Highly Reliable 40-mW 25-GHz × 20-ch Thermally Tunable DFB Laser Module, Integrated with Wavelength Monitor

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ABSTRACT To suppress crosstalk between adjacent channels in communications systems based on dense wavelength-division multiplexing (DWDM) requires a laser module that incorporates a wavelength monitor capable of high-precision locking on the channel of the desired wavelength. We have developed a distributed feedback (DFB) laser module with a PMF output of 40 mW, integrated with a wavelength monitor for DWDM with 25-GHz spacing. By means of a highly efficient and highly reliable DFB laser diode and an optimized thermal design, it has been possible to realize thermally tunable operation, and, under variations in laser diode temperature of approximately 40°C, a tunable range of 4 nm or more and a maximum power consumption of 4 W or less. High-temperature storage tests and aging tests showed that despite a structure that is more complex than conventional DFB laser modules, these modules exhibit higher reliability, making them applicable to DWDM systems.

1. INTRODUCTION

With increased use of the Internet and of broadband access, the growth in the volume of information on trunk lines is accelerating. In WDM systems, the following three methods are available to increase transmission volumes:

1) increasing the bit rate per channel, from 2.5 to 10 to 40 Gbps;
2) broadening the bands of wavelengths used, from C-band to the S-, C- and L-bands; and
3) narrowing channel spacing, from 100 to 50 to 25 GHz.

Of these the third, which supports most C-band systems with EDFAs and existing equipment, promises to allow a comparatively low-cost means of increasing information transmission volumes. In the past we have reported on DFB laser modules integrated with wavelength monitors[1)~5)].

When the number of channels exceeds 100, however, it is necessary to keep so many DFB laser modules as spares for system maintenance that the cost becomes a problem. Device vendors also have to maintain enormous inventories. Tunable laser light sources offer one solution to these problems of cost and inventory. Not only this, but the lasing wavelength of such tunable light sources can be remote controlled, showing promise in applications in the next generation of WDM systems, in which dynamic wavelength allocation is carried out. Thermally tunable lasers using the DFB laser diodes developed in this work have single-mode lasing characteristics superior to those of most other tunable lasers, and have a long track record in the optical transmission field promising high reliability.

Against this background, this paper reports on a thermally tunable DFB laser module integrated with a wavelength monitor capable of high-precision wavelength locking at 25-GHz spacing, including long-term reliability.

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2. LASER MODULE STRUCTURE

Figure 1 shows a schematic view of the tunable DFB laser module with an integrated wavelength monitor for 25-GHz spacing. The structure of the integrated monitor is as follows. The light from the back facet of DFB laser diode is passed through a collimator to produce parallel rays, which are divided in two beams by a prism. One of these beams is used as an optical output power monitor directly coupled to a photodiode (PD), and the other is coupled to a PD via an etalon with 25-GHz spacing for use as a wavelength monitor. Using a prism to divide the light from the back facet makes possible savings in space in comparison with the conventional structure using a half mirror, allowing a wavelength monitor structure for 25-GHz spacing and a DFB laser diode to be accommodated in a standard 14-pin butterfly package. It was also possible to reduce the component count and simplify the optical alignment. The module is extremely strong, since all components are YAG welded or soldered. Thus, as will be

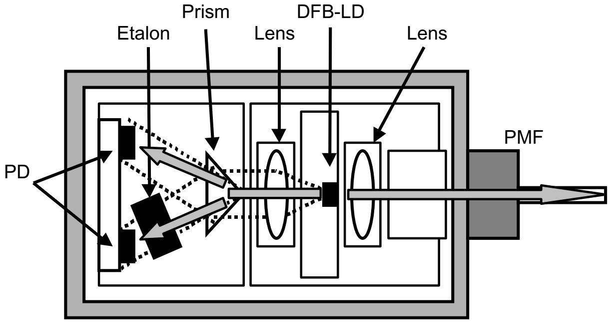

Figure 1 Schematic view of tunable DFB laser module with integrated wavelength monitor.

described in Section 5 below, the module is resistant to thermal and mechanical shock and to moisture, offering high reliability.

