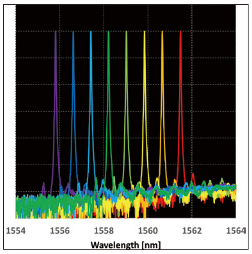


8-Wavelength Tunable 25 Gbit/s Electro-Absorption Modulator Integrated Laser

Takayuki SUZUKI*, Hiromi TANAKA, Toshimitsu KANEKO, and Noriaki KAIDA

This paper presents our development of an 8-wavelength tunable electro-absorption modulator integrated laser, designed for mobile and access networks. The laser was created in response to the increased data traffic and data rate demands within 5G mobile fronthaul communication networks, particularly in areas with limited fiber infrastructure. This solution addresses the growing need for wavelength tunable optical transceivers and supports the adoption of wavelength division multiplexing. The performance of the laser was evaluated in a compact 25 Gbit/s dense wavelength division multiplexing (DWDM) transceiver, housed in an SFP28 form-factor.

Keywords: wavelength tunable light source, EML, DWDM, mobile fronthaul

1. Introduction

The utilization of 5G communication services is witnessing a significant surge due to the widespread availability of video distribution services and advancements in mobile terminal capabilities. These services enable high-speed and low-latency communications. In the realm of 5G wireless access networks, the utilization of evolved common public radio interface (eCPRI)*1-compliant optical fiber communications is extensive for establishing a connection between antenna equipment and centralized wireless control equipment housed at a central location, commonly referred to as mobile fronthaul. The data rate of mobile fronthaul fiber links has increased to 25 Gbit/s. In urban areas where communication traffic is concentrated, a large number of antenna devices are deployed in a small area, and therefore, the optical fiber utilization efficiency needs to be improved by using dense wavelength division multiplexing (DWDM) technology. Until now, fixed-wavelength optical transceivers have been widely used in mobile fronthaul, but different models are required for each wavelength, which poses challenges for procurement and inventory management. To solve this problem, demands for wavelength tunable optical transceivers are increasing. Another advantage of wavelength tunable optical transceivers is that they can greatly simplify installation work by incorporating a function that automatically tunes its transmission wavelength to match the port of the optical filter to which each transceiver is connected.

Full-band tunable optical transceivers with a tunable range of 40 wavelengths at 100GHz spaced grid DWDM are known,(1) but they are based on technology originally developed for long-haul communications, and the integration of Mach-Zehnder modulators has led to larger transmitters, more complex control, higher power consumption, and higher costs. We have developed an 8-wavelength tunable electro-absorption modulator integrated laser (EML) that can be mounted on a conventional fixed-wavelength compact transmitter by utilizing the technologies we have cultivated in the wavelength tunable light source(2) and the EML.(3),(4) In order to evaluate the various characteristics, we have developed a prototype optical transceiver small form-factor pluggable (SFP28)*2 that combines a transmitter equipped with an 8-wavelength tunable EML and an optical receiver equipped with a waveguide avalanche photodiode (APD).(5)

2. Target Specifications

Table 1 shows the target specifications for an optical transceiver with 8-wavelength tunable EML, based on the standards defined by the Institute of Electrical and Electronics Engineers (IEEE)*3, International Telecommunication Union Telecommunication Standardization Sector (ITU-T)*4, O-RAN ALLIANCE*5, and our specifications, taking market requirements into account. The minimum wavelength tunable range is equivalent to 8 wavelengths at 100GHz spaced grid DWDM in Conventional-band (C-Band)*6.

Table 1. Target specifications for optical transceiver

Item	Specifications	Unit
Operating temperature	-40 to 85	°C
Data rate	25.78125	Gbit/s
Modulation format	NRZ	-
Maximum fiber length	15	km
Wavelength tunable range	≥5.6	nm
Average optical output power	≥0	dBm
Side-mode suppression ratio	≥35	dB
Extinction ratio	≥7	dB
Power consumption	≤2.5	W
Loss-budget	≥19	dB
Self-tuning time	<60	s

Based on Table 1, target specifications for the EML were established as shown in Table 2. The target values for optical output power were estimated considering modulation loss, coupling loss, aging degradation, and temperature variation.

Table 2. Target specifications for EML chip

Item	Specifications	Unit
Wavelength tunable range	≥5.6	nm
Optical output power†1	≥4.5	mW
Side-mode suppression ratio	≥35	dB
Power consumption†2	≤250	mW

†1: Optical output power at front-facet of EML at modulator voltage 0V.
†2: Total power consumption of EML under driving conditions with modulator voltage applied.

