+18 dBm High-Power Tunable Laser Modules for Digital Coherent Optical Communication Systems

Mitsuyoshi MIYATA*, Hirokazu TANAKA, Masao SHIBATA, Yoshiki OKA, Toshimitsu KANEKO and Hiromitsu KAWAMURA

With the rapid increase in communication traffic, digital coherent communication technology has spread, particularly for trunk networks. For the application of the technology to metropolitan area networks and data center interconnection, compact and high-power light sources that enable high-density mounting in communication units are required. We have developed a micro-integrable tunable laser assembly (Micro-ITLA) using a tunable distributed amplification chirped sampled grating distributed reflector (TDA-CSG-DR) laser that achieves the industry's highest output power of +18 dBm.

Keywords: coherent, tunable, high-power, narrow linewidth, Micro-ITLA

1. Introduction

Communication traffic is continually increasing due to various factors, such as the dissemination of smartphones and tablet PCs, as well as the spread of cloud computing services. The laser module we have developed is a continuous wave (CW) tunable light source mainly used for optical trunk networks that support such communication demand.

Optical trunk networks use a dense wavelength division multiplexing (DWDM) system to achieve high-speed and high-capacity communication of 10 Gbit/s x n_λ (n_λ: about 90). Furthermore, using a digital coherent system, ultrahigh-speed communication of 200 Gbit/s per wavelength has recently been put into practical use.

In a coherent optical communication system, a signal is superimposed over the optical phase. This particular system simultaneously detects polarization and therefore it is suitable for long-distance transmission thanks to its high tolerance for transmission line dispersion. However, since optical interference with the local oscillator is necessary to reproduce the signal, large and complicated equipment is needed. Thus, conventionally the use of coherent optical communication was limited to long-distance communication.

It has been attempted to use this communication system for metropolitan area networks (transmission distance: up to 600 km) and data center interconnection in recent years. For such use, there are stringent requirements for the system in terms of the size of the communication equipment and the power consumption, and therefore light source modules are required to be downsized and power efficient. In January 2016, the specifications of CFP2 analog coherent optics (CFP2-ACO),*1 a CFP2 size transceiver, were standardized(1) by the Optical Internetworking Forum (OIF).*2 The package size is 41.5 × 107.5 × 12.4 mm and the number of tunable light sources that can be installed is substantially limited to only one unit. The optical output power from the light source is branched and used for both transmission and receiving functions; therefore, an optical output power higher than ever is required.

Under such circumstances, we have developed and successfully mass-produced a compact tunable laser module of the micro-integrable tunable laser assembly (Micro-ITLA)(2) that can achieve an optical output power of +18 dBm. This paper provides an overview and the characteristics of the module, including a comparison with the conventional ITLA(3) product.

2. Product Specifications and Development Targets

Table 1 shows the outline dimensions and power supply voltage of a tunable laser module standardized by the OIF. As compared to the conventional ITLA standard, the outline dimensions specified by the Micro-ITLA standard are less than 40% in area and less than 30% in volume (Fig. 1) and the usable power supply voltage is also set to a lower level.

Table 1. Required specifications for a tunable laser module

Item	ITLA	Micro-ITLA	Unit
Max. outline dimensions	74.0×30.5×10.5	45.0×20.0×7.5	mm
Power supply voltage	+3.3 -5.2	+3.3 -5.2 (Not used by us) +1.8	V

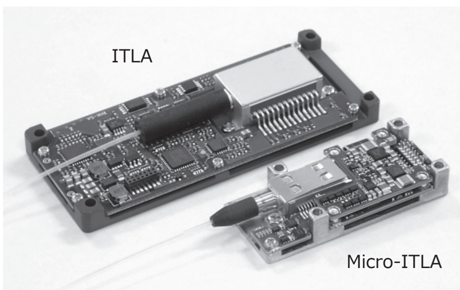

Fig. 1. Tunable laser module size comparison

To downsize the whole laser module, it is required to downsize not only the laser device package but also its circuit boards. We have selected smaller and lower profile components and efficiently arranged them in two circuit boards. This allows them to be mounted to a small module while achieving the functions equivalent to those of a conventional module. In addition, the voltage required for driving elements has been lowered to comply with the OIF standard.

Table 2 shows the target specifications as a Micro-ITLA. Conventionally, an optical output power of about +16 dBm was considered high. However, even higher optical output power is required because the modulation loss is increasing in line with higher functionalities and only a single unit is used for both the transmitter and local oscillator. We set the target to +18 dBm for product development. The target for the linewidth, or a frequency stability indicator, was set to 300 kHz, which is required for dual-polarization-16 quadrature amplitude modulation (DP-16QAM)*3 used for digital coherent optical communication at 100 Gbit/s or more. We also aimed to reduce the power consumption and set the target to 4.5 W for driving at a case temperature of 75°C with an optical output power of +18 dBm.

