Series FOL0903m Mini-Pump Coolerless Laser Modules for Optical Amplifiers

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ABSTRACT A more compact 980-nm laser module with low power consumption has been developed as a pumping source for optical amplifiers in metropolitan networks. To cope with miniaturization and low power consumption, a coolerless structure has been newly employed. To ensure high-temperature operation we have adopted a new diode chip structure and fiber Bragg grating (FBG) parameters. The resulting device has one-fourth the package size and one-third the power consumption of the conventional butterfly type. Wavelength stability is achieved over the entire operating temperature range.

1. INTRODUCTION

The widespread use of the Internet has drastically accelerated the increase in capacity and data transmission speeds in backbone systems, leading to the popularity of dense wavelength division multiplexing (DWDM). As optical systems spread to local area/metropolitan networks, the devices used, specifically optical amplifiers, should be of low cost, smaller size, and lower power consumption than in backbone systems.

For example, a gain module containing erbium-doped fiber (EDF), optical couplers, monitor photodiodes (PD) and pump laser modules for amplification must be of credit card size and priced around US$ 1000. This means that pump laser modules for optical amplifiers must also be smaller in size, lower in power and lower in cost.

Here, a coolerless structure was chosen for the laser module to achieve these requirements. Eliminating the

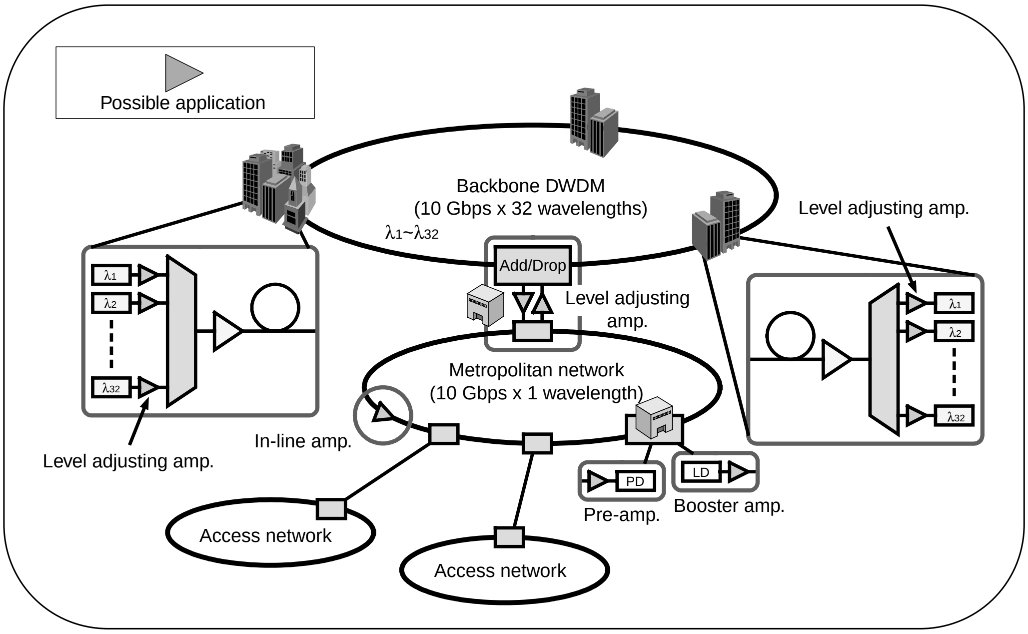

Figure 1 Application of coolerless pump for metropolitan network.

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thermo-electronic cooler in the module was the key concept, as it accounts for a high percentage of component cost, physical size and electrical power consumption. The new structure for a 980-nm diode chip has maintained quantum efficiency and reliability, especially at high temperatures.

2. MODULE DESIGN

2.1 Optical Design

We chose a two-lens coupling system and a thermal expansion core (TEC) fiber having good coupling efficiency and wide tolerance. Figure 2 shows the relationship between coupling loss and the offset between the diode chip and the 980-nm fiber with and without TEC processing. The mode field diameter of the 980-nm fiber is smaller than that of a conventional single-mode fiber. The tolerance width with single mode fiber at a coupling loss of 0.2 dB is only about 1 μm, but with the TEC fiber this increases to about 2 μm, making it better suited to mass production assembly.

