Development of Full-Band Tunable Laser

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ABSTRACT A novel laser module has been developed comprising a tunable laser that is indispensable as a signal light source for increasing the capacity of DWDM systems. DFB laser array known for its wavelength stability in principle has been employed for the wavelength tuning scheme. The module includes a low-noise semiconductor amplifier enabling high-power operation. This paper describes the structure, operating principle and optical characteristics of this wavelength tunable laser, and also presents the structure, characteristics and reliability of the laser module with a built-in wavelength locker.

1. INTRODUCTION

The increasing capacity of dense wavelength-division multiplexing (DWDM) communication systems absolutely requires, in order to realize reconfigurable networks adaptable to traffic conditions and to reduce the inventory cost of equipping backup transmitters, full-band tunable lasers with tunable lasing wavelengths. Figure 1 shows an optical communication network in which various optical transmitters are used depending on application. Whereas light sources with a fixed wavelength have been used conventionally, full-band tunable lasers combined with modulators are recently mounted in transponders and line cards for medium- to long-range applications, thereby rapidly replacing conventional fixed-wavelength lasers. Application areas of the new laser have been expanded from long-range areas to the medium- to short-range areas such as the metro and access networks.

In order to meet such market requirements, a variety of tunable lasers have been proposed so far, including lasers using mechanical movable mechanism, lasers with external cavity and lasers with distributed Bragg reflector. But the wavelength tuning methods are complicated for all these lasers, raising problems in terms of operating performance against environmental changes as well as characteristic changes due to deterioration with age. Moreover, since their wavelength tuning mechanisms are significantly different from that of thermally tuned distributed feedback (DFB) lasers conventionally used in optical communications, use of sophisticated control circuit is indispensable. On the other hand, wavelength selectable lasers [1)~4)] have been proposed as a wide wavelength tunable laser based on the DFB laser technology with proven reliability and established track record. The laser consists of an array of DFB laser elements of different lasing wavelengths that is integrated with an optical coupler and a semiconductor optical amplifier (SOA), whereby a wide range of wavelength tuning can be realized by means of laser element switching and thermal wavelength tuning. Since it is based on the same operation principle as for the DFB laser, it has good long-term reliability, and it allows for using a simple feedback circuit to easily control the wavelength and optical output. In this development, we have expanded the wavelength tuning range of this wavelength selectable laser to enable full-band wavelength tenability, and improved its fundamental characteristics such as optical output and noise characteristics. Furthermore, we have developed a laser module with a built-in wavelength locker, which is capable of wavelength tuning and controlling over the entire range of the C band and L band, respectively.

2. INTEGRATED FULL-BAND TUNABLE LASER CHIP

A tunable laser for transponder application is required to provide a tunable wavelength range of 35 nm or more

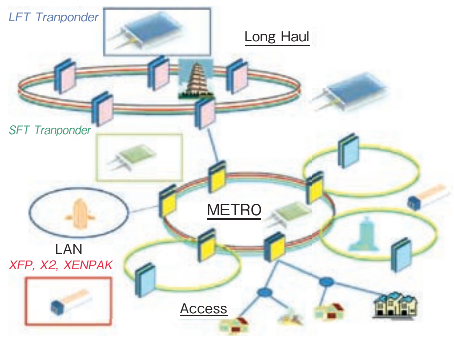

Figure 1 **Wavelength-division multiplexing optical network and optical transmitter.**

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and a fiber-coupled output of 20 mW or more. The tunable wavelength range of thermally tuned DFB laser elements that constitute the laser developed here is determined by the power consumption and the operating temperature range specified from the standpoint of reliability, and is typically about 4 nm. With a view to covering the full band, the laser was designed to be such that, taking manufacturing variation into account, twelve DFB laser elements having different wavelengths at a wavelength spacing of 3.45 nm were integrated. From the standpoint of lasing wavelength control, a phase shift-type diffraction grating was employed. This design has achieved a wavelength tuning range of 38 nm by means of changing the operating temperature between 10℃ and 50℃. Figure 2 shows a photomicrograph of the integrated laser elements manufactured here. In addition to the DFB laser array, an optical coupler to combine the output from every DFB laser element is integrated together with an optical amplifier that allows compensating for the loss in the optical coupler. The chip size is 500 μm × 2600 μm, and the lengths of the DFB laser element and the optical amplifier are 600 μm and 900 μm, respectively. Bent waveguides and antireflection coating were provided at the end facet to suppress the reflection from there.

