Wavelength Monitor Integrated CW DFB Laser Module for DWDM Applications

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ABSTRACT For signal transmission on DWDM systems, cross-talk between the nearest channels in the wavelength region must be suppressed to maintain the required quality of optical signals, hence good wavelength stability is strongly required of the optical signal. As an essential solution for signal sources in DWDM applications, we developed wavelength monitor integrated CW DFB laser modules. The unique structures of our laser module were optimized for 25 GHz spacing DWDM and 50 GHz spacing DWDM, respectively. In particular, the module for 25 GHz spacing usage was contrived to meet very tight wavelength stability requirements. This report introduces the structures and the performance of both laser modules.

1. INTRODUCTION

In dense wavelength division multiplexing (DWDM) to enable high-capacity transmission, the emission wavelength of optical signal must be stabilized to sufficiently suppress cross-talk, which causes a deterioration of optical signal quality. Wavelength monitor integrated distributed feedback (DFB) laser modules are promising light sources for such DWDM applications, and an emission wavelength of the laser module [1), 2)] can be precisely stabilized to a certain fixed wavelength using a feedback circuit.

A high insertion loss is a disadvantage of the $LiNbO_3$-based external intensity modulator employed for optical amplitude modulation in long-haul DWDM systems. High-power continuous wave (CW) light maintained in a constant polarization state is required to obtain a large enough extinction ratio of optical signals and increase loss budget.

We developed such DFB laser modules supported by a polarization maintaining fiber (PMF) pigtail, achieving a very high output power of over 40 mW [3)], and they have been widely supplied for actual applications.

Integrating a wavelength monitor into high power CW DFB laser module led to the development of an optimum light source for long-haul DWDM applications [4), 5)]. The requirement of wavelength stability is basically dominated by the value of wavelength spacing in DWDM systems. In general, when a narrower wavelength spacing is employed, tighter wavelength stability is required. For example, the current light source for introducing 50 GHz spacing DWDM systems must support a wavelength stability of ±20 pm or less over service life. Furthermore, there is much tighter wavelength stability for 25 GHz spacing DWDM systems, which are promising for ultra-high capacity transmission in next-generation systems. To achieve a transmission rate of 10 Gbit/s per channel with this system, wavelength stability of at least ±10 pm or less is required. To meet the requirements for each system, we developed laser modules which have the proper structures for 50 GHz spacing DWDM and 25 GHz spacing DWDM, respectively.

In this report, the performance of fiber-coupled output is described first. Subsequently, the structure and the performance of the wavelength monitoring function are introduced.

2. APPEARANCE OF LASER MODULE AND FIBER-COUPLED OUTPUT

The high power characteristics of the DFB laser module are mainly derived from the high power performance of the laser diode and high coupling efficiency based on lenses. A strained layer multiple quantum well (SL-MQW) structure has been employed in the active layer for the high power characteristics of laser diode. To enhance front facet power as well, the front facet has an anti-reflection (AR) coating against the high-reflection (HR) coating of the rear facet. Output power launched from the front facet is coupled to the fiber pigtail through two lenses. This realizes a high coupling efficiency of over 70 % in mass production.

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Figure 1 shows the appearance of the laser module, which is based on an industry standard 14-pin butterfly package and a wavelength monitor is integrated into it. A stable polarization extinction ratio of 20 dB or higher is realized by precisely polarization-controlled optics when coupling to the PMF, in which the polarization state is maintained on the slow axis.

Figure 2 shows typical *L-I* curve and optical spectrum. The submount temperature is controlled to 28.5°C for an output power of 20 mW to obtain a fixed ITU wavelength of 1538.98 nm. Our high power performance enables a low operating current to be used such as 86 mA at 20 mW, and 162 mA at 40 mW.

3. LASER MODULES FOR 50 GHZ SPACING DWDM APPLICATIONS

3.1 Module Structure

The schematic structure of the laser module is shown in Figure 3 where Figure 3 (a) and Figure 3 (b) show top and side views, respectively. In these wavelength monitor optics, a laser beam launched from the rear facet is collimated by a collimating lens and then is symmetrically divided by a prism. The divided beam is coupled to a photodiode for power monitoring. The other beam is incident on a 25 GHz spacing etalon and then the transmitted beam is coupled to a photodiode for wavelength monitoring.

Compared to previously reported structures using a half mirror for the beam splitter, this unique structure provides significant advantages in terms of compactness, reducing parts, and ease of alignment. For example, the availability of mounting two photodiodes to a submount is specifically related to reducing parts and saving space for mounting a wavelength monitor. It also provides an easy process for adjusting the coupling ratio using a prism as a beam splitter, since the alignment to adjust the coupling ratio can be achieved without rotating a prism. Furthermore, this unique structure achieves integration of a long cavity etalon supporting the very short period required for DWDM application.