2.2 Module Structure

An 8-pin miniature dual in-line (mini-DIL) package was selected, and the internal components were re-designed to fit the package.

In a coolerless laser module, the mechanical test conditions for the standard (Telcordia) reliability tests change significantly. For a module with a built-in Peltier cooler, the maximum acceleration is 500 G, for a coolerless module, this rises to 1500 G. To satisfy this condition, the internal components are fixed more rigidly by YAG laser welding.

To prevent degradation in the coupling efficiency with changes in the relative position of the diode chip and optical system due to ambient temperature changes, materials for the internal components were selected to have similar coefficients of thermal expansion. Furthermore, optimizing the thickness of the solder fixing the sub-mount in the package prevents solder creep and degradation of coupling efficiency, which ensures long-term reliability. Figures 3 and 4 show the appearance and the internal structure of the coolerless 980-nm LD module.

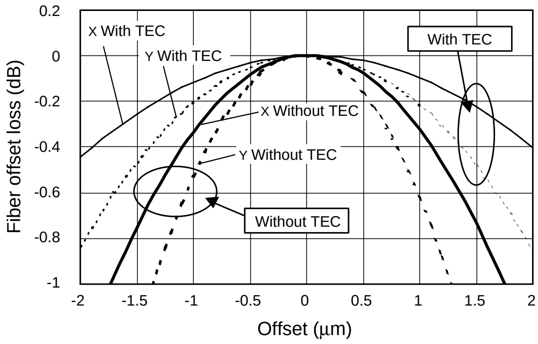

Figure 2 Fiber offset loss.

2.3 LD Chip

Because the coolerless laser module operates under a wide range of ambient temperatures (0~70°C), the requirements for the diode chip are that (1) quantum efficiency should not deteriorate drastically at high temperatures; (2) lasing wavelength should be stabilized over the full operating temperature range; and (3) high reliability should be guaranteed in high-temperature operation. In addition, (4) stability of fiber output is an important characteristic in achieving low noise amplification in an EDFA with 980-nm pumping. A suitable diode chip, known as the FF chip, was developed expressly for the coolerless 980-nm pump laser module to satisfy these requirements.

The FF chip is ridge-guided with a cavity length of 1800 μm. The purpose of making the cavity longer than that of a conventional diode chip was to increase kink output power and to improve reliability by increasing thermal conductivity with a heat sink. The active layer structure of the diode chip was also optimized to ensure stability of lasing wavelength and output power due to provision of an FBG.

Figure 5 shows the structure of the FF chip. MOCVD was used to fabricate the epitaxial wafer for the chip, and its active layer consists of an InGaAs single quantum well with compression strain, a GaAsP barrier layer and an AlGaAs separate-confinement-heterostructure (SCH)

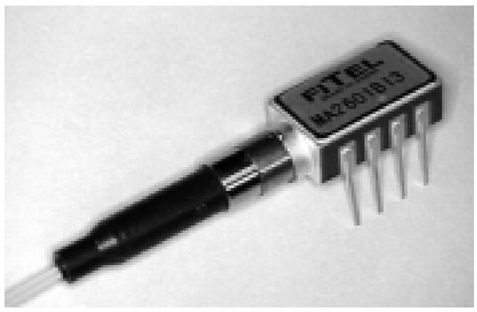

Figure 3 Appearance of laser module.

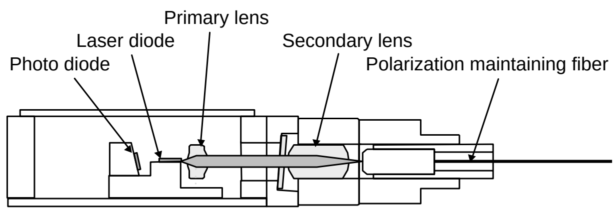

Figure 4 Structure of laser module.