Table 2. Target specifications for Micro-ITLA development

Item	ITLA (Reference)	Micro-ITLA	Unit
Optical output power	+16	+18	dBm
Effective linewidth	500	300	kHz
Power consumption	5.3	4.5	W
Temperature range	-5 to 75		°C

3. Tunable Laser Chip

The laser chip used this time is our original tunable laser diode chip called tunable distributed amplification-chirped sampled grating-distributed reflector (TDA-CSG-DR) laser.[(4)] Figure 2 shows its section diagram. The laser cavity has a single-stripe type structure, with (1) a tunable distributed amplification-sampled grating-distributed feedback (TDA-SG-DFB) region, i.e. a gain region, and (2) a chirped sampled grating-distributed Bragg reflector (CSG-DBR) region, i.e. a reflection region, optically coupled together. In the TDA-SG-DFB region, an active waveguide having a gain and a passive waveguide are alternately located, and underneath each, a sampled grating (SG) region is formed with partial gratings periodically laid out. Current injection to the laser electrodes located on top of the active waveguides generates periodic gain peaks in the gain spectrum. The CSG-DBR is a DBR having SGs whose intervals are periodically varied. The periodic reflection peaks obtained here form a gradual envelope curve, which functions as a band reflection filter. Wavelength tuning can be performed using heaters at the gain and reflection regions by controlling the refractive index of the waveguides right underneath them.

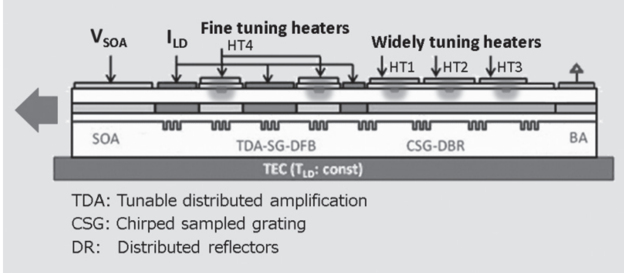

Fig. 2. TDA-CSG-DR laser structure

In addition, on the optical output side, a semiconductor optical amplifier (SOA) function is integrated for optical amplification and shutter functions. In the back of the reflection region, a backside absorber (BA) is located to prevent light scattering inside the package.

The most significant feature of this chip is that it can easily obtain high optical output power. An SOA function is integrated for some tunable laser assemblies for communication systems like ours. However, the intensity of the light incoming to the SOA must be increased in order to efficiently obtain high optical output power because the gain of any amplifier is saturated. The TDA-SG-DFB structure optimally amplifies the light that enters the SOA.

Furthermore, the laser cavity length including both the gain and reflection regions is as long as about 2 mm. This is structurally advantageous for low phase noise characteristics (narrow linewidth characteristics), which are important for the light source of coherent communication. In terms of power consumption, we tried to suppress thermal diffusion from the heater, and the maximum heater power consumption is as low as 0.5 W in the whole chip.

3-1 Basic wavelength tuning principle

Figure 3 shows the gain mode generated at the gain region and the reflection mode generated at the reflection region as well as the resultant oscillation wavelength of the

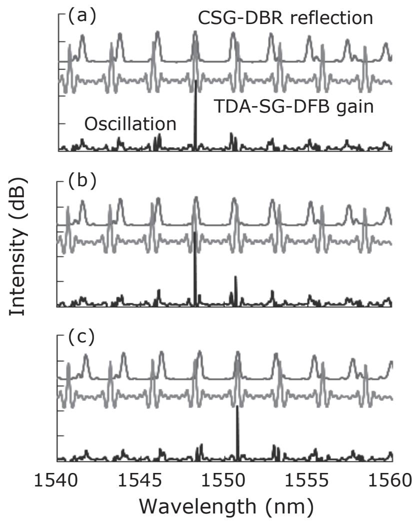

Fig. 3. The behavior of each function when the heater power at the reflection region is changed

chip. For the gain and reflection regions, the interval length of partial gratings L (= segment length) is designed so that each mode spacing may slightly differ from each other, and laser oscillation is generated at the wavelength at which these modes coincide with each other (Fig. 3 (a)).

Figures 3 (b) and (c) show the behavior when the power of the phase adjustment heater slightly changed at the reflection region. Slightly shifting the wavelength mode on the reflection region enables the coinciding wavelength to jump to the adjacent mode at the gain region.

Tuning wavelength with a slight phase change is generally called the Vernier effect, and this mechanism is used in almost all single-stripe type tunable lasers available on the market. Any wavelength can be tuned if the heater in the gain region can be simultaneously controlled to shift the gain mode.

