High Brightness Pump Module

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We report the development of high brightness laser diode modules used as pump sources for high power fiber lasers. Laser diode modules are key devices which characterize the performance of the fiber lasers. We have achieved the highest brightness by combining the new packaging technology and high power laser diode technology developed by OPTOENERGY Inc.

1. Introduction

The market demand for fiber lasers has been increased in a laser processing area because of their competitive properties such as high conversion efficiency, good beam quality and small-footprint compared to CO_2 lasers or YAG lasers [1]. Especially, market size of kilowatt-class fiber lasers for metal cutting or welding are growing significantly [1]. Tens of laser diode (LD) modules are used in those high power fiber laser systems for pumping sources. As the brightness of the modules increase, it can be possible to reduce the number of the modules, to simplify a pump combiner configuration, to save space of the system, and to reduce cost. It is also possible to increase the fiber laser power by increasing the total pump power. Therefore, increasing brightness of the pump module is one of the most critical issue to achieve the competitive fiber lasers. [2), 3), 4)]. Fujikura has developed ultra-high power LD module with over 300 W optical power from 100 μm core fiber.

2. Technology for high brightness LD module

High power, high brightness pump module is realized by means of beam multiplexing techniques. The module consists of several parts, such as collimating and focusing lenses, mirrors and so on. There are two methods to increase the power and the brightness of the modules. One method is to increase the number of emitters. The other method is to increase output power of each emitter. However these method are not easy to achieve. As the number of emitters increases, it becomes more difficult to focus the light from the laser diodes on the fiber core. On the other hand, as the output power density of each emitter increase, random failure rate raises because of Catastrophic Optical Damage (COD) at laser facet. In addition, high power operation would cause reduction of conversion efficiency. That leads to elevation of temperature in the LD. As a result thermal rollover occurs. Because of these technical problems, brightness of the laser diode module have been restricted. We realized world's highest level brightness LD module by combining high power LD developed by OPTOENERGY Inc. and our unique optical design, package design, and assemble technique.

2.1 Laser diode

There are two general approach to increase output power of a laser diode without degradation of reliability. One is to elongate the length of the cavity. The other is to make the emitter width wider. For both methods, the temperature of the laser active layer becomes low because of decreasing of thermal and electrical resistance. Therefore high power operation can be possible. In case of long cavity length, power conversion efficiency generally decreases because of effect of internal loss and increasing threshold current. On the other hand, threshold current also increases by widening stripe width, but high efficiency can be achieved at high current range because thermal elevation rate of the LD becomes small due to wider stripe width [5]. Then we adopted the design as widening the stripe width. However, widening stripe width causes degradation of beam-parameter-products (BPPs = half stripe width times half beam divergence angle) of horizontal direction. This means that the amount of increased stripe width is greater than the reduction of beam divergence angle due to thermal lens effect. The concept of high power operation offers essentially rising BPPs and needs advanced optical design. We optimized laser stripe width giving the highest coupled power to 100 μm core NA 0.22 fiber by our optical design and high-precision alignment techniques.

To improve the reliability at higher power operation, we have also utilized Asymmetric Decoupled Confinement Heterostructure (ADCH) for laser diodes [5]. Significantly high COD level is realized by minimizing optical confinement at the laser active area.

Wide stripe and ADCH structure realized extremely high reliability, in addition, our laser modules do not use a laser bar but single emitter lasers, there is no

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Panel 1. Abbreviations, Acronyms, and Terms.

LD—Laser Diode
COD—Catastrophic Optical Damage
BPP—Beam-Parameter-Product
NA—Numerical Aperture
ADCH—Asymmetric Decoupled Confinement Heterostructure
MTTF—Mean-Time-To-Failure
DDL—Direct Diode Laser

thermal interference between the adjacent emitters. Mean-Time-To-Failure (MTTF) of random failure mode of developed laser diodes is estimated to be over 1,000,000 hours at 15 W, 80 degrees C at p-n junction.

2.2 Optical design

The collimated beam diameter is relatively short in fast-axis direction and long in slow-axis direction due to the near field pattern of the laser diode. To obtain the high space-filling density of the beams, optical layout in the LD module is designed to align the beams in the fast-axis direction as shown in Figure 1. And to couple the light of large BPPs from wide stripe laser diodes to the fiber most efficiently, the center of the beams for the slow-axis direction are aligned to the optical axis of the fiber precisely. Micro lenses and mirrors are also required to be aligned submicron accuracy. We realized assembly accuracy of optical layout with the high coupling efficiency by using uniquely developed self-aligning machine. Not only spatial multiples but also polarization multiplex technique was used to double the brightness.

2.3 Package

To improve heat dissipation performance is one of the most important issue in package design. In general, metals having high thermal conductivity shows much higher thermal expansion property than the laser diode crystal. There is a concern that huge thermal stresses occurs by the solder bonding in the package. Thermal stress may induce internal failure of the laser diode. We realized both high reliability and low thermal resistance by designing the sub-mount multilayer structure of the package decreasing thermal stress, even using high thermal conductivity metals. Appearance of the manufactured module is shown in Figure 2. It is a compact size of about 100 mm square.