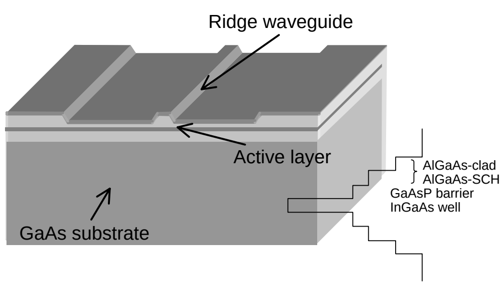

Figure 5 Structure of 980-nm FF chip.

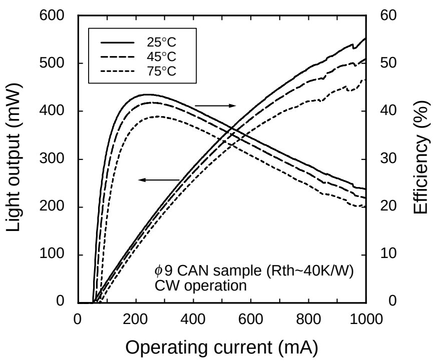

Figure 6 I-L curve of 980-nm FF chip.

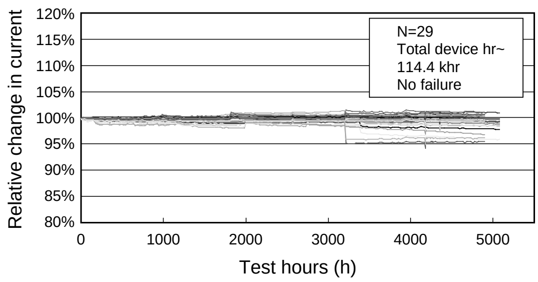

Figure 7 Aging test results for FF chip.

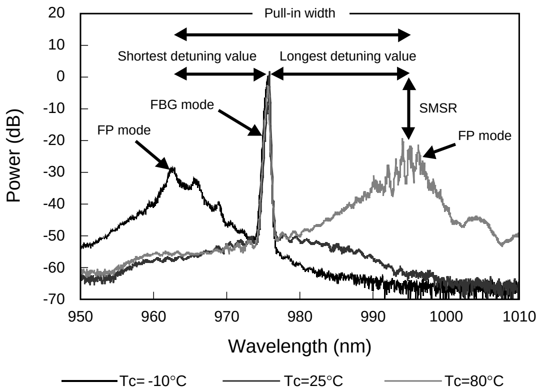

Figure 8 Definition of pull-in width of FBG mode lock.

layer. To obtain stable single transverse mode lasing, a ridged waveguide approximately 3.5 μm in width was formed.

Figure 6 shows the current dependence of light output at selected ambient temperatures. The kink output obtained at room temperature was 500 mW and even at 75°C was 400 mW. The maximum conversion efficiency from electrical power to optical power was 44 % at room temperature and 40 % at 70°C. Figure 7 shows the result of an aging test under APC at 250 mW with a junction temperature Tj of 85°C. Twenty-nine devices were tested under these conditions, and after 5000 hours no failures occurred, confirming that the chip offers sufficient reliability under 70°C operation.

2.4 Method of Wavelength Locking

At around 980 nm the wavelength dependence of EDF gain profile increases, so to achieve stable gain profile of EDFA the pumping wavelength should be locked.

The lasing wavelength of the 980-nm diode chip in Fabry-Perot (FP) mode has a wavelength shift coefficient with temperature change of about 0.34 nm/°C. Thus from 0 to 70°C the FP mode lasing wavelength shifts about 24 nm. When the difference between the FP mode lasing wavelength and reflecting wavelength of the FBG, known as the detuning value, is too large, the lasing wavelength cannot be locked at the FBG reflecting wavelength.

The maximum pull-in width is defined, as illustrated in Figure 8, as the range of wavelengths from the shortest detuning value to the longest, in both cases the lasing wavelength is locked at the reflecting wavelength of the FBG. The shortest and longest detuning values are evaluated when the side mode suppression ratio (SMSR), which is the intensity ratio of FP mode lasing to FBG mode lasing, is greater than 13 dB.