Another feature is that it has two thermoelectric coolers (TECs) for compatibility with DWDM systems of 25-GHz spacing, allowing the temperatures of the laser and the optical filter (etalon) to be controlled independently. As will be described in Section 4, this structure enables all wavelength channels to be locked almost exactly at the mid-point of the negative slope of the wavelength discriminator curve. In addition the high-precision etalon temperature regulating capability means that wavelength drift can be made extremely low against both case temperature and operating current.

3. L-I CHARACTERISTICS AND OPTICAL SPECTRUM

When wavelength tuning is accomplished by controlling the temperature of the laser diode, it is very important to achieve low operating current and high output as a means of assuring reliability during high-temperature operation, and by optimizing the coupling coefficient of the grating κ and the cavity length L of the DFB laser diode from the standpoint of output and temperature characteristics, it is possible to realize low operating current and high output at high temperatures.

Figure 2 shows the light output vs. current (L-I) characteristics at selected laser diode temperatures (5, 25 and 45°C). Even at a temperature as high as 45°C, the deterioration in slope efficiency is slight, and a PMF output of 60 mW or more can be obtained. The operating current for 40 mW is less than 175 mA. This order of low operating current is important in terms of laser diode reliability and reduced power consumption. Since operation at outputs as high as 40 mW is possible these diodes are also applicable to amp-less systems in metro system WDM.

Figure 3 shows optical spectra at laser diode temperatures T_{LD} of from 5 to 40°C, when optical output P_f is 40 mW. By varying diode temperature by approximately 40°C, tunable range of 4 nm or more was achieved, and in all temperature ranges the side mode

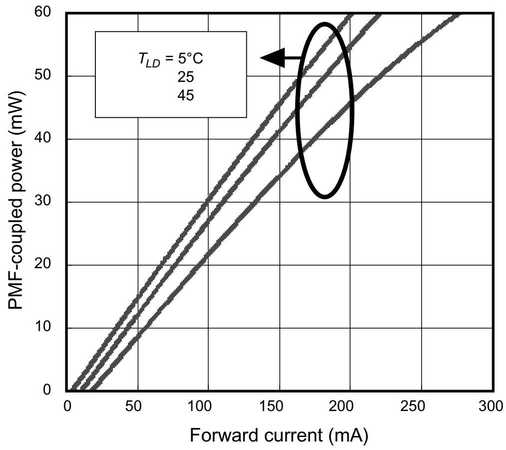

Figure 2 L-I characteristics at selected laser diode temperatures.

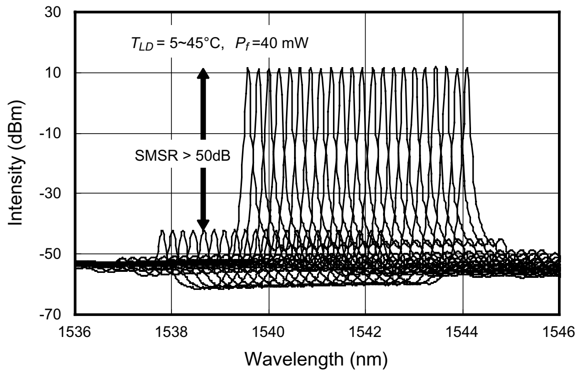

Figure 3 Optical spectra at selected laser diode temperatures (T_{LD} = 5~40°C, P_f = 40 mW).

suppression ratio (SMSR) was greater than 50 dB. Other characteristics were also satisfactory for all temperature ranges, i.e., linewidth greater than 5 MHz and relative intensity noise (RIN) better than -150 dB. These results confirm that this tunable laser is applicable to 10- and 40-Gbps trunk and metro DWDM systems.