Figure 1 shows a schematic diagram of the wavelength bands widely used in C-Band DWDM, sorted according to the 8-wavelength tunable EML. 40 wavelengths (100 GHz spacing) from 1529.55 nm (196.0 THz) to 1560.61 nm (192.1 THz) are grouped into 5 groups by 8 wavelengths. In this paper, λ1 and λ2 are counted from the shortest wavelength in each group of 8 wavelengths, and the longest wavelength is defined as λ8.

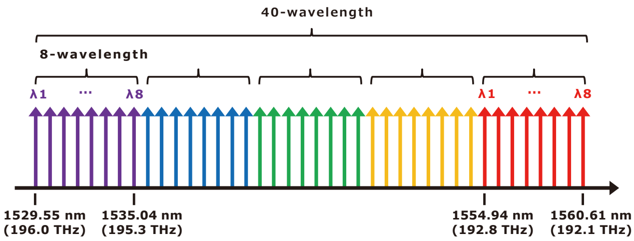


Fig. 1. Wavelength groups

3. Device Design

The laser chip was designed with a size of 1.25 × 0.25 mm, which corresponds to about 1/5 the footprint of a typical full-band tunable laser, and can be mounted on a conventional compact transmitter optical sub-assembly (TOSA) as shown in Photo 1.

Figure 2 shows a block diagram of the prototype optical transceiver. The 25 Gbit/s electrical signal input from the host equipment to the optical transceiver is re-timed by the clock data recovery (CDR), amplified by the laser driver, and converted to an optical signal by the EML inside the TOSA. The EML is temperature-controlled by a small Peltier cooler inside TOSA. In addition, the current is applied to 3 sections of the EML, the gain section, and two heaters for wavelength control, respectively. The received 25 Gbit/s optical signal is converted to an electrical signal by the APD inside the receiver optical sub-assembly (ROSA), amplified by the transimpedance amplifier (TIA), re-timed by the CDR, and transmitted to the host equipment. The prototype optical transceiver is equipped with a wavelength self-tuning function compliant with SmartTunable Multi Source Agreement (SmartTunable MSA)*7.

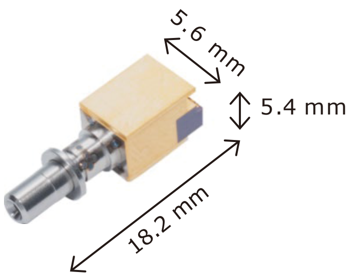


Photo 1. Small package size TOSA

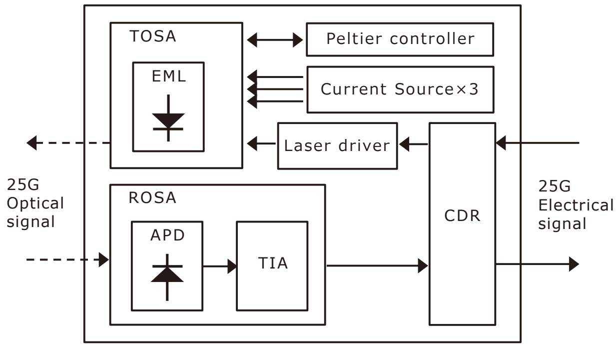


Fig. 2. Block diagram of optical transceiver

4. Device Static Characteristics

The wavelength tuning characteristics of the laser are shown in Fig. 3. The oscillation wavelength varies linearly with heater power, approximately 0.1 nm/mW, and a wavelength tunable range of more than 8 nm is obtained within the operating power range. Compared to conventional fixed-wavelength DWDM products, the 8-wavelength tunability was successfully achieved with an additional power of less than 80 mW.