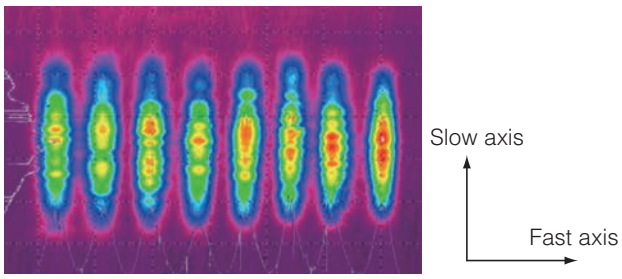

Fig. 1. Typical beam alignment profile image of part of the beam column in the module.

3. Performance of the LD module

3.1 Optical, electrical, and thermal characteristics

Optical power and forward voltage of the developed module as a function of current are shown in Figure 3. Optical power reaches 300 W at 15.5 A driving current with heatsink temperature at 25 degrees C. Linearity of the I-L curve is maintained up to 16 A and very few thermal rollover is observed.

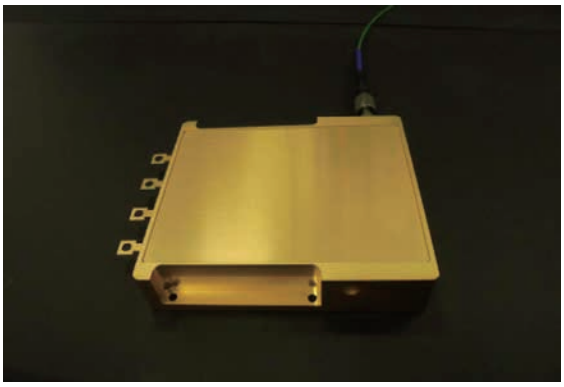

Fig. 2. Appearance of the 300 W LD module.

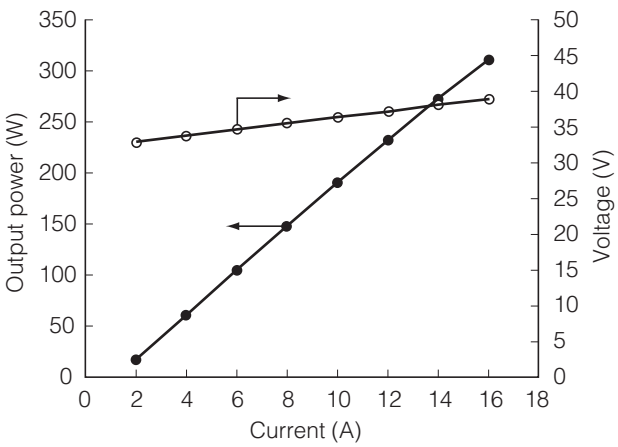

Fig. 3. I-L and I-V characteristics of the module.

Figure 4 shows power conversion efficiency as a function of current. It reaches 50% at 300 W, which is high enough as commercial use. And the degradation of the efficiency at higher current operation range is markedly small. It is confirmed that the effects of wide stripe structure and ADCH structure of the laser diode as we expected.

Heat release property of the module can be estimated from the wavelength shift because emission wavelength of semiconductor laser shifts longer as the temperature increases. Figure 5 shows center wavelength shift characteristics by the driving current. Wavelength shift is less than 1 nm/A even at 300 W, so it was confirmed that the thermal resistance of the module is sufficiently small.

Figure 6-7 shows temperature dependences of optical power and power conversion efficiency respectively. A characteristic temperature is generally used as an index representing the temperature characteristics of the semiconductor. The characteristic temperature of threshold current of the module is 182 K, and that of slope efficiency is 1,000 K obtained respectively, that are almost similar values of LD's. This indicates the coupling efficiency of the module is stable at 15-45 degrees C range of case temperature.

3.2 Reliability

To verify the reliability of the developed high brightness modules, we ran accelerated test by using several number of modules with total number of 158 single emitting LDs. The test condition is 16.5 A on driving current, 35 degrees C at heatsink temperature. The power degradation has not been observed and there

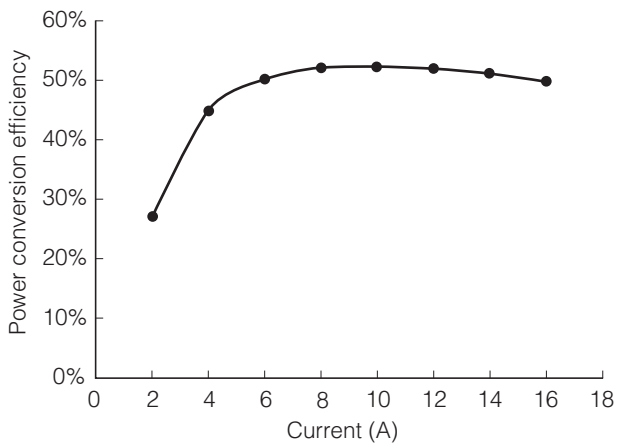

Fig. 4. Power conversion efficiency of the module.