4. WAVELENGTH MONITOR CHARACTERISTICS

4.1 Wavelength Discriminator Curve

The curve shown in Figure 4 is known as the wavelength discriminator curve, and shows the relationship between lasing wavelength λ and wavelength monitor current I_{wm}. Measurement was carried out at an etalon temperature T_f of 30°C (constant), with fiber output current held to 40 mW by automatic power control (APC) at constant power monitor current, with laser diode temperature T_{LD} varied between 5 and 45°C. Using the slope of the wavelength discriminator curve, the wavelength shift can be detected as a change in photodiode current. Since this module has an integrated etalon of 25-GHz spacing, the ITU grid for all 20 channels at 25-GHz spacing coincides almost exactly with the mid-point of the negative slope. The slope of the wavelength discriminator curve of the ITU grid is steep, at approximately 14 %/GHz, and the wavelength drift when the wavelength monitor photodiode deteriorates and I_{wm} fluctuates is slight.

4.2 Wavelength Drift Characteristics

For DWDM systems with a channel spacing of 25 GHz and a bit rate of 10 Gbps, the wavelength stability required for a laser module with integrated wavelength monitor is extremely high, with a permissible wavelength drift of no more than ±10 pm [6]. To evaluate the wavelength drift characteristics, measurements were made using the wavelength monitor and a simple external analog feedback control circuit with the wavelength actually locked. With respect to the drift characteristics an average was taken over time and the fluctuation due to the control circuit is not included.

Figure 5 shows the wavelength drift characteristics versus case temperature when the wavelength is locked to an ITU grid with a P_f of 20 mW. Over a range of case temperatures T_c from -5 to 70°C, wavelength drift was extremely low--less than ±1 pm. The factor in wavelength drift that relates to case temperature is due to the effect of the heat radiated from the case and received by the etalon, so that, even though etalon temperature is controlled by the TEC, its temperature changes by minute amounts. This minute temperature change is suppressed by optimizing the positional relationship between the etalon and the thermistors that act as temperature sensors. In this way even if the case temperature changes, the temperatures of the thermistors and the etalon agree and wavelength drift is suppressed, yielding the low levels of drift described above.

Figure 6 shows the dependence of wavelength drift on operating current. The wavelength drift due to changes in operating current is extremely low--less than ±0.2 pm. When operating current increases due to aging of the laser diode, diode temperature increases and the wavelength shift to the longer side. When wavelength monitoring is in effect diode temperature is reduced as operating current increases to keep the wavelength constant. The temperature control mechanism can be understood from Figure 6. In the conventional structure in which the laser diode and wavelength monitor are mounted on a single TEC, control of laser diode temperature causes changes in etalon temperature, which becomes a factor in wavelength drift. In the module presented here, however, the use of two TECs enables the temperatures of the laser diode and the etalon to be controlled independently, achieving an extremely low drift and allowing application to DWDM systems with 25-GHz spacing.

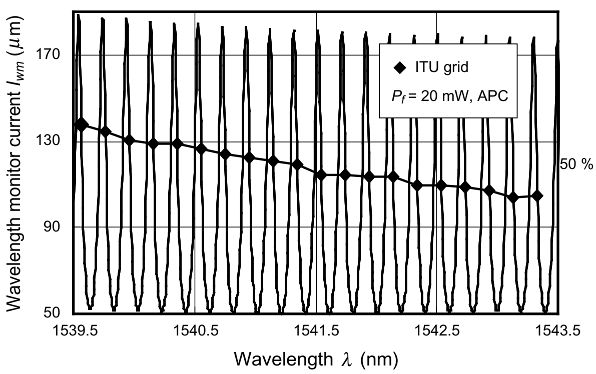

Figure 4 Wavelength discriminator curve.

