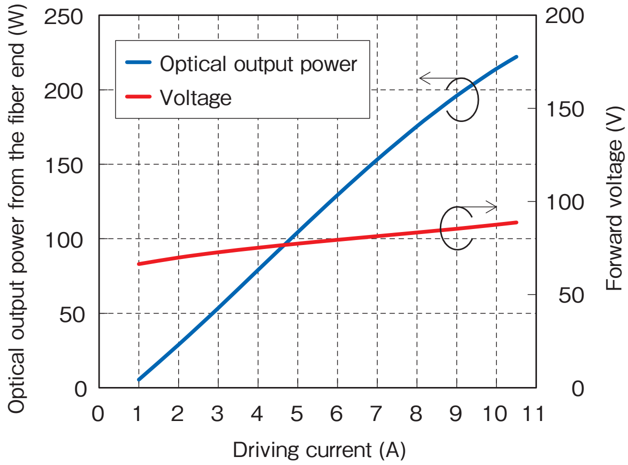

Figure 3 Typical L-I and V-I characteristics of the blue LDM.

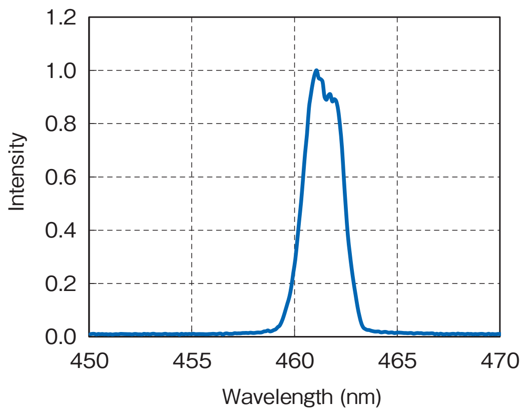

Figure 4 Typical wavelength spectrum of the blue LDM.

4. RELIABILITY OF THE HIGH-POWER BLUE LDM

The summarized result of aging test with 5 samples of blue LMDs under the end of life current: 10.5 A is shown in Figure 5. Excellent reliability of our blue LDM which is a fusion of exceptionally reliable blue LDs of Nichia Corporation and the LDM manufacturing technology of Furukawa Electric is shown as the changing rate of optical output power from the fiber end is no more than 1% even after 1000-hour aging.

Further, the summarized result of heat shock test and high-temperature storage test with 5 samples, which are examples of the reliability test is shown in Figure 6. In the heat shock test, 1 cycle consists of temperature change from -20°C to +70°C and from +70°C to -20°C. After exposing to the temperature load as many as 100 cycles, the optical output power changed only by ±4% or less to show a good sufficient result. In the high temperature storage test, the optical output power changed only by ±1% or less after exposing for 500 hours in the environment of 70°C which is high enough against 50°C of specified storage temperature. Considering these results, we think we have developed a blue LDM reliable enough for industrial applications such as copper processing.

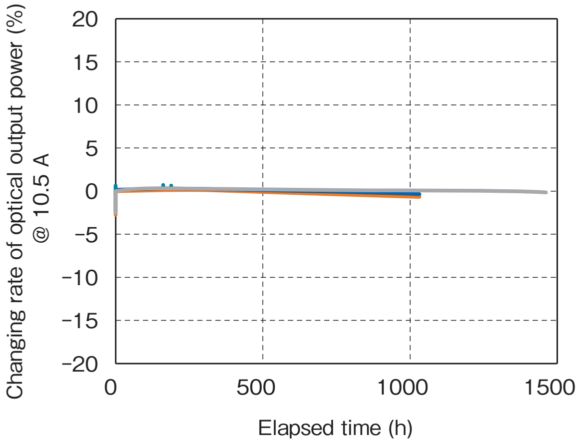

Figure 5 Aging test result of the blue LDM.