As for the manufacturing process, a quantum well structure to be used as the emitting region of DFB laser and the amplifying region of SOA was grown on an InP substrate, followed by formation of diffraction gratings by using an electron beam lithography system and dry etching equipment. Then, etching and regrowth processes were carried out to form the passive waveguide structure and the current blocking layer for current confinement, as well as the cladding layer that serves for current injection and light guiding. Finally, electrodes for current injection were formed and the laser elements were electrically separated to complete the laser chip. Layer growth was carried out using metal organic chemical vapor deposition (MOCVD), and methane hydrocarbon-based dry etching was used for etching. Figure 3 shows the optical fiber-coupled output characteristics of the integrated laser chip.

The DFB laser is driven at a constant current of 150 mA, and the optical output is controlled by adjusting the SOA current. To tune the wavelength, the laser is operated at an operating temperature between 10℃ and 50℃. Any DFB laser element can output, even when driven at an operating temperature of 50℃, an optical power of 30 mW or more, which is sufficient for applications to be combined with external modulators. Figure 4 shows the superimposed lasing spectrum. It has been confirmed that both the C band and L band integrated laser chips show a high side-mode suppression ratio (SMSR) of 40 dB or more and good optical signal-to-noise ratio (OSNR).

3. REDUCTION OF SPECTRUM LINEWIDTH

The tunable laser is required to have characteristics equivalent to those of the DFB lasers conventionally used, including, when application to long-haul transmission is intended, low-noise characteristics shown by such indexes as spectrum linewidth and relative intensity noise (RIN). In the case of the integrated laser developed here, return light that is reflected to the DFB laser from the laser element itself and from the outside should be taken into account. Thus, we have optimized the structure of the integrated laser to achieve low-noise characteristics [5]. Figure 5 shows a model of possible reflection points within the laser chip, including those at the joint between the passive and active elements, the end facet of coupler and the end facet of the SOA. Analysis results of the lasing spectrum have shown that the return light from the end facet of the SOA influences the noise characteristics, resulting in periodic increases in the spectrum width

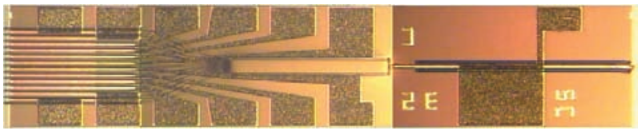

Figure 2 Optical integrated chip of full-band tunable laser showing DFB laser array, coupler and SOA.

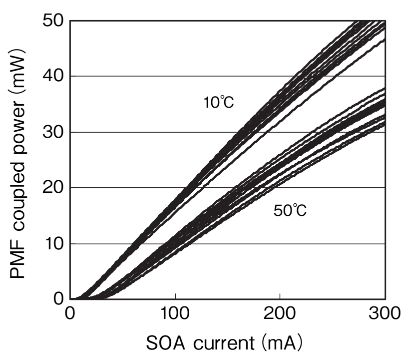

Figure 3 Optical output characteristics.

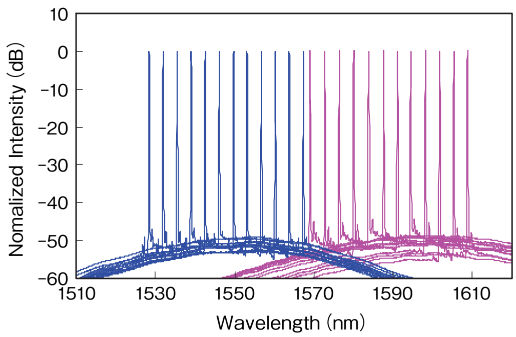

Figure 4 Superimposed lasing spectrum of the C-band and L-band lasers.

depending on the laser driving conditions. This is caused by the fact that the reflected return light is amplified again in the SOA, giving disturbance to stabilized operation of the DFB laser.

We have optimized the structure of the SOA end facet to minimize the effects of the return light. Figure 6 shows the dependency of the spectrum linewidth on the DFB laser driving current for the lasers with different end facet reflectivity. As can be seen, while the spectrum linewidth exceeds 10 MHz at a reflectivity of 5.7×10^{-3} depending on the DFB current, oscillatory behavior of the linewidth is suppressed at a reflectivity of 1.1×10^{-5}, achieving a superior value of 2 MHz or lower. Figure 7 shows the SOA current dependency of the light output and the spectrum linewidth at an operating temperature of 25℃. It can be seen that spectrum linewidths of 2 MHz or lower and optical outputs of 50 mW or higher have been achieved for all DFB lasers. Moreover, as shown in Figure 8, the effect of spontaneous emission of the SOA on the spectrum linewidth is minimal, together with a low RIN of -145 dB/Hz.

Thus, as the result of optimization through modeling of the spectrum linewidth for the integrated laser, the wavelength selectable light source using semiconductor amplifier with maximized output and narrowest spectrum linewidth has been realized.