To lock the wavelength in the 0 to 70°C temperature range the maximum pull-in width should be about 30 nm, to compensate for the temperature dependent wavelength shift as well as the current dependent shift and production variations in the wavelength of the diodes.

To achieve this wider maximum pull-in width, the reflectivity of the anti-reflection (AR) coating on the front facet of the diode chip and of the FBG was studied. Generally, a wider pull-in width can be obtained by decreasing AR coating reflectivity or increasing FBG reflectivity [1], but high FBG reflectivity leads to decreases in quantum efficiency and kink current. In this work the reflectivity of the AR coating and the FBG were optimized to achieve both a wider pull-in width and a higher kink current.

LD chips are also polarization dependent. When the returned light from the FBG to the diode chip is TE mode, the highest effective reflectance can be obtained. Changing the polarization state of the returned light increasing the TM mode component is equivalent to decreasing FBG reflectivity, thereby reducing the pull-in width and unlocking the wavelength. To avoid this phenomenon, a polarization-maintaining fiber was adopted for the coolerless laser module, and the polarization state of the light returned from the FBG was stabilized thus pull-in width can always be kept constant regardless of strain on the fiber when twisted or being mounted. A single-mode fiber is fusion spliced to the end of the fiber to facilitate connection to other optical components such as couplers on customers' premises.

3. SPECIFICATIONS

Table1 shows the specifications of the coolerless laser module developed here. Operating temperatures were from 0 to 70°C, and fiber output power was 80 mW.

Table 1 Specifications of 980-nm coolerless pump laser module

Parameter	Sym.	Min.	Typ.	Max.	Unit	Condition
Optical output power	Pf					
FOL0903mNR-D14- λ		60	-	-	mW	Tc=0~70°C, If$_{BOL}$=<280 mA
FOL0903mNS-D14- λ		70	-	-	mW	Tc=0~70°C, If$_{BOL}$=<280 mA
FOL0903mNT-D14- λ		80	-	-	mW	Tc=0~70°C, If$_{BOL}$=<280 mA
Threshold current	Ith	-	30	50	mA	CW
Threshold current at 70°C	Ith$_{70}$	-	50	85	mA	Tc=70°C, CW
Kink current	Ikink	IfEOL	-	-	mA	-
LD forward voltage	Vf	-	2	2.5	V	If$_{BOL}$
Center wavelength	λc	λ–1.5	λ	λ+1.5	nm	Tc=0~70°C, If$_{BOL}$, Peak
Spectral width	Δλ	-	-	3	nm	Tc=0~70°C, If$_{BOL}$, FWHM
Monitor current	Im	50	-	3000	μA	VrPD=5 V, If$_{BOL}$
Monitor dark current	Id	-	-	100	nA	VrPD=5 V
Thermistor resistance	Rth	9.5	10	10.5	kΩ	Ts=25°C
Thermistor B constant	Bth	-	3900	-	K	-

Tc: Case temperature
BOL: Beginning of life
EOL: End of life

4. PRODUCT CHARACTERISTICS

Figure 9 shows the outline dimensions of the coolerless laser module. Compared to a conventional module with a 14-pin butterfly package, the volume is reduced to about one-fourth.

4.1 Optical Output Power

Figure 10 shows optical output power vs. driving current (L-I curves) at case temperatures Tc of 0, 25 and 70°C. Figure 11 shows the injection current dependence of fluctuation of fiber output power and lasing wavelength. In coolerless pump laser module developed here wavelength fluctuation was less than 0.3 nm and power fluctuation was less than 0.5 % at driving currents from around threshold current right up to rated current, and the multi-mode lasing spectrum was stable at all driving currents, as shown in Figure 12.

4.2 Output Spectrum

Figure 13 shows the optical spectrum of the laser module. Wavelength is locked within a range of 976±1.5 nm from low-temperature low output operation (Tc = -10°C, injection current 100 mA) to high-temperature high output operation (Tc = 95°C, injection current 500 mA). The center wavelength can be selected for each EDFA by means of diode chip and FBG parameters.