3-2 Full band tuning range achieved by CSG-DBR

The C-band (wavelength: 1530 to 1565 nm) mainly used in the DWDM is a wavelength band of about 40 nm in width; however, a tuning range of only about 20 nm can be obtained by the aforementioned Vernier effect alone. This is attributable to the fact that the tuning range obtainable by the Vernier effect is generally about nine times the mode spacing. To fulfill the required bandwidth, a wider mode spacing of about 5 nm is necessary, which requires a shorter segment length of 70 µm or less. (The mode spacing is inversely proportional to the segment length.) Should the 30µm-heater region be used in the segment, the maximum heater temperature would exceed 300°C.

To solve this problem, we made modifications to the SG-DBRs, which are normally laid out with a constant segment length. To be specific, the reflection region was arranged to comprise three segments of different lengths (L, L + ΔL, L - ΔL), with each segment being independently controlled by the heater. This SG-DBR, for which the segment lengths are modulated with a constant interval, is called chirped SG-DBR (CSG-DBR).

Figure 4 shows the reflection spectrum of the CSG-DBR and the oscillation wavelength obtained by changing the power of three heaters constituting the CSG-DBR. With appropriate driving conditions, the wavelength filtered by the CSG-DBR can vary widely and the wavelength range where the Vernier effect works can move significantly. Consequently, the whole C-band range is covered.

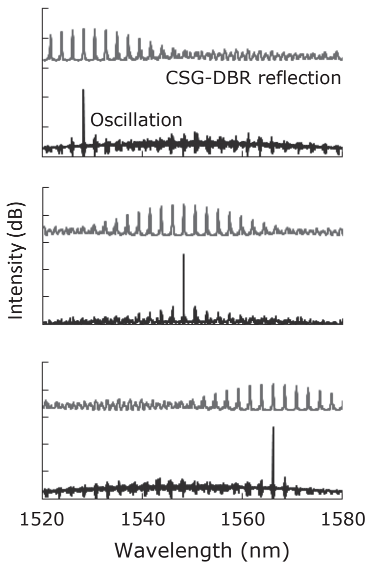

Fig. 4. CSG-DBR reflection characteristics and oscillation wavelength

4. Characteristics

4-1 Frequency tunability characteristics and optical output power

Figure 5 shows the frequency tunability characteristics of the Micro-ITLA. The automatic frequency control (AFC) using the frequency locking mechanism provided in the laser package has achieved good frequency stability of less than +/-0.5 GHz within a case temperature range of -5 to 75°C.

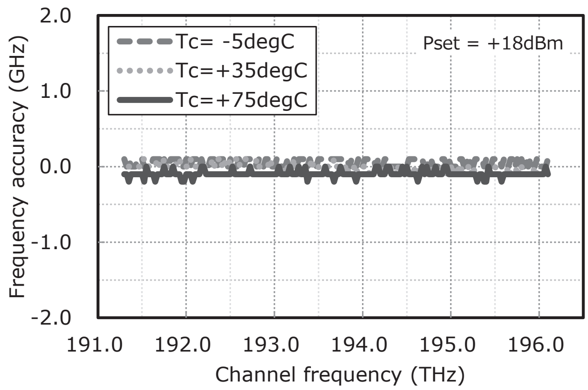

Fig. 5. Frequency characteristics

Figure 6 shows the optical output power characteristics. The automatic power control (APC) by monitoring the optical output power has achieved good stability of less than +/-0.5 dB.

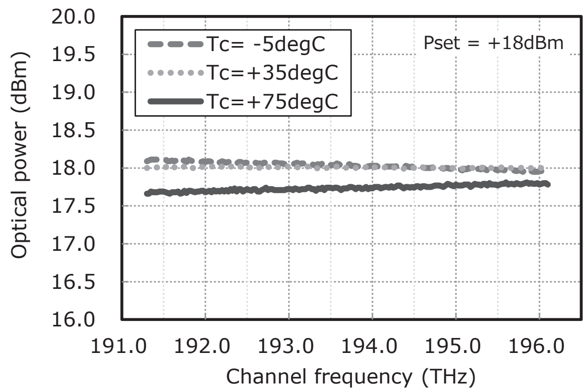

Fig. 6. Optical output power characteristics

Figure 7 shows the power consumption characteristics. The power consumption was less than 4.5 W, lower than the conventional level. The TDA-CSG-DR laser tunes the oscillation wavelength by adjusting the phase of the TDA-SG-DFB region instead of changing the laser temperature as in the conventional way. Thus, it keeps the laser temperature almost constant at high side, enabling low power consumption.