The wavelength monitor is mounted with a laser diode on a base plate. An etalon has temperature dependence, but the influence can be neglected by controlling etalon temperature. The laser modules are assembled with highly reliable soldering and laser welding without any adhesives.

3.2 Module Characteristics

Wavelength monitor photocurrent as a function of lasing wavelength of DFB laser (i.e. wavelength discriminator curve) is shown in Figure 4. Laser temperature control enables the lasing wavelength of the DFB laser to be controlled. Wavelength tuning is achieved by controlling the temperature of the DFB laser, the temperature range of which is between 20°C and 35°C. Fiber-coupled power is controlled to be 20 mW by driving an auto power control circuit (APC). Wavelength drift from the initial set wavelength derives amplitude variations in the wavelength monitor photocurrent on the wavelength discriminator slope. The angle of the etalon to the incident laser beam is tuned and then fixed in the assembly process so that

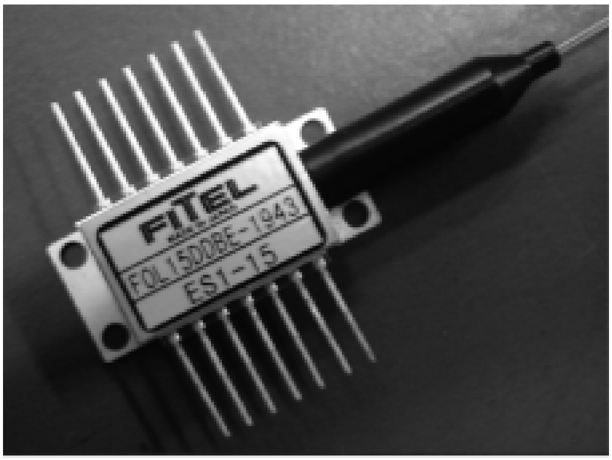

Figure 1 Appearance of wavelength monitor integrated DFB laser module.

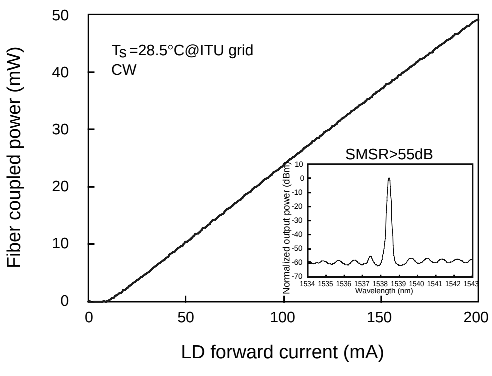

Figure 2 *L-I* curve and optical spectrum.

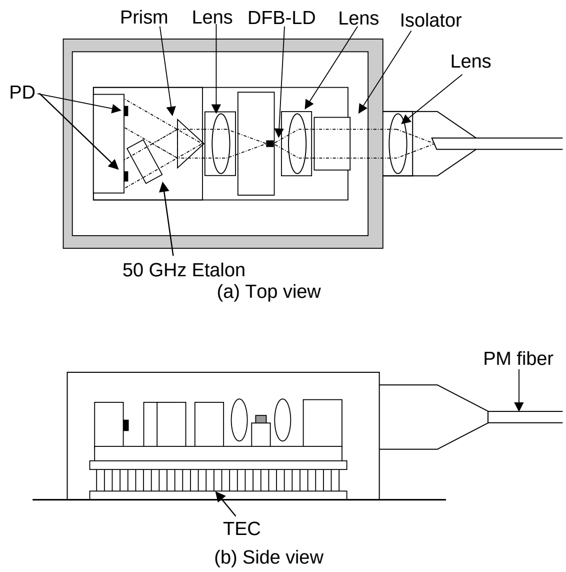

Figure 3 Schematic structure of 50 GHz spaced wavelength monitor integrated DFB laser module.

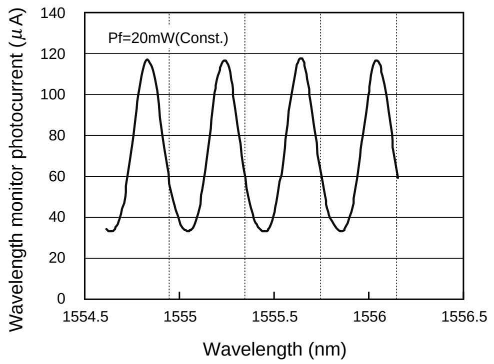

Figure 4 Wavelength discriminator curve for 50 GHz spaced wavelength monitor.