5. RELIABILITY TESTS

With regard to thermally tunable DFB lasers, that laser diodes themselves have a long track record and are recognized as a highly reliable technology. Care must, however, be taken with respect to reliability when the laser diodes are operated at high temperature. We have carried out tests of laser diode reliability at various temperature conditions and operating conditions. Omitting the details for the present, when diode life is defined as an increase in operating current of 20 % from the initial value, the wear-out failure rate found by linear extrapolation for operating conditions of fiber output power equivalent to

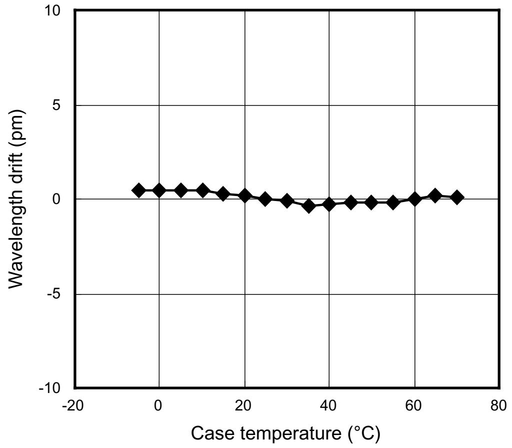

Figure 5 Wavelength drift vs. case temperature.

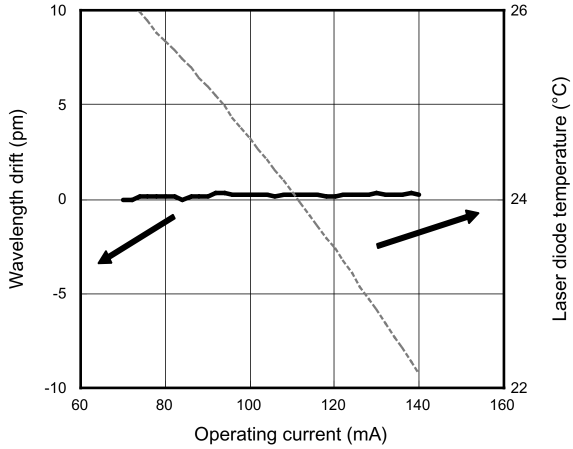

Figure 6 Wavelength drift vs. operating current.

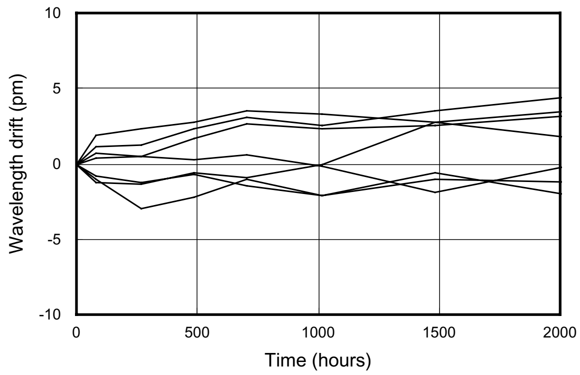

Figure 7 Wavelength drift during high-temperature storage.

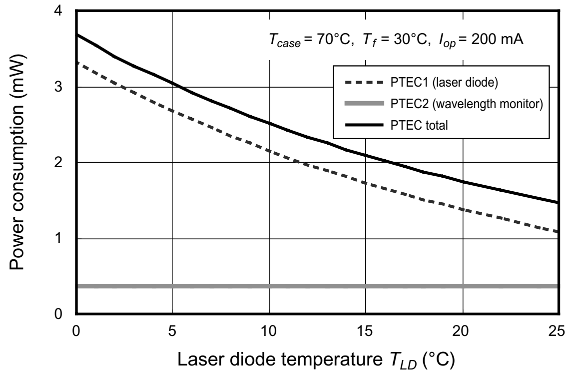

Figure 9 Power consumption of thermoelectric coolers (at T_c = 70°C, T_f = 30°C, I_{op} = 200 mA).