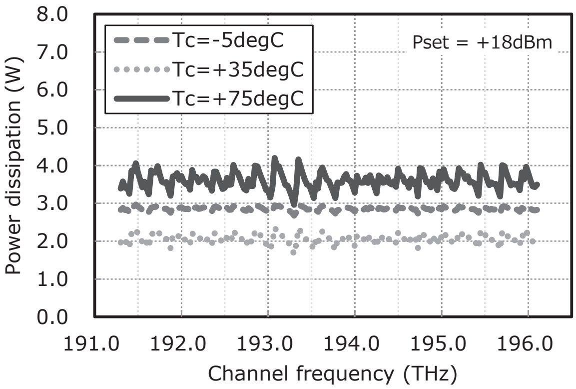

Fig. 7. Power consumption characteristics

4-2 Effective linewidth

The linewidth of the Micro-ITLA was evaluated by the coherent detection method using an intradyne coherent receiver (ICR). Figure 8 shows the measurement system configuration. An external cavity laser with a linewidth of 20 kHz or less is used as a reference light source. The light of the Micro-ITLA interferes with the reference inside the ICR. The electrical output from the ICR is directly observed using a real-time oscilloscope and the instantaneous frequency fluctuation is used to calculate the effective linewidth. Good effective linewidth characteristics of less than 300 kHz were confirmed as shown in Fig. 9.

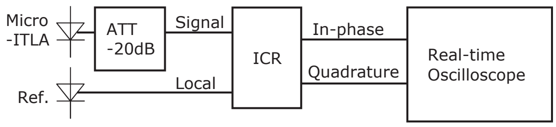

Fig. 8. Effective linewidth measurement system configuration using ICR

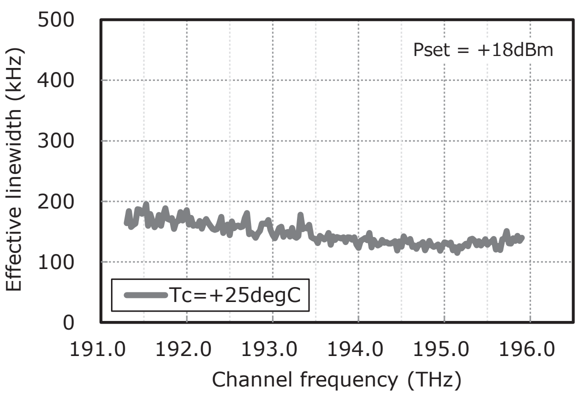

Fig. 9. Effective linewidth characteristics

5. Conclusion

We have developed a Micro-ITLA as a compact tunable light source that enables high-density mounting in units for digital coherent optical communication systems. Use of the newly developed laser chip achieved the industry's highest optical output power of +18 dBm while realizing low power consumption. In addition, an effective linewidth of less than 300 kHz was achieved, which is required for large capacity communication of 100 Gbit/s or more. We hope that our Micro-ITLA will become a key device that can respond to the increase in communication traffic that is expected to accelerate in the future.

Technical Terms

∗1 CFP2-ACO (CFP2 Analog Coherent Optics): A CFP2 size transceiver having a coherent communication function but not equipped with a digital signal processor (DSP), which digitally processes electrical signals.

∗2 Optical Internetworking Forum (OIF): An optical technology industry association engaged in standardization activities.

∗3 DP-16QAM (Dual-polarization-16 quadrature amplitude modulation): QAM stands for quadrature amplitude modulation. The 16-QAM is a communication system that combines two different amplitudes in addition to four phases mutually different by 90° and thus simultaneously transmits 16 values, or 4 bits of information. The DP-16QAM is a communication system that additionally uses orthogonal dual polarization (DP) and thus simultaneously transmits 16-QAM signals, or a total of 8 bits of information.

References

(1) OIF-CFP2-ACO-01.0, "Implementation Agreement for CFP2- Analogue Coherent Optics Module"

(2) OIF-Micro-ITLA-01.1, "Micro Integrable Tunable Laser Assembly Implementation Agreement"

(3) OIF-ITLA-MSA-01.3, "Integrable Tunable Laser Assembly Multi Source Agreement"

(4) T. Kaneko, Y. Yamauchi, K. Uesaka, and H. Shoji, "A Single-Stripe Tunable Laser Operated at Constant Temperature Using Thermo-Optic Effect," Microoptics Conference (MOC), G-2 (2011)

Contributors The lead author is indicated by an asterisk (*).

M. MIYATA*

• Lightwave Components Division, Sumitomo Electric Device Innovations, Inc.

H. TANAKA

• Lightwave Components Division, Sumitomo Electric Device Innovations, Inc.

M. SHIBATA

• Manager, Lightwave Components Division, Sumitomo Electric Device Innovations, Inc.

Y. OKA

• Lightwave Components Division, Sumitomo Electric Device Innovations, Inc.

T. KANEKO

• Assistant General Manager, Transmission Devices R&D Laboratories

H. KAWAMURA

• Group Manager, Lightwave Components Division, Sumitomo Electric Device Innovations, Inc.