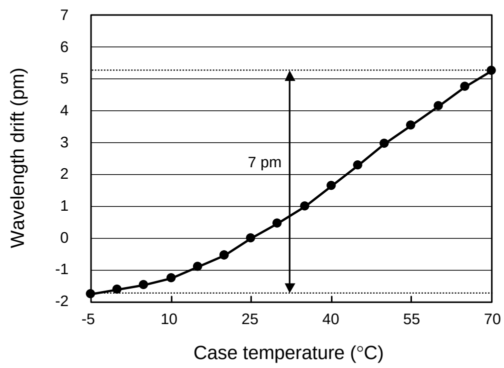

Figure 6 Wavelength drift as a function of case temperature.

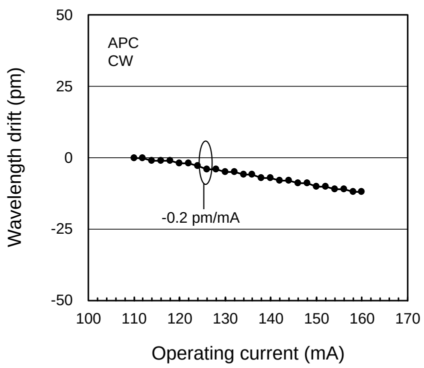

Figure 5 Wavelength drift as a function of operating current.

the required ITU wavelength can be positioned on the slope. In Figure 4, dotted lines indicate 50 GHz spaced ITU wavelengths that are located on all negative slopes.

We evaluated the wavelength-locking performance of this laser using the wavelength monitor function and an electronics circuit. The relationship between wavelength drift and operating current is shown in Figure 5. The wavelength dependency upon operating current is as small as -0.2 pm/°C, which is explained with the following phenomena. An operating current increase induces a temperature increase of the active layer of the DFB laser. The lasing wavelength accordingly has a blue-drift. The wavelength monitor senses the wavelength drift. The monitor signals are utilized for feedback to the TEC control circuit to decrease laser temperature and return the lasing wavelength to its original value. Since the wavelength monitor is mounted on a TEC together with a DFB laser, a laser temperature decrease accompanies a wavelength monitor temperature decrease. Due to its temperature decrease and the temperature dependency of the etalon, the wavelength discriminator curve has a blue-drift as operating current increases, and a locking wavelength accordingly has a wavelength drift. Assuming actual use in transmitters, the operating current increase is induced by laser diode degradation over service life. With failure criteria of a 20 % increase in operating current at the end of life (EOL) and an initial operating current of 120 mA, its increase is 24 mA, which induces a very small wavelength drift of -4.8 pm.

Another dominant factor for wavelength drift is case temperature variation, in which radiant heat affects a slight change in etalon temperature. Figure 6 shows wavelength drift as a function of case temperature between -5°C and 70°C. It has a wavelength drift of 7 pm over case temperature with a fairly linear relationship.

This excellent performance promises a wavelength drift of 20 pm or less sufficiently.

4. LASER MODULES FOR 25 GHZ SPACING DWDM APPLICATIONS

4.1 Module Structure

25 GHz wavelength-spaced 10 Gbit/s DWDM systems require very tight wavelength stability. According to an ITU-T recommendation for wavelength spacing [6], a minimum wavelength stability of ±10 pm is required. To meet this requirement, wavelength dependency upon operating current and case temperature must be suppressed. In terms of the module assembly for 25 GHz spaced DWDM systems, the cavity length of a 25 GHz period etalon is exactly twice that of a 50 GHz period etalon. Since such a long cavity requires a large space in which to equip it, a module structure should be contrived.

A schematic structure of a laser module is shown in Figure 7. Top and side views are shown in Figure 7 (a) and Figure 7 (b), respectively. Employing our unique structure for the wavelength monitor, a 25 GHz period etalon was successfully equipped in an industry standard 14-pin butterfly package for the first time. To meet the wavelength stability requirement of 10 pm or less, independent temperature control of the wavelength monitor is achieved so that operating current dependence can be fundamentally eliminated and case temperature dependence can be suppressed.

4.2 Module Characteristics

Figure 8 shows a wavelength discriminator curve where the wavelength is tuned by DFB laser temperature between 20°C and 35°C. As the wavelength range is the same as that of the 50 GHz spaced wavelength discriminator curve shown in Figure 4, the period in Figure 8 is as short as a half. Dotted lines show 25 GHz spaced ITU

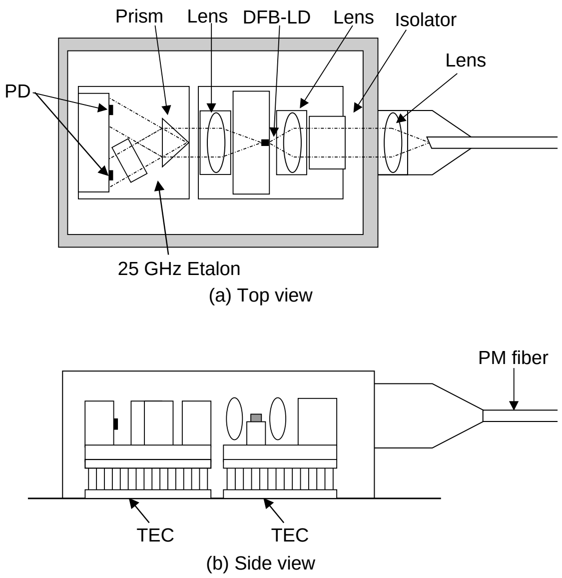

Figure 7 Schematic structure of 25 GHz spaced wavelength monitor integrated DFB laser module.