4.3 Power Consumption

Figure 14 shows the total power consumption of the coolerless and conventional laser modules. At Tc of 70°C and optical output power of 80 mW, the power consumption of the coolerless module was less than 0.5 W, about one-third that of a conventional LD module in a 14-pin butterfly package with a Peltier cooler.

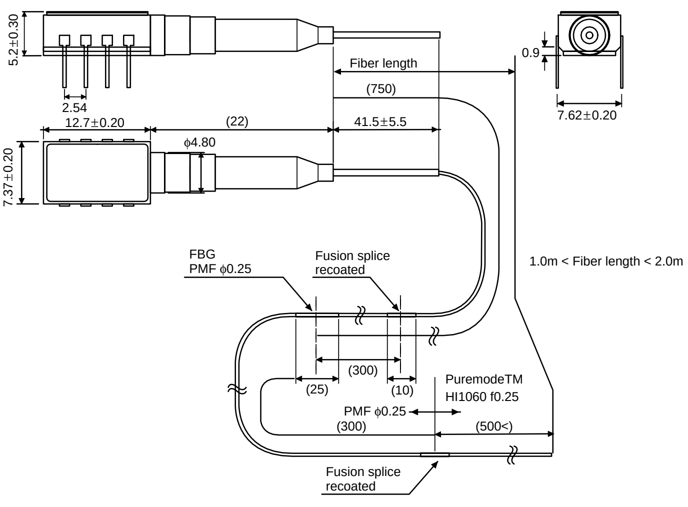

Figure 9 Dimensions of coolerless pump laser module.

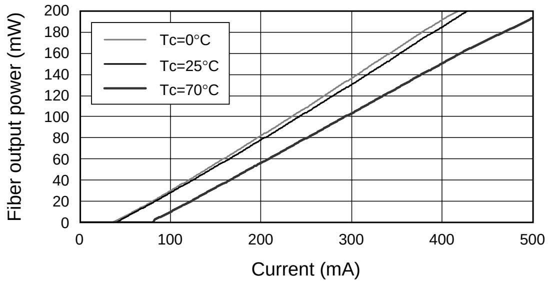

Figure 10 L-I curve of 980-nm coolerless pump laser module. Tc = 0°C, 25°C, 70°C

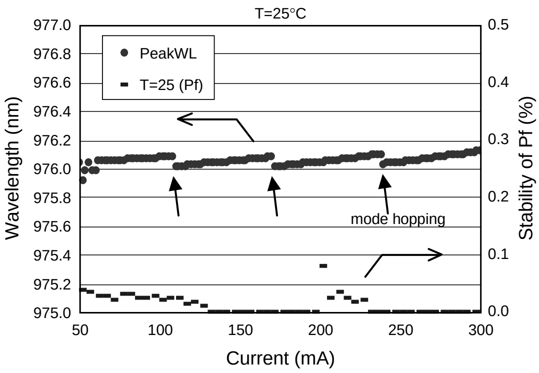

Figure 11 Fiber output power stability.

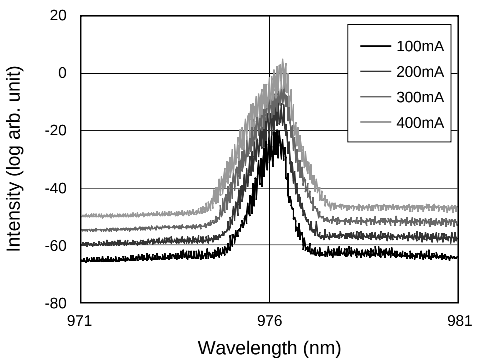

Figure 12 Multimode spectrum of FBG mode lock at room temperature.

5. RELIABILITY

To verify the long-term reliability of the coolerless laser module, the reliability tests specified by Telcordia GR-468 was carried out. Typical mechanical impact and vibration test results are shown in Figure 15, temperature cycling test results in Figure 16, and aging test results in Figure 17.