4. LASER MODULE WITH BUILT-IN WAVELENGTH LOCKER

In actual DWDM systems, the wavelength channels are arrayed with a wavelength spacing of 50 GHz, so that the wavelength accuracy should be kept within a range of ±2.5 GHz including deterioration with age. To realize such a precise range of wavelength control, it is necessary to install a wavelength locker in the tunable laser module. In general, however, laser modules with a built-in wavelength locker reported so far were relatively large in size.

Accordingly, we have developed a new laser module with a built-in wavelength locker that can lock the full-band wavelength channels [6]. Figure 9 shows a schematic of the laser module with built-in wavelength locker. The package is a 26-pin butterfly package, the industry standard, making it adapted to high-density mounting in the recent optical communication systems. The module accommodates a beam splitter for collimated beam branching, an etalon for 50-GHz channel spacing (possibly 25-GHz in future), and two photodetectors for wavelength and power monitoring. Figure 10 shows the wavelength discrimination curve using a 25-GHz spacing etalon. Two sets of Peltier elements are used to independently control the temperatures for laser wavelength tuning and for wavelength locking, so that by means of feedback

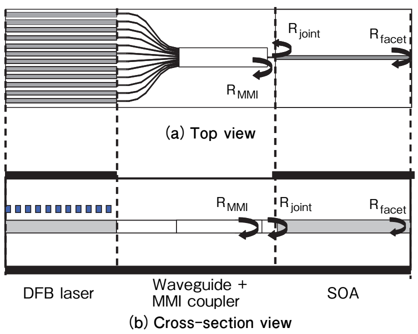

Figure 5 Typical model of reflected return light in optical integrated chip.

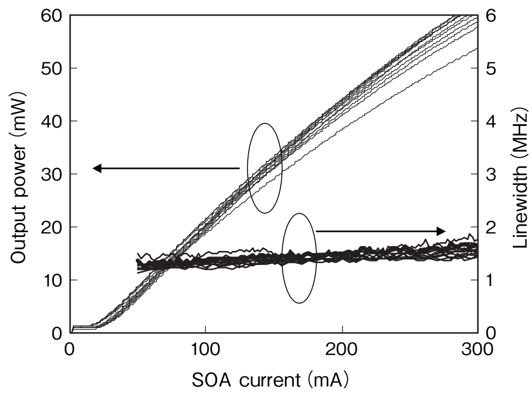

Figure 7 SOA current dependency of optical output and spectrum linewidth.

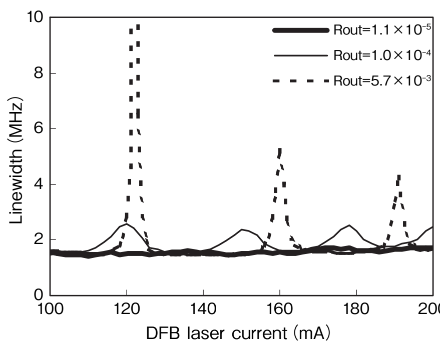

Figure 6 Dependency of spectrum linewidth on facet reflection coefficient and DFB current.

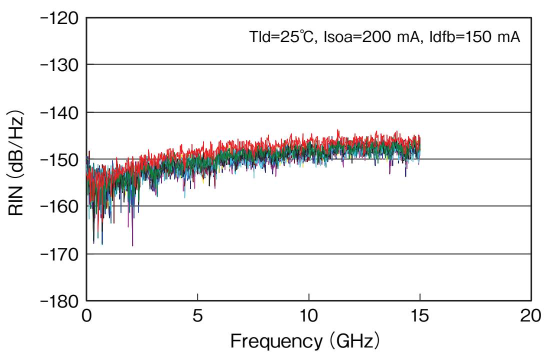

Figure 8 Relative intensity noise (RIN) characteristics.

control based on this curve, it is possible to control the wavelength very precisely.

Not only initial characteristics but also long-term reliability is important for laser modules for optical communications. Figures 11 and 12 show the changes in output power and wavelength, respectively, after high-temperature shelf tests at 85℃ for 2000 hours. It can be seen that the power change and the wavelength change are very precisely controlled at 10 % or less and 5 pm or less, respectively. An assembly process using YAG laser-based welding and soldering has enabled us to manufacture such a laser module with built-in locker that is robust, low in deterioration with age and highly reliable. Figure 13 shows the result of consumption power evaluation of this module including the control circuit. Even under the most severe condition of external temperature at 75℃, the power consumption is 3 W or less for the laser portion, or 5 W or less including the control circuit. While it is recommended that, in view of installation on transponders, the power consumption of a laser with control circuit should be 6.6 W or less [7], the results here fully satisfy this criterion.

Thus it has been shown that the laser module with built-in wavelength locker developed here is tunable over the full-band wavelengths, low in noise and is highly reliable, thereby meeting the requirements for optical transmitters to be used in transponders and the like.

