12 kW Multi-Mode Fiber Lasers

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In recent years, the demand for high power fiber lasers for metal processing applications is expanding. A high output power exceeding a kilowatt is required for metal processing. Generally speaking, the higher the output power becomes, the faster processing is possible. Therefore there is a strong demand from laser processing equipment manufacturers to increase the output power of lasers. Our group possesses all the key technologies required for fiber lasers and has developed and sold fiber lasers with a maximum output power of 8 kW. This time, we have newly developed and designed major optical components such as high power pumping light source, optical fiber circuit, and delivery fiber cable, and successfully developed a 12 kW multimode fiber laser using these new technologies.

1. Introduction

In recent years, new application for laser material processing has been developed actively. Fiber laser material processing technology has been applied to cutting thick steel plates, welding thick steel plates, remote high-speed welding, dissimilar materials welding, and cutting the carbon fiber reinforced plastic (CFRP).

Among fiber lasers, the demand for high output power (several kW class) fiber lasers is steadily increasing and is expected to grow steadily in the future.

To realize high output power fiber lasers, new technologies for rare earth-doped optical fibers, pump lasers for excitation, and transmission cables for high power laser delivery are required. The suppression technology of nonlinear phenomena and the elimination technology of unwanted light are also required.

By utilizing these technologies, we have succeeded in developing a 12 kW fiber laser which has high reliability and high durability enough to withstand industrial applications. High output power technology of fiber lasers our high-power fiber laser consists of several fiber laser units (FLUs) which outputs a continuous wave (CW) laser light by pumping a rare earth fiber, a combiner unit (CMBU) that combines laser light output from multiple FLUs into one optical fiber, and the transmission cable which guides a laser beam to a processing point.

There are two main issues for achieving an output of 12 kW. One is to cool heat-generating parts which have optical loss in itself. The other is to suppress non-linear phenomena caused by increased laser power propagating in the fiber.

We have solved these problems by utilizing each component design. In this report, we introduce our efforts for these representative issues.

2. 1 Fiber laser units

The basic configuration of FLU is shown in Fig. 1. The resonator is composed of some LDs, a pump combiner, an optical amplification fiber (YbDF) in which Yb ions are doped in the core, and Fiber Bragg Gratings (FBGs) which acts as a resonator mirror.

The pump light output from LD is input to YbDF through the combiner.

Yb ions doped in the YbDF absorb pump light and generate ASE (Amplified Spontaneous Emission) light which becomes a seed of laser light.

The ASE light at a specific wavelength is reflected by FBGs, and is amplified repeatedly by YbDF, resulting in laser oscillation.

In order to achieve 12 kW output, the output power of a FLU should be increased. In principle, it is necessary to increase the output of the LD module (LDM) and improve the absorption efficiency of the pump light in YbDF to increase the output of a FLU. However, the occurrence of heat generation and non-linear phenomenon is an impediment to high output.

・Hight power laser diode

If the output of the LDM is increased, there is a concern that damage may occur due to an increase in

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Panel 1. Abbreviations, Acronyms, and Terms.

FBG—Fiber Bragg Grating
A fiber type optical component designed to reflect light of a specific wavelength by fabricating a diffraction grating on the core of the optical fiber.
It is used to construct a resonator in a fiber laser.

SRS—Stimulated Raman Scattering
When light is incident on a substance, light is modulated by lattice vibration of the substance to generate Stokes light (Raman scattering) which is a component of light whose frequency is shifted by the frequency component of photon vibration. The phenomenon that Stokes light is amplified in proportion to the light intensity when stronger light is incident.

ASE—Amplified Spontaneous Emission
A light that is amplified by absorbing light in the rare earth fiber and spontaneously emitting light in the gain medium.

BPP—Beam Parameter Product
It is defined as the product of the radius of the beam waist and the half width at half maximum of the divergence angle of the beam, and the unit is represented by [mm・mrad].
It is used when evaluating beam quality.

the power density of the laser output end face or heat generation from the laser diode (LD).

We have introduced an Asymmetric Decoupled Confinement Heterostructure (ADCH) structure to the structure of the LD chip. Furthermore, by increasing the stripe width of the emitter conventionally, the power density of the end face could be reduced. The increasing of the stripe width leads to the deterioration of the beam parameter product (BPP), but the effect on the coupling efficiency to the fiber is eliminated by optimizing the optical system.

In response to the increase in the amount of heat generated by CoS due to higher output, the cooling structure is changed from the conventional indirect cooling to a direct cooling structure in which a water channel is directly formed in the LDM housing to improve cooling efficiency.

As a result, although the calorific value has increased compared to the conventional model, the junction temperature can be kept at the same level and the reliability has been improved. The output characteristics is shown in Fig. 2.

・Improvement of energy conversion efficiency from input power to laser light

In order to improve the energy conversion efficiency, it is effective to increase the efficiency of converting excitation light into laser light (the quantum efficiency). The smaller the difference of the excitation light wavelength and the laser light wavelength become, the higher the quantum efficiency becomes. The absorption characteristics of YbDF has two peaks at 915 nm and 976 nm. Our conventional model adopted 915 nm excitation, but in this development, the excitation wavelength was changed to 976 nm. Since the wavelength of the laser light is 1070 nm, the quantum efficiency is improved 85% to 91%. In addition, the absorption coefficient of Yb ions at 976 nm is three times larger than that of 915 nm. Thanks to changing the pumping wavelength, it also becomes possible to shorten the YbDF length to one third. As a result, the influence of YbDF propagation loss is reduced, and the efficiency can be more improved.

・Nonlinear suppression

Stimulated Raman scattering (SRS), which is one of

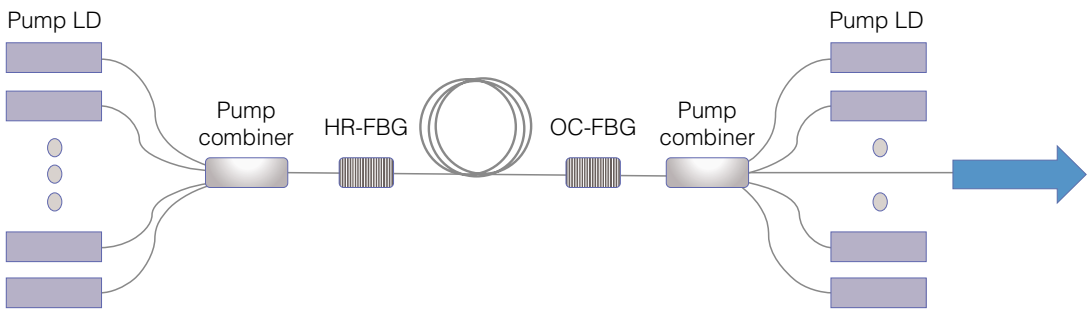

Fig. 1. Basic configuration of fiber laser unit.

non-linear phenomena, is a factor that impedes the increase in laser output power.

SRS occurs when the intensity of laser light propagating in the core increases, and a light component called Stokes light is generated on the long wavelength side of the laser light.

The generation of SRS causes problems such as the laser power shifting to Stokes light and the laser output becoming unstable.

The threshold power Pth for SRS generation is defined as the input power to the fiber when the power of the output light and the Stokes light becomes equal, and the relationship of equation (1) is known.

$$P_{th}(SRS) \propto A_{eff}/g_R l_{eff} \cdots\cdots\cdots\cdots\cdots(1)$$

Aeff is the effective area of light propagating in the fiber, gR is the Raman gain coefficient of the fiber, and L is the fiber length.

From the above relational expression, SRS is more likely to occur as the power density becomes higher and the resonator length becomes longer.

In order to reduce the power density, it is necessary to increase the core diameter. However, it is not a preferable solution from the viewpoint of beam quality.

On the other hand, , the resonator length can be shortened to one third compared to that of 915 nm by setting the excitation wavelength to 976 nm. Furthermore, it can be further shortened by increasing the Yb concentration as much as possible to improve the absorption efficiency of the excitation light per unit length.

The FLU's DC efficiency of 45% has been achieved by optimizing the FBG reflectivity of the optical resonator, and the output has been improved by 30% from the previous model.

2. 2 Combiner Unit (CMBU)

One of CMBU's issues with higher output is removal of clad mode light.

The clad mode light is the light that leaks from the core to the clad region due to mismatch at the fusion splicing point or due to external pressure bending of the fiber.

An increase in clad mode light causes deterioration of beam quality and heat generation of optical parts and fused parts, and has an adverse effects such as failure.

By improving the coupling efficiency of the output combiner, the cladding mode light can be reduced. However, there is a limit to improvement, and the cladding mode cannot be completely eliminated.

Therefore, the performance of a clad mode stripper (CMS) that removes the clad mode light from the fiber and converts it into heat is being improved.

We have improved the power resistance performance of CMS more than 20% from the conventional design by performing a new design.

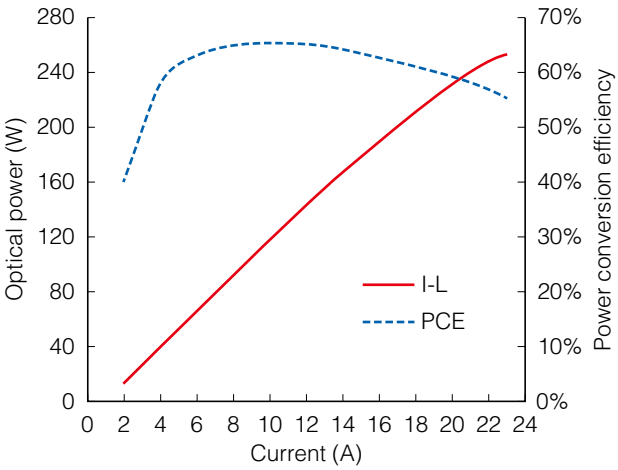

Fig. 2. Optical output power and electrical-optical power conversion efficiency characteristics of the developed module.

This ensures reliability for the cladding mode that increases at 12 kW output,

It is designed to improve the reflection performance for the increase in reflected light in laser processing, and to maintain stable output characteristics.

In addition, by optimizing the structure of the splice portion for laser quality, the value of the beam product (BPP) which indicates the condensing performance in the spread and condensing diameter of the beam indicating the laser quality has been achieved ≦4 mm. mrad, which can ensure the laser processing performance.

2. 3 Laser delivery cable with connector

In the case of a delivery cable which transmits a laser to a processed object, damage to the laser light emitting end face and damage due to reflected light at the time of laser processing are concerned with the increase in power.

The causes of damage at the laser emitting end face are mainly the increase in fluence and scratches and dust on the end face. Higher power makes the power density emitted from the core high. The end cap structure is adopted to enlarge the size of the end face to reduce the fluence. In addition, the quality control of the end face eliminates the risk of damage at the output end face.

It has been found that recoupling to the fiber interface in the connector is a damaging factor for the reflected light from laser processed objects. By designing the internal structure of the connector by in-house production and preventing the reflected light from being coupled to the fiber, the anti-reflection performance has been improved. Also, by improving

the fusion technology and making the intensity distribution symmetrical as shown in Fig. 3, the processing quality is improved. Figure 4 shows the appearance of a laser delivery cable with a connector that supports 12 kW output.

3. Basic performance of 3.12 kW fiber laser

Figure. 5 shows a schematic configuration of a 12 kW high power fiber laser. As a basic configuration, high power is achieved by combining multiple FLUs with an output combiners to achieve 12 kW output.

The output characteristics is shown in Fig. 6. The laser output conversion efficiency with respect to the power supplied to the excitation LD is more than 42%, which is excellent in power saving performance compared to about 38% of the previous model.

In addition, there is redundancy with respect to the rated output, and the rated output can be stably obtained by driving the excitation LD. For the nonlinear phenomenon that is a concern due to the 12 kW output, in the spectral distribution at 12 kW output shown in Fig. 7, no peak is observed around 1120 nm

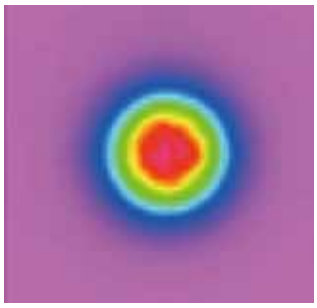

Fig. 3. FFP Beam pattern.

Fig. 4. Delivery cable for 12 kW fiber laser.

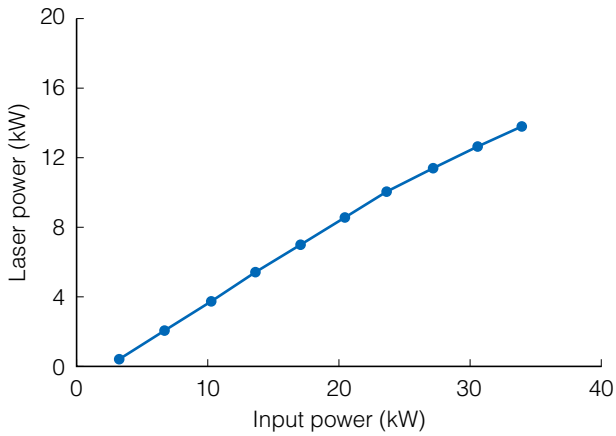

Fig. 6. Output characteristics of 12 kW CW fiber laser.