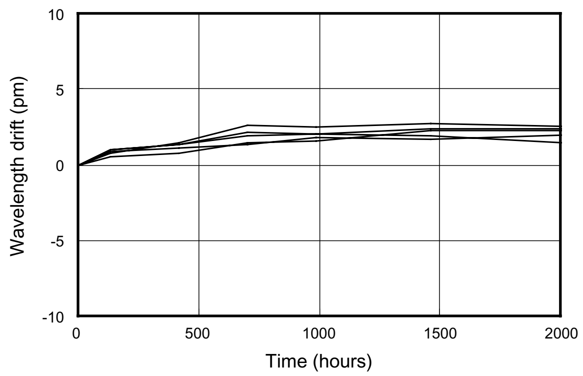

Figure 8 Wavelength drift during aging test (at P_f = 20 mW, T_c = 80°C, T_f = 30°C and T_{LD} = 10°C).

40 mW and T_{LD} of 40°C, was less than 500 FITs after 20 years, confirming high reliability at high-temperature operation.

In the module with integrated wavelength monitor, it is the optical axis displacement from the back facet of the laser diode to the prism, etalon, wavelength monitor and photodiode that gives rise to wavelength drift. We carried out a high-temperature storage test for 2000 hours at an ambient temperature of 85°C. Figure 7 shows the results. An initial fluctuation can be discerned but saturates at less than ±5 pm. This module is constructed using highly reliable YAG welding and soldering, and it was confirmed that the two-TEC structure, though more complex than in the past, was more resistant to optical axis displacement.

And since tuning is effected by temperature control, it can be anticipated that there will be a much higher load on the TECs than with the fixed-wavelength module of the past. It is therefore possible that there could be increased optical axis displacement due to strain in the TECs. To evaluate these aspects an aging test was carried out for 2000 hours at conditions designed to increase the load on the TECs: P_f = 20 mW, T_c = 80°C, T_f = 30°C and T_{LD} = 10 °C. The results are shown in Figure 8. Wavelength drift is apparent at the initial stages, but saturates at less than ±3 pm

From these results it was possible to confirm that wavelength drift including long-term reliability, was less than the ±10 pm, which is the range permissible for 10-Gbps DWDM systems with 25-GHz spacing.

6. POWER CONSUMPTION

Since an extremely large number of laser modules are used in DWDM systems, reducing the power consumption of the modules plays an important role in reducing the consumption of the system as a whole. Since the modules presented here use two TECs, it was to be expected that they would be power-hungry, but when tuned to shorter wavelengths, for example, the wavelength monitor is kept constant at a comparatively high etalon temperature T_f of around 30°C, and only the laser part is controlled to around 0°C, so that the amount of heat absorbed by the two TECs is different. Thus by designing each TEC to be optimally suited to its heat absorption, it is possible to reduce the power consumption. Figure 9 shows the power consumption of the TECs at laser diode temperatures of 0 to 25°C at operating conditions that would place a high load on the TECs, namely T_c = 70°C, T_f = 30°C, and operating current I_{op} of 200 mA. For T_{LD} = 0°C, a low total TEC power consumption--4 W or less--was achieved, and since power consumption was below 4 W at T_{LD} = 0°C, even in the case of a tunable range of 4 nm, the specified temperature can be set at the comparatively low range of 0~40°C, holding promise of high reliability for the laser diode.

7. CONCLUSION

A CW-DFB laser light source with integrated wavelength monitor has been developed for DWDM systems with 25-GHz spacing. Wavelength drift, which is the most important characteristics with respect to DWDM system applicability, was evaluated in terms of variation in temperature, variation in operating current, and long-term reliability. By means of a structure that makes use of two TECs to control the temperatures of the laser and wavelength monitor sections separately, together with optimized thermal design, it has been possible to obtain highly precise temperature control of the etalon, and thereby achieve a wavelength drift with respect to case temperature of ±1 pm and with respect to operating current of ±0.2 pm.

High-temperature storage tests and aging tests were also carried out, and although there were initial fluctuations in wavelength drift, it was confirmed that these saturated to ±5 pm, and wavelength drift including long-term reliability was less than ±10 pm, demonstrating that these laser modules are applicable to DWDM systems with 25-GHz spacing.

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