Figure 4 shows the optical output power at the front-facet of the EML. The laser temperature during the evalua-

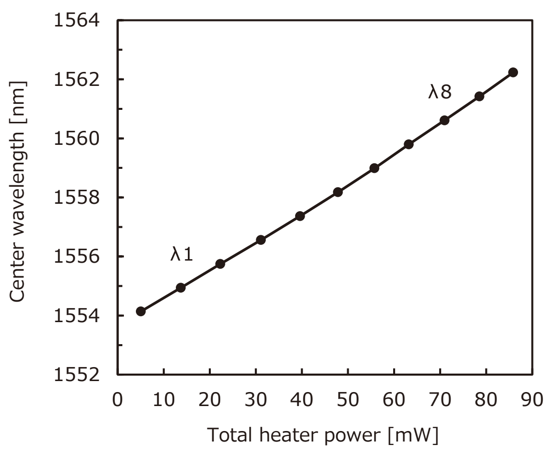


Fig. 3. Wavelength tuning characteristic

tion was 45°C, the laser current was 90 mA, and the modulator voltage was 0 V. Even at the shortest wavelength (λ1), where the difference between the absorption spectral edge of the modulator and the oscillation wavelength of the laser is the smallest, an optical output power of 5 mW or higher is obtained.

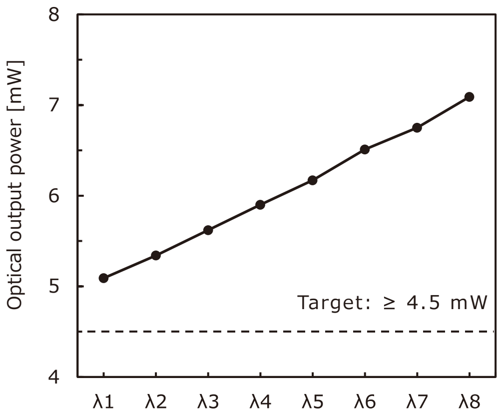


Fig. 4. Optical output power characteristics

Figure 5 shows the optical spectrum. The side-mode suppression ratio is better than 50 dB for all 8 wavelengths, exceeding the target.

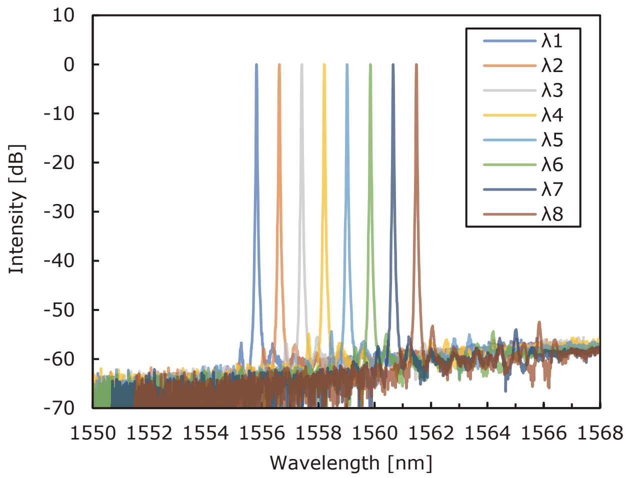


Fig. 5. Optical spectrum

Figure 6 shows the power consumption of the EML at λ1 and λ8 and its breakdown. The laser temperature during the test was 45°C, the laser current was 90 mA, and the modulator voltage was adjusted for each wavelength. Even at the longest wave (λ8), where the heater power is the largest, the total power consumption of the EML chip is 236 mW, satisfying the target specifications in Table 2.

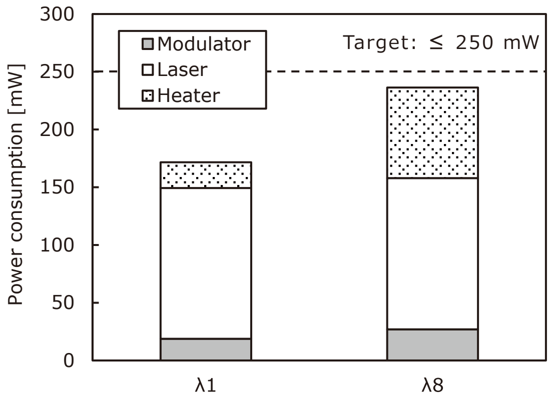


Fig. 6. Power consumption of EML chip

5. Device Dynamic Characteristics

5-1 Transmitter characteristics

Figure 7 shows the average optical output power when modulated in the optical transceiver. The optical output power at all 8 wavelengths satisfies the target specifications in Table 1, and the variation between each wavelength is small, less than 0.2 dB.