Results of all the reliability tests including the above satisfied all the requirements of Telcordia GR-468, thereby confirming sufficient reliability.

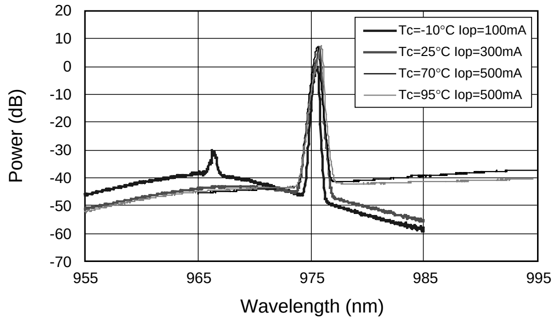

Figure 13 Output spectrum of 980-nm coolerless pump laser module.

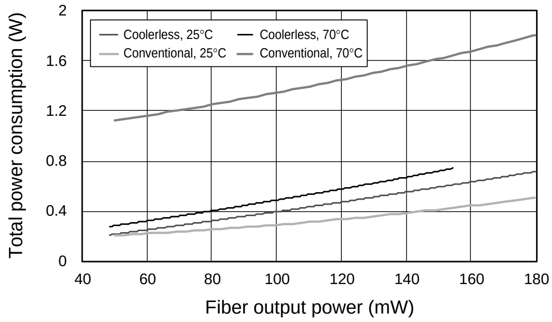

Figure 14 Comparison of coolerless and conventional laser modules.

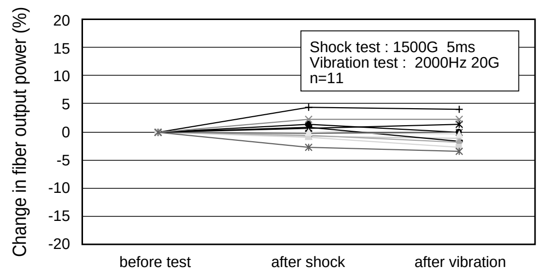

Figure 15 Result of mechanical impact and vibration tests.

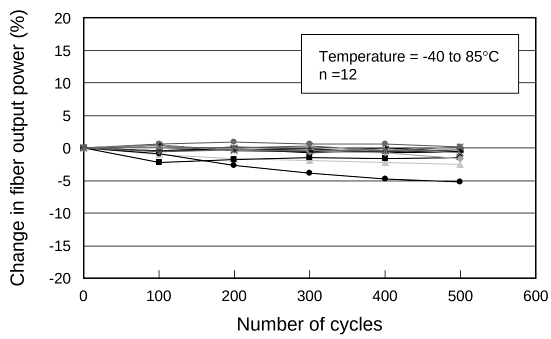

Figure 16 Result of temperature cycling test.

6. CONCLUSION

A compact coolerless module has been developed as a pumping laser module for optical amplifiers for metropolitan networks. This module has only one-third the power

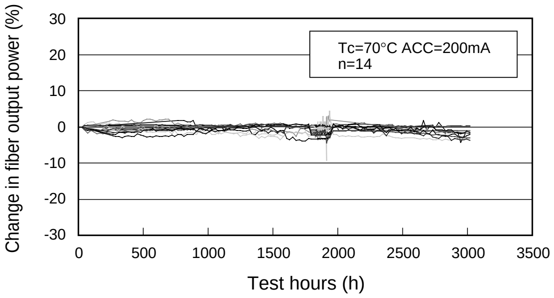

Figure 17 Result of aging test.

consumption and one-fourth the size of a conventional module and realizes a fiber output power of 80 mW at ambient temperatures from 0 to 70°C.

REFERENCES

1) A. Mugino, Y. Irie: "Output Power Optimization in 980-nm Pumping Lasers Wavelength-Locked Using Fiber Bragg Gratings", Furukawa Review, No.19, 2000 (http://www.furukawa.co.jp/english/review/fr019/fr19_08.pdf)