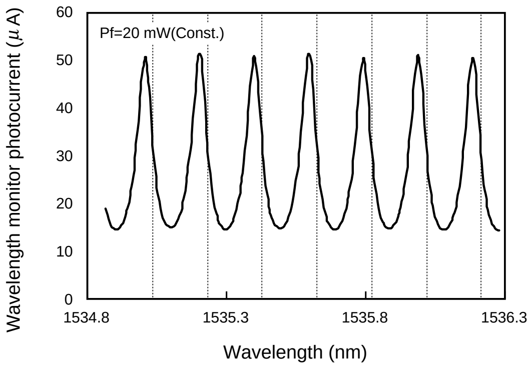

Figure 8 Wavelength discriminator curve for 25 GHz spaced wavelength monitor.

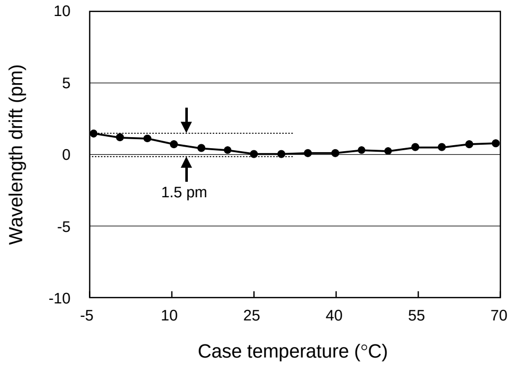

Figure 9 Wavelength drift as a function of case temperature.

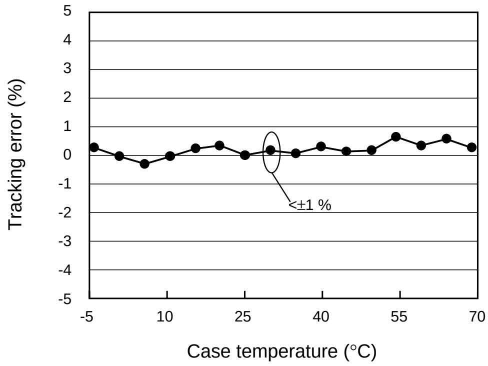

Figure 10 Change of fiber-coupled power as a function of case temperature.

wavelengths on which wavelength discriminator slopes are positioned.

The dominant wavelength drift factor is case temperature variation. To suppress this, the temperature of the sensor should precisely correspond to the etalon temperature, regardless of case temperature variation. Optimizing the position of the temperature sensor can suppress dependency. Figure 9 shows wavelength drift as a function of case temperature. A very small wavelength drift of 1.5 pm is obtained over operating case temperature (-5°C to 70°C).

The unique structure might induce a mechanical instability that causes optical axis off, since DFB laser and wavelength monitor are mounted on separate TEC. To confirm this, the change in fiber-coupled power as a function of case temperature under the condition of a driving APC circuit was measured as shown in Figure 10. With optical axis off in the coupling between wavelength monitor and laser, the coupled power from the back facet to the power monitor photodiode is varied significantly. In the APC drive, while maintaining a constant power monitor photocurrent, the coupling efficiency variation derives a large operating current variation, which causes a large change in fiber-coupled power. The measured value is less than 1 pm, which is much smaller than the common requirement of 10 % or less for laser modules.

Therefore, it is concluded that the module structure employed for the laser module is sufficiently stable. These results promise a laser module with stable optics, even with separate temperature control of the wavelength monitor, and further meet the wavelength stability of 10 pm or less.

5. SUMMARY

We developed wavelength monitor integrated CW DFB laser modules as essential signal sources for long-haul DWDM systems. Employing our unique wavelength monitor structure, an etalon having the very short period required for DWDM application was successfully equipped in an industry standard 14-pin butterfly package. We optimized the laser module structures for 25 GHz spacing and 50 GHz spacing DWDM applications, respectively. By characterizing laser module performance, we confirmed that a wavelength stability of ±20 pm for 50 GHz spacing and a wavelength stability of ±10 pm for 25 GHz spacing can be guaranteed over service life.

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