Table 3 shows the optical transmitter eye waveforms of the prototype optical transceiver. The data rate is 25.78125 Gbit/s, the signal pattern is Pseudo-Random Bit

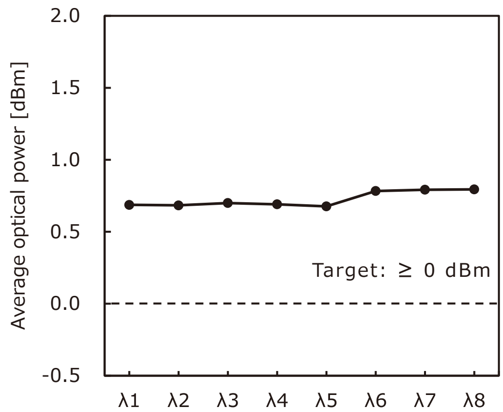
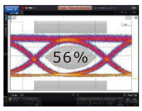
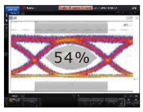
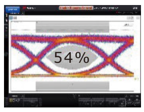
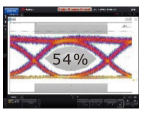
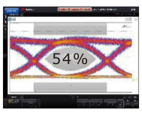
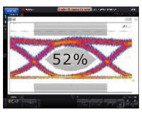
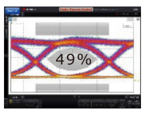


Fig. 7. Average optical power characteristics

Table 3. Transmitter eye waveforms

λ1	λ2	λ3	λ4
 56%	 55%	 54%	 54%
E.R.=9.3 dB	E.R.=9.3 dB	E.R.=9.3 dB	E.R.=9.3 dB
λ5	λ6	λ7	λ8
 54%	 54%	 52%	 49%
E.R.=9.5 dB	E.R.=9.2 dB	E.R.=9.1 dB	E.R.=9.0 dB

(E.R.: Extinction ratio)

Sequence (PRBS)31*8, and the driving amplitude of the modulator is 1.7 Vpp. The extinction ratio achieved is greater than 9 dB for all wavelengths, satisfying the target specifications. Additionally, the mask margin based on the IEEE802.3cc 25GBASE-LR standard is obtained to be 49% or higher for all wavelengths, resulting in a clear eye opening.

5-2 Receiver characteristics

Figure 8 shows the test system for the receiver characteristics; a bit error rate tester was used to generate the 25.78125 Gbit/s signal and to measure the bit error rate, which was evaluated by self-loopback.

Figure 9 shows the results of the bit error rate test, and Fig. 10 shows the relationship between the minimum receiver

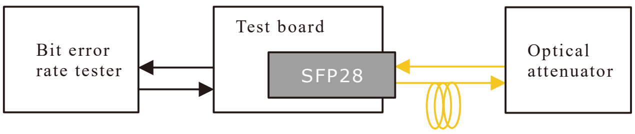


Fig. 8. Receiver characteristics test system

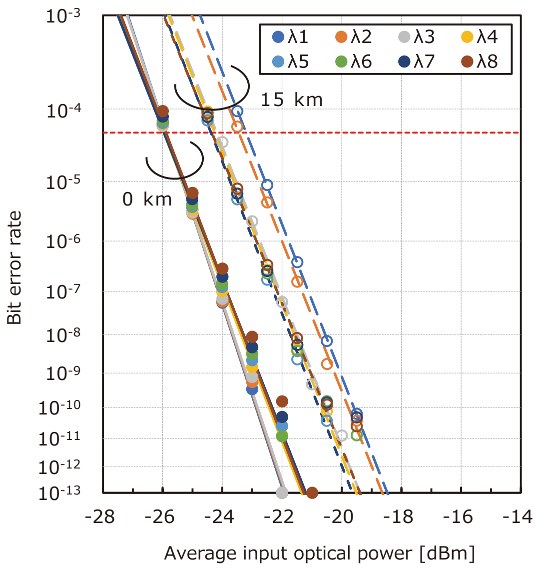


Fig. 9. Bit error rate characteristics

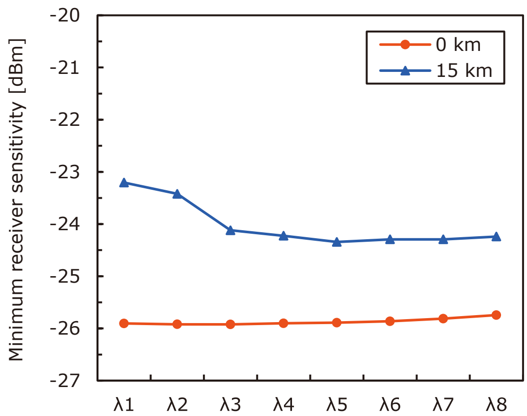


Fig. 10. Transmitter wavelength and minimum receiver sensitivity

sensitivity at which the bit error rate is 5×10^{-5} and the transmission wavelength. The transmission distance is 0 km or 15 km. The minimum receiver sensitivity after 15 km transmission was well below -23 dBm for all 8 wavelengths. When combined with the transmission characteristics in 5-1, the loss budget is more than 23.5 dB, well exceeding the target of 19 dB.