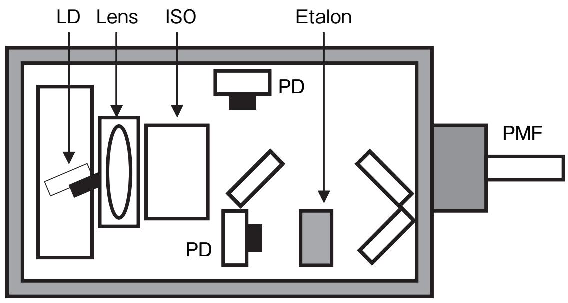

Figure 9 Laser module with built-in wavelength locker.

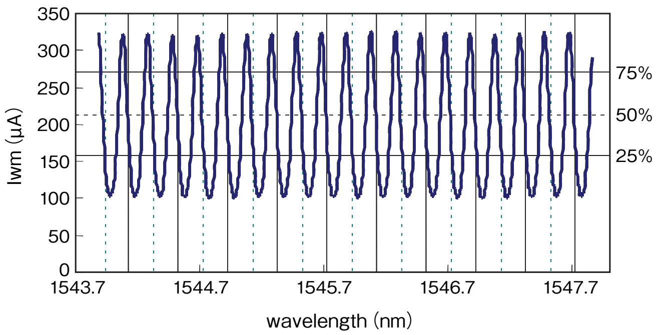

Figure 10 Wavelength discrimination curve with 25-GHz wavelength spacing.

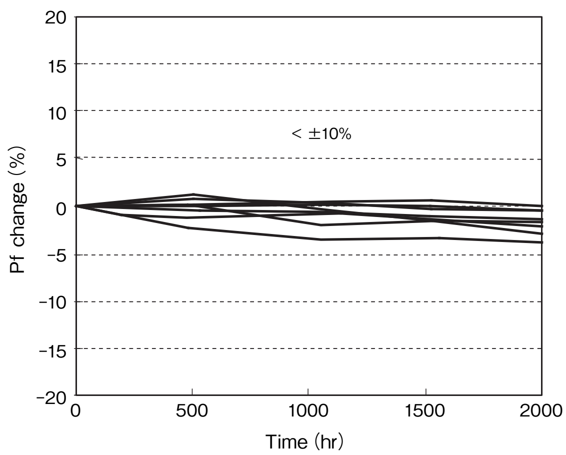

Figure 11 Results of high-temperature shelf test: change in optical output.

5. CONCLUSION

A tunable laser module that is indispensable as a signal light source for increasing the capacity of DWDM systems has been developed. DFB laser array known for its wavelength stability in principle has been employed as the wavelength tuning scheme, and the long-held problem of noise in semiconductor amplifier has been solved to real-

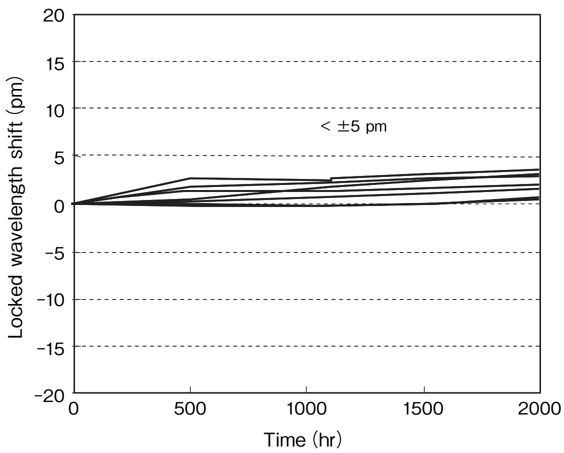

Figure 12 Results of high-temperature shelf test: change in wavelength.

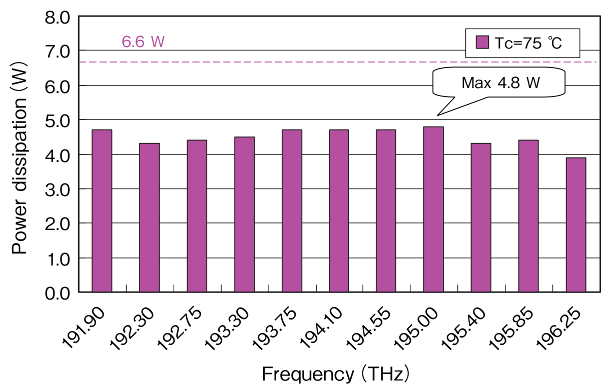

Figure 13 Power consumption of module (control circuit included).

ize lower noise characteristics, achieving a wide wavelength tuning range covering the entire bandwidth of the C and L bands, as well as high power operation. Moreover, a compact laser module with built-in wavelength locker that is compliant to the size of industry standard has been manufactured, thereby realizing highly reliable control of wavelength and optical output. The full-band tunable laser developed here has high reliability, and is very promising as a light source for application to the developing DWDM optical communications.

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