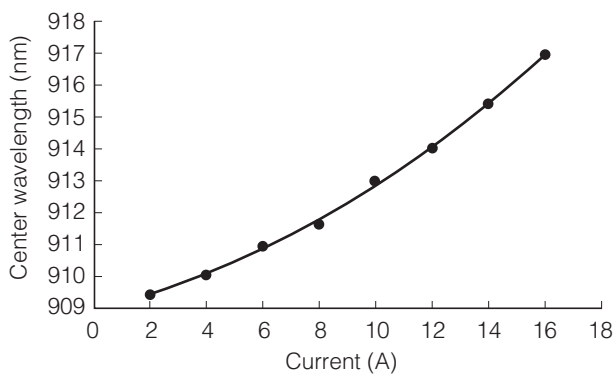

Fig. 5. Center wavelength shift of the module.

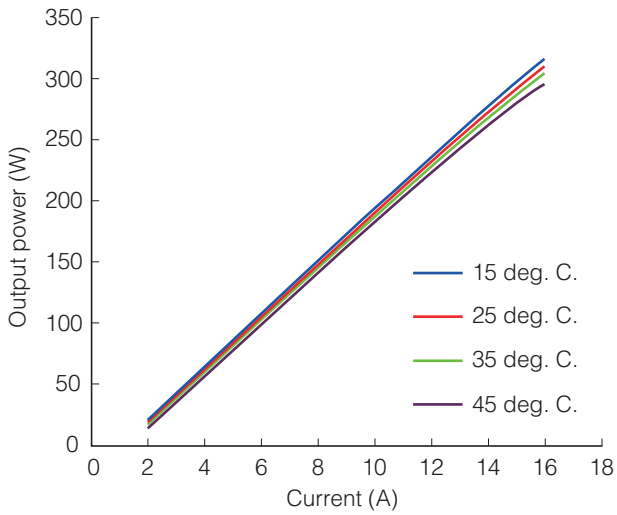

Fig. 6. Temperature dependence of the output power of the module.

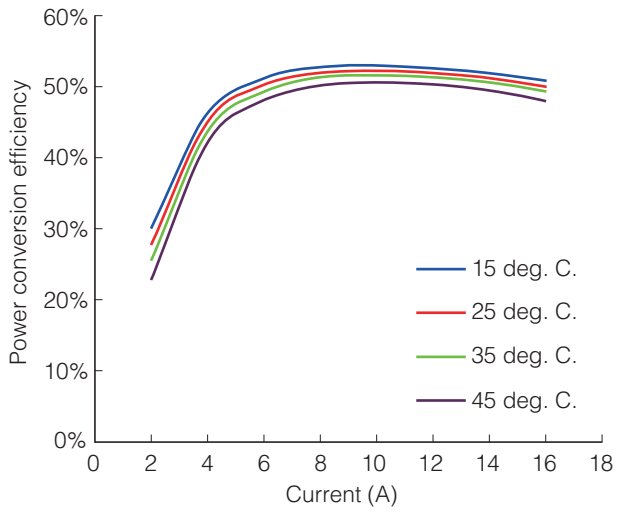

Fig. 7. Temperature dependence of power conversion efficiency of the module.

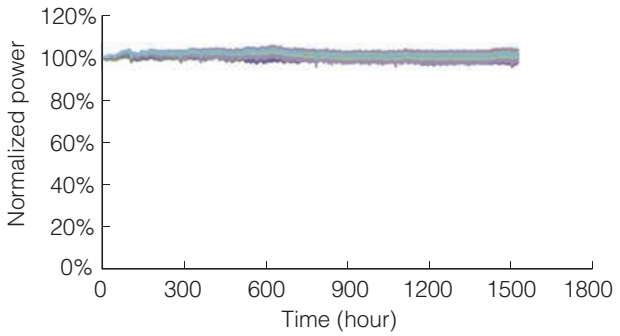

Fig. 8. Accelerated test result of the modules.

was no fail up to 1,500 hours as shown in Figure 8. This result indicates that there are no reduction of COD level nor induction of internal deterioration of the laser diode by packaging process, and maintains the inherent high reliability of the chip.

4. Conclusion

We developed high brightness laser diode module which outputs over 300 W from 100 μm core NA 0.22 fiber. These ultra-high brightness pump modules contribute to further cost reduction and compactness of kilowatt fiber laser systems. Increasing power of pump modules directly increase power of a fiber laser, so the high brightness modules are also utilized to make over 10 kW systems. Furthermore, the module is expected to be applied to a direct diode laser (DDL) irradiating the target object directly from the output fiber of the module without mode conversion, and accumulated technology through this development become base technology for DDL.

References

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