5-3 Self-tuning characteristics

Figure 11 shows a test system for wavelength self-tuning time, which is the time needed for the paired transceivers to complete wavelength tuning according to the algorithms specified in SmartTunable MSA. The transmission signal of an optical transceiver was input to a wavelength tunable filter and was paired with another optical transceiver. The center wavelength of the wavelength tuning filter was randomly set from λ1 to λ8 each time, and the wavelength self-tuning time until the wavelengths of the two units were fixed was measured 100 times in total. As shown in Fig. 12, the average wavelength self-tuning time was 15 seconds, and the maximum was 28 seconds. Taking advantage of the 8-wavelength tunable concept, the wavelength self-tuning time, which took up to 5 minutes for Full-Band Tunable products, was significantly reduced.

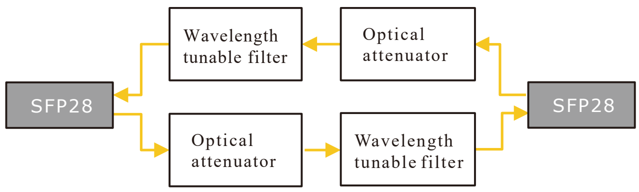


Fig. 11. Test system of self-tuning time

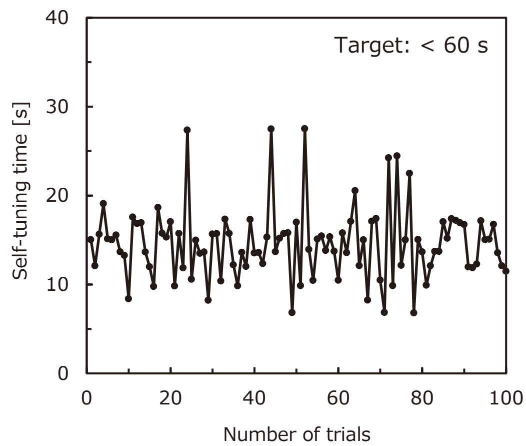


Fig. 12. Self-tuning time test results

6. Conclusion

We have developed a compact and low power consumption 8-wavelength tunable EML that is ideal for mobile fronthaul. We have fabricated a prototype SFP28 combined with our high-sensitivity APD receiver and confirmed that it meets the various characteristics required by the market. The developed wavelength tunable EML is also promising for application to Next Generation Passive Optical Network 2 (NG-PON2)*[9] and future update to 200 Gbit/s (8 wavelength × 25 Gbit/s) in fiber-to-the-home (FTTH)*[10] by further increasing the output power.

Technical Terms

*1 Evolved Common Public Radio Interface (eCPRI): An Ethernet-based communication standard used for communication between radio base stations and antennae.

*2 Small Form-factor Pluggable (SFP28): One of the industry standards for 25GbE-compliant compact optical transceivers. The transmission speed is 25 Gbit/s.

*3 Institute of Electrical and Electronics Engineers (IEEE): An association that develops standards for electrical and electronic engineering.

*4 International Telecommunication Union Telecommunication Standardization Sector (ITU-T): A division of the International Telecommunication Union. It is responsible for the standardization of telecommunications.

*5 O-RAN ALLIANCE: An organization that standardizes specifications for wireless access networks to promote openness and virtualization of the networks.

*6 Conventional-band (C-Band): One of the wavelength bands used in optical communications. Wavelengths range from 1530 to 1565 nm.

*7 SmartTunable Multi Source Agreement (SmartTunable MSA): A standard for wavelength self-tuning features implemented in tunable transceivers.

*8 Pseudo-random bit sequence (PRBS)31: PRBS31 is a random signal sequence with a period of 2^{31}-1.

*9 Next Generation Passive Optical Network 2 (NG-PON2): A communication standard for access networks that supports a downlink transmission capacity of 40 Gbit/s by four-wavelength multiplexing at a transmission rate of 10 Gbit/s per wavelength.

*10 Fiber-to-the-home (FTTH): Communication service for the home using optical fiber.

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