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25 Gbps Optical Receiver with Waveguide Avalanche Photodiode

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Mobile networks are shifting to the fifth-generation mobile communication system (5G) to address the need for increasing data traffic associated with the spread of high-performance mobile terminals and the diversification of services provided. 25 Gbps optical transceivers are used in 5G mobile fronthaul, and wavelength division multiplexing is widely used to expand transmission capacity. We have developed a new optical receiver that can be integrated into a 25 Gbps DWDM transceiver by combining our CAN-type optical receiver and edge-illuminated waveguide APD chip for C-Band. This paper presents the design and performance of the new optical receiver.

Keywords: 25 Gbps, high responsivity, wide bandwidth, waveguide APD

1. Introduction

With the widespread use of high-performance mobile terminals, such as smartphones and tablