1480-nm Laser Diode Module with 250-mW Output for Optical Amplifiers (FOL 1404QQ Series)

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ABSTRACT 1480-nm laser diode modules for pumping optical amplifiers have been developed to realize an optical fiber output of 250 mW at a case temperature of 70°C by optimizing the laser diode chip and by reviewing the thermal design of the module.

1. INTRODUCTION

Accompanied by the widespread use of the Internet and digital image transmission, WDM (Wavelength Division Multiplexing) of an optical transmission system is now going to be used to expand transmission capacity per optical fiber. Increase in multiplexed signals requires higher power performance of the optical amplifier. High output power laser diode module (LD module, hereinafter) is used for pumping erbium-doped fibers (EDFs) in optical amplifiers in the 1.55 μm band. Pump LD modules used are in the spectrum of either 980 nm or 1480 nm. The advantages of 1480-nm LD modules are:

1) High reliability
2) High conversion efficiency of EDF, suitable for higher output of the amplifier
3) Broad absorption bandwidth of EDF, capable of multiplexing many wavelengths
4) Availability of a variety of peripheral optical components for this band such as isolator, wavelength multiplexer, and polarization coupler

The 1480-nm LD module, therefore, is used as pump source for high power optical amplifiers that combine a plurality of LD module outputs by bi-directional pumping, wavelength multiplexing and polarization multiplexing. [1)] In addition to the EDF pumping, the LD module is expected to be used as pumping source for Raman amplifier. [2)]

Since pump LD modules with high output are demanded by the market, competition among manufacturers for higher power has resulted in new devices reaching an output power of 200 mW for 1480-nm LD modules.

Also, the requirement for the operating temperature of the modules is becoming severe; for example, the module has to work with good stability within a wide range of case temperatures (T_c) between -20 and +70°C and is also expected to operate at higher temperatures.

Furukawa Electric has developed and is marketing the following modules:

PA series; maximum fiber output power of 160 mW at a driving current of 600 mA

PB series; maximum fiber output power of 200 mW at a driving current of 800 mA

In order to meet the need for higher output power, a new 250-mW module, the QQ series, has been developed achieving the highest power in the world. Here is a report on the study and development of the module.

2. 1480-NM PUMP LD MODULE

A pump LD module consists of an LD chip, an optical coupling which couples the laser beam from the LD chip to optical fiber, and a temperature controller which stabilizes

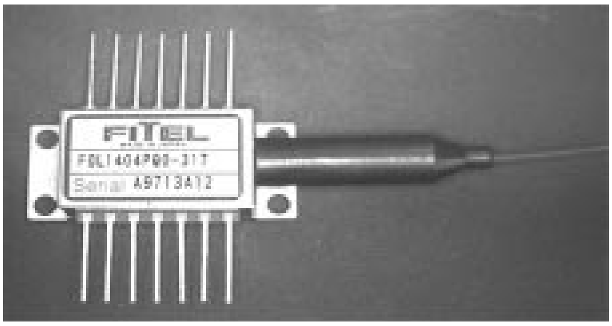

Figure 1 Appearance of LD module

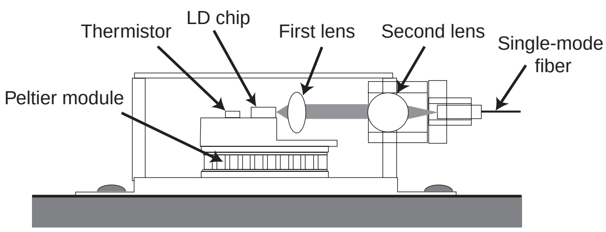

Figure 2 Structure of 1480-nm LD module

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the lasing condition of the LD chip. Figure 1 and Figure 2 show the appearance and structure of the LD module, respectively.

2.1 LD Chip

Figure 3 shows the structure of an LD chip, in which GRIN-SCH-BH (Graded Index- Separate Confinement Heterostructure-Buried Heterostructure) with compressively strained MQW (Multi Quantum Well) active layer is adopted to realize low-leakage current, stable transverse fundamental mode and high efficiency operation. [3] On the front facet of the chip, AR (Anti-reflection) film is coated, and on the rear facet of the chip, HR (High Reflection) film is coated. The chip is bonded onto the carrier junction-down via an aluminum nitride heat sink.

2.2 Optical Coupling Portion

Usually, an LD chip emits a beam with a cone angle of approximately 30°. The beam is collimated by the first lens and then is focused by the second lens on the end facet of the optical fiber thereby effecting optical coupling. The positioning accuracy of these optical components is required to be within 1 to 10 µm, or within 1 µm for fixing the optical fiber in particular.

The LD chip is spatially coupled to the optical fiber through these lenses; therefore, it is possible to insert optical components such as optical isolator and the like between the lenses and the fiber.

2.3 Temperature Control Portion

The wavelength and optical output from an LD chip depend on temperature. Therefore, in order to prevent the fluctuation of characteristics due to self-heating and environmental temperature changes, a thermo-electric cooler is used in the pump LD module to control the temperature. A thermistor is also mounted near the LD chip. The temperature of the LD chip is kept constant, usually at 25°C, by monitoring the thermistor to autonomously control the thermo-electric cooler.

3. PROBLEMS ABOUT HIGH OUTPUT OPERATION

Factors that determine the driving limits of an LD module are categorized into those of fiber output power and those of operating temperature. The former includes the maximum facet power from the LD chip and the coupling efficiency of the LD to the optical fiber; the latter includes power consumption of the LD chip, thermal impedance in the heat dissipation path inside the LD module and the heat absorption performance of the thermo-electric cooler. Thus, the driving limit of an LD chip having a certain heat-dissipation structure and a thermo-electric cooler depends on the reactive power of the LD chip (i.e., the difference between the LD driving power and the facet power of the LD chip, which is mainly converted into heat).

Excluding the issue of the LD driving current limit, and especially in the case of operation in a high temperature environment, heat dissipation design becomes important. We decided to overcome this problem as follows:

1) Improving the maximum facet power of the LD chip, and optimizing the structure of the chip in terms of energy conversion efficiency (i.e., the ratio of the LD facet power to the LD driving power).
2) Improving the performance of the thermoelectric cooler to suppress the increase in temperature of the LD chip due to the reactive power of the device.

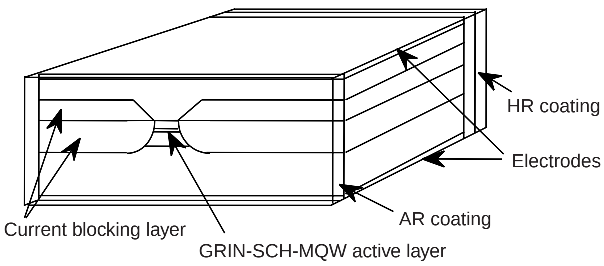

Figure 3 Structure of LD chip

4. IMPROVEMENT OF LD CHIP

Generally, when a current begins to flow into an LD chip, the facet power of the chip gradually increases. At the same time, however, heat produced from the chip itself decreases the facet power of the chip, and finally the facet power begins to saturate at a point where a larger current will no longer give a higher facet power. In order to make the saturating current larger, the cavity length of the chip was extended, so as to reduce the forward voltage and the thermal impedance. Given a coupling efficiency of the LD module of 80%, the facet power of the LD chip must be more than 310 mW to obtain a fiber-coupled power of 250 mW.

Figure 4 shows the relationship between the LD driving current and the fiber-coupled power using the cavity length of the LD chip as a parameter. It is seen that at a driving current of less than 500 mA, a cavity length of 800 µm has the advantage; however, at 700 mA and higher, a 1300 µm length has the advantage.

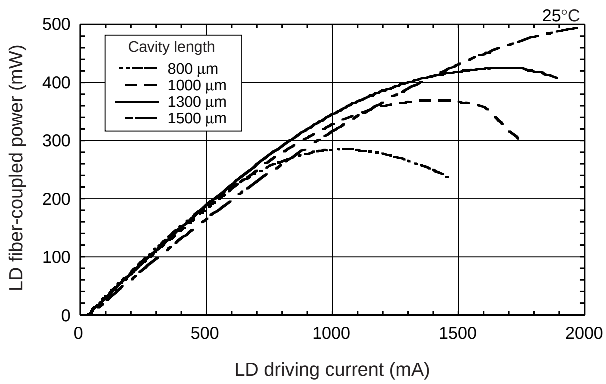

Figure 4 Relationship between LD driving current and fiber-coupled power with cavity length as a parameter

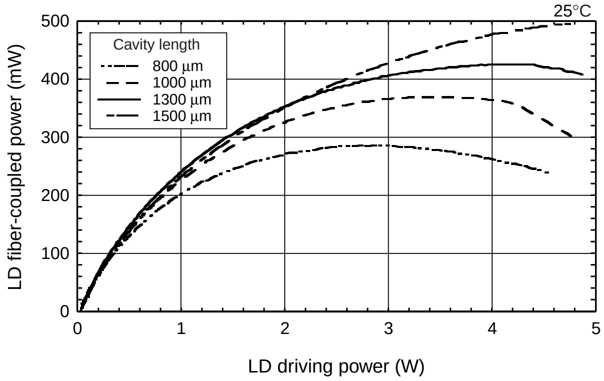

Figure 5 Relationship between LD driving power and fiber-coupled power with cavity length as a parameter

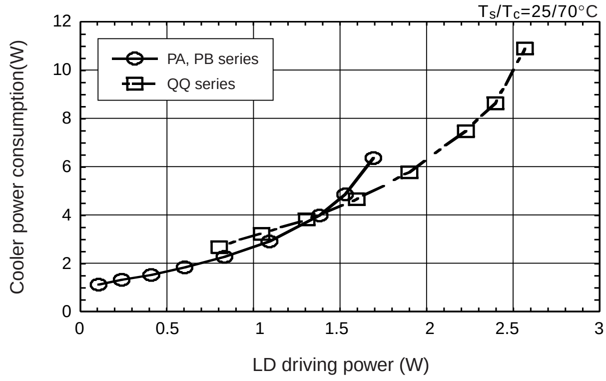

Figure 6 Optimization of Peltier cooler and LD driving power

Figure 5 shows the relationship between the driving power and the fiber-coupled power of the LD chip. Note that energy conversion efficiency is implicitly included in the figure. In the range of low fiber output power of approximately 100 mW already, the cavity length of 1300 μm is seen to be advantageous; and at the point where the driving power reaches 2 W, or the fiber output power reaches 350 mW, the cavity length of 1500 μm becomes advantageous. On the contrary, the advantageous feature of the 800 μm length does not appear even in the low fiber-coupled power range. Thus, consideration on the energy conversion efficiency is important to identify great changes in the optimum length of the cavity. Other design parameters such as the carrier density of the clad layer are optimized based on the concepts described above.

Considering these results mentioned above, the authors determined the cavity length of the LD chip to be 1300 μm. Also adjustments were made on the reflectivity of the AR-coated front facet in order to suppress the decrease in external differential quantum efficiency due to the degradation in the reflection loss. Thus, the driving voltage of the LD is restrained to approximately 2 V at a driving current of 1 A. These results have achieved the characteristics of the new LD: LD driving power of 1.6 W, LD facet power of 320 mW, and fiber output power of 250 mW.

An LD facet power of 490 mW was attained at a driving current of 2 A with a cavity length of 1500 μm. However, as described hereinafter, a high power operation of such an LD chip with limited LD module dimensions and at operating temperatures (T_s/T_c = 25/70°C) --which is the target of current development-- results in an excessive driving power. This problem including module dimension changes must be solved in the near future.

5. HEAT DISSIPATION CHARACTERISTICS OF LD MODULE PACKAGE

It is necessary for a pump LD module to guarantee long-term reliability; therefore, the degradation of the module output --which is caused by the degradation of the LD chip or the optical coupling-- must be considered. Usually, 1.2 times the LD driving current at the BOL (Beginning Of Life) is defined as the EOL (End Of Life) driving current. The authors confirmed that the LD operated satisfactorily with the EOL current under the most severe (in most cases at high temperatures) environment conditions.

In the PA and PB series, the thermoelectric cooler is optimized at an LD driving current of 600 to 800 mA, and an LD driving power of approximately 1 W. As shown in Figure 6, the maximum heat absorption at this operation is approximately 1.6 W, just a little higher than the LD driving power at EOL.

In the case of 250-mW operation, however, the thermoelectric cooler is required to dissipate 1.6 W even at the BOL and, when the increase in the LD drive current together with deviations in characteristics are taken into account, 2.5 W at the EOL. Considering the above factors, a more detailed review of the thermoelectric cooler was carried out. Generally, in order to increase the maximum heat absorption, the number of Peltier elements in the thermoelectric cooler must be increased. This leads to a growth of series resistance to increase the power consumption of the cooler. Thus, there exists an optimum set of design parameters for the maximum heat absorption to be targeted.

In the QQ series, as shown in Figure 6, the LD driving was optimized by keeping the maximum heat absorption high in the range of 1.6 W to 2.5 W. Here, we took into account the fact that the power source used for the optical amplifier is mainly rated at 5 V, and that the size of the LD module should preferably be the same as for the existing PA and PB series. The design enabled high power operations of LD module at 1000 mA BOL and 1200 mA at EOL thereby augmenting the maximum LD driving power from 1.6 W to 2.5 W under the severe temperature conditions of T_s/T_c = 25/70°C.

6. PRODUCT CHARACTERISTICS

Figure 7 shows outer dimensions of the LD module, which are the same as for the 1480-nm LD module in the PA and PB series.

Figure 8 shows the light vs. current characteristics of a typical LD module in the QQ series. The figure shows that a fiber-coupled power of 250 mW is achieved at an LD driving current of 900 mA and a case temperature of 70°C. The maximum fiber-coupled power is more than 330 mW. Figure 9 shows the output spectrum of the LD module at 250 mW.

Figure 10 and Figure 11 show the current/voltage characteristics of the thermoelectric cooler while the case temperature and the LD driving current are varied. The cooler current is 3 A and the cooler voltage is 3.2 V, at a case temperature of T_c = 70°C together with an LD driving current of 1200 mA EOL. Optional accessories of the LD module are:

- Built-in optical isolator
- Various types of fibers, including polarization maintaining fiber (PMF)
- Wavelength locking and spectrum narrowing by Fiber Bragg Grating (FBG) [4]

The above features may be the same as those of the PA and PB series. By combining the above features, extremely high output optical amplifiers become available by bi-directional pumping, polarization multiplexing, wavelength multiplexing, etc. Table 1 shows the characteristics of the modules in the QQ series.

Since high output power becomes available with the QQ series LD modules, a combination of two 140-mW class LD modules in the PA or PB series can be replaced by one 250-mW class module in the QQ series. Figure 12 illustrates that, to obtain a multiplexed fiber output power of 250 mW, the power consumption of one 250-mW module is equivalent to that of two 140-mW modules. The new LD module helps to save space, the control circuit and other devices become simple, and optical components for multiplexing become unnecessary. Thus, optical amplifiers based on the new modules become compact and inexpensive.

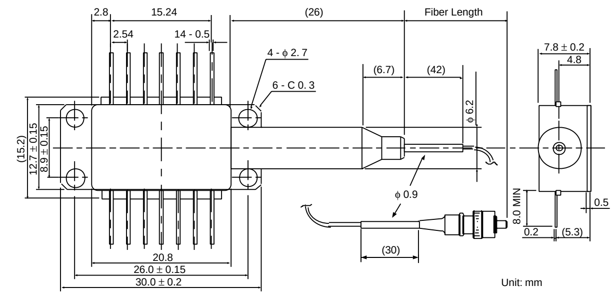

Figure 7 Dimensions of LD module

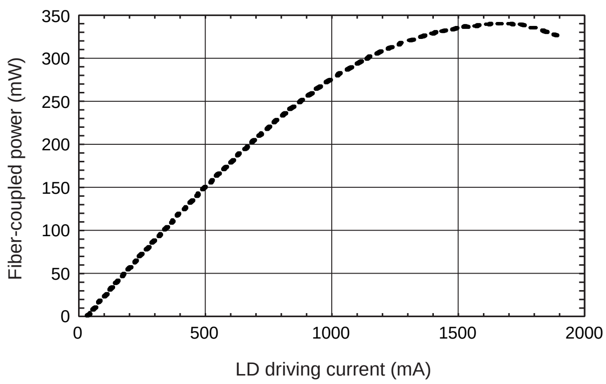

Figure 8 *L-I* curve

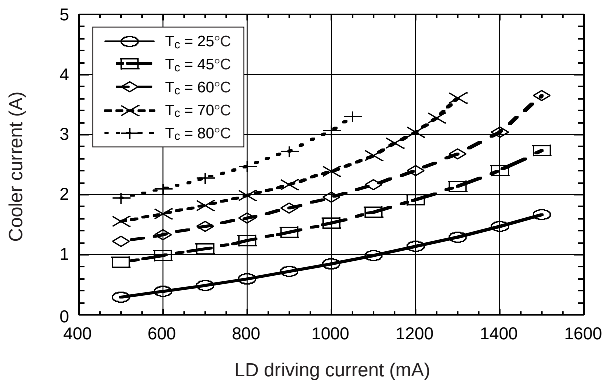

Figure 10 Characteristics of TEC current

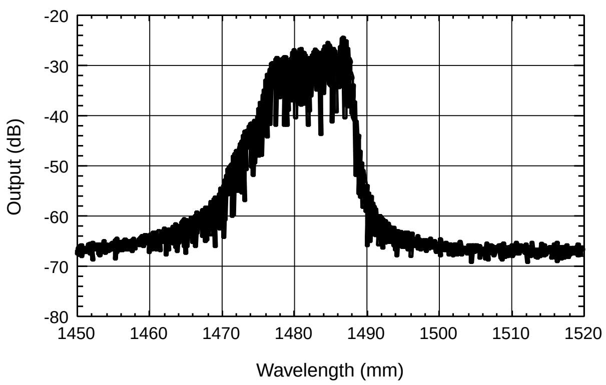

Figure 9 Output spectrum of LD module

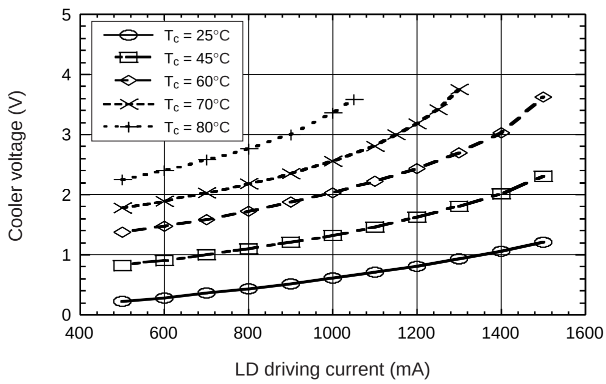

Figure 11 Characteristics of TEC voltage

Table 1　Specifications of QQ series laser diode module

Parameter	Sym.	Min.	Typ.	Max.	Condition
Threshold current (mA)	I_{th}	-	35	70	T_s=25°C, CW
LD forward voltage (V)	V_f	-	-	2.7	P_f=250 mW, BOL
Fiber output power (mW), POL 1404 QQO	P_f	250			I_{fBOL} =<1000 mA
LD forward current (mA) (BOL)	I_{fBOL}	-	-	1000	P_f=250 mW
LD forward current (mA) (EOL)	I_{fEOL}	-	-	1200	I_{fEOL}=I_{fBOL} x 1.2
Center wavelength (nm)	λ_c	1460	-	1490	RMS, P_f=250 mW
Spectral width (nm)	$\Delta\lambda$	-	4	8	RMS, P_f=250 mW
Monitor current (μA)	I_m	200	-	1500	V_{rPD}=5 V, P_f=250 mW
Monitor dark current (nA)	I_d	-	-	100	V_{rPD}=5 V
Cooler current (A)	I_c	-	3	4	T_s=25°C, T_c=70°C, EOL
Cooler voltage (V)	V_c	-	3	4	T_s=25°C, T_c=70°C, EOL
Thermistor resistance (kΩ)	R_{th}	9.5	10	10.5	T_s=25°C
Thermistor B constant (K)	B	-	3900	-	-
Isolation *1 (dB)		30			
Extinction ratio *2 (dB)		13			

*1 Type 3 or 4 (Isolator built-in)

*2 Type 2 or 4 (PMF is used)

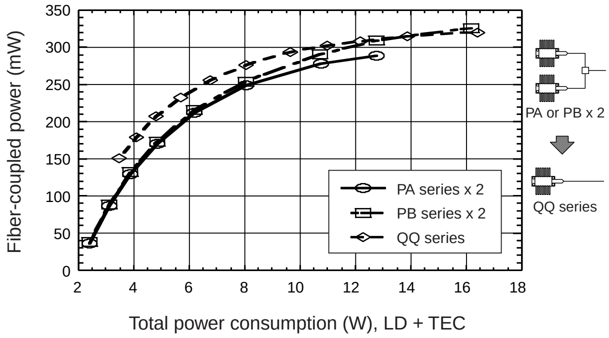

Figure 12　Total power consumption vs. fiber output power of the PA, PB and QQ series

7. CONCLUSION

We have successfully developed QQ series 1480-nm pump laser modules for single-mode fibers. The modules are capable of high-temperature operation providing a fiber-coupled power of 250 mW, the world's highest.

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Manuscript received on November 11, 1999.