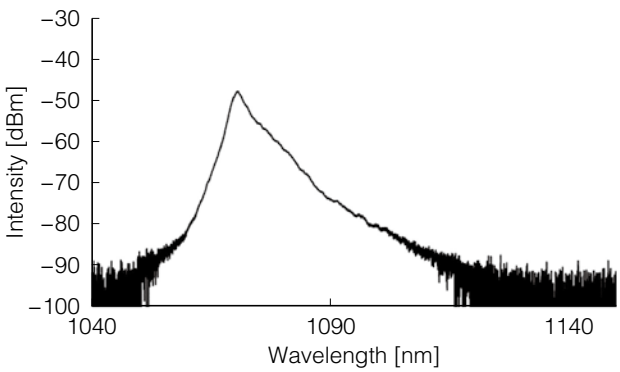

Fig. 7. Wavelength characteristics of 12 kW CW fiber laser.

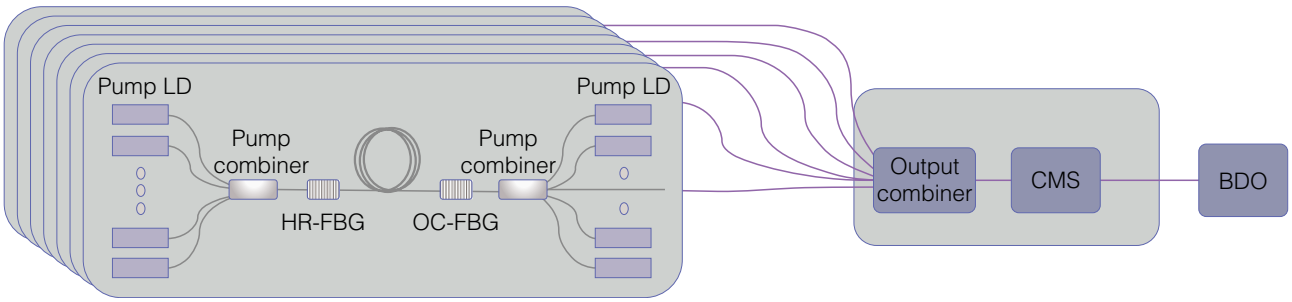

Fig. 5. Basic configuration of 12 kW fiber laser.

Table 1. Specification of 12 kW CW fiber laser product.

Item	Spec.
Wavelength	1070 (Typ.)
Rated Output power	12 kW
BPP	< 4 mm・mrad
Core size	100 μm
Output power instability	≦±2%
Modulation frequency	10 kHz
Power supply	200 V
Cooling method	water
size	W 567 x L 519 x H 560

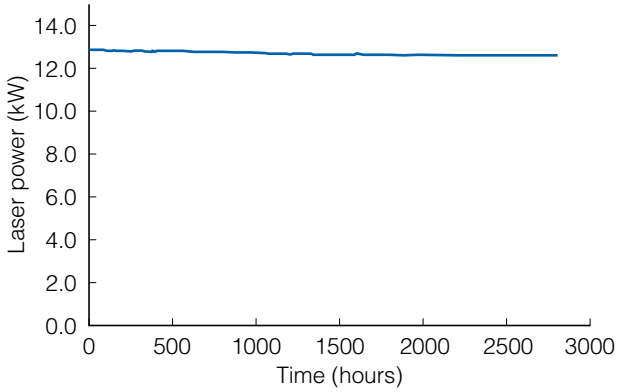

Fig. 8. long-term reliability of 12 kW CW fiber laser.

at which the Raman gain is maximum, so it can be confirmed that the nonlinear phenomenon of SRS can be suppressed.

Thus, 12 kW output can be achieved without deteriorating the optical characteristics. Table 1 shows the specifications of the 12 kW output fiber laser. In addition, a continuous energization test for long-term reliability verification was also conducted. As shown in Fig. 8, no significant decrease in output occurred even after about 2800 hours had passed.

4. Conclusion

According to this report, Development of 12 kW output fiber laser by suppressing the nonlinear phenomenon and improving our anti-reflection performance by improving the performance of various major components for the reliability required for fiber laser processing has been successful.

In the near future, we will verify laser processing using the developed 12 kW fiber laser and demonstrate its performance.

Reference

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