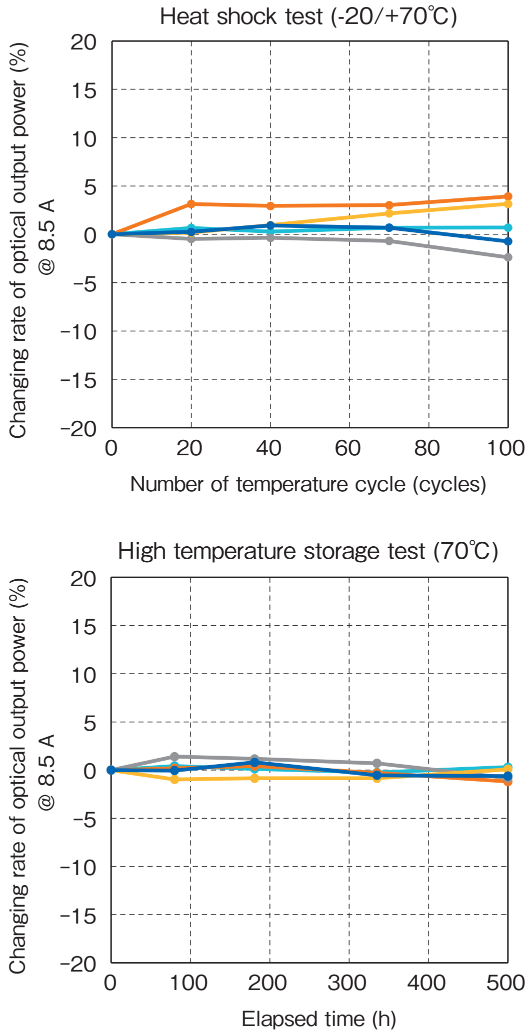

Figure 6 Heat shock test and high temperature storage test results of the blue LDM.

5. BLUE-IR HYBRID LASER SYSTEM "BRACE"

We have built a blue DDL by connecting the blue laser module mentioned above with a control circuit and a drive circuit and have successfully developed the Blue-IR Hybrid Laser System "BRACE" by combining it with an IR fiber laser. The shape of the apparatus is shown in Figure 7 and the output characteristics of the blue laser and the IR laser is shown in Figure 8. Output power of 150 W or more is gained for the blue laser and 1 kW or more for the IR laser.

Figure 7 Blue-IR hybrid laser "BRACE".

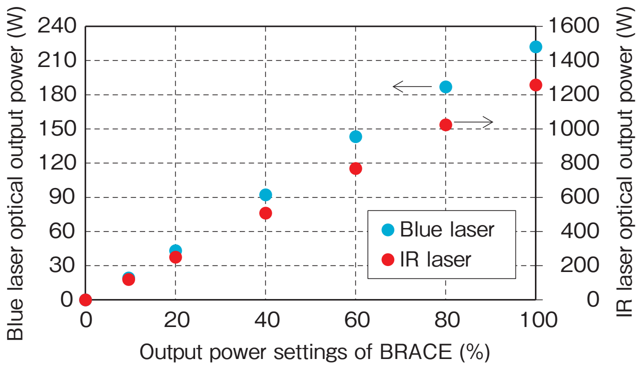

Figure 8 Typical L-I characteristics of BRACE.

6. SUMMARY AND AN OUTLOOK FOR THE FUTURE

With the goal of applying blue lasers to the metal processing, we have developed a high-power blue diode module in collaboration with Nichia Corporation. We integrated the SLP developed by Nichia Corporation into the LDM applying our technology of IR-LDM of Furukawa Electric and have developed the optimized LDM. As a result, we have successfully developed the blue laser diode module "blue LDM" which outputs an average optical power of 185 W at the rated driving condition through an optical fiber of approximately 100 μm in core diameter and furthermore, has a high reliability with change of only approximately 1% or less of the optical output power even after continuous operation with as high as 220 W output for 1,000 hours or longer. We have built an blue DDL by connecting the developed blue laser module with a control circuit and other circuits and combined it with an IR fiber laser and successfully launched the Blue-IR Hybrid Laser “BRACE” into market.

From now on, Nichia Corporation will concentrate its efforts to develop further high-output blue LD. And Nichia Corporation and Furukawa Electric are planning to improve the optical coupling efficiency from LD to optical fiber furthermore and will develop a blue LDM which outputs 300 W or more from an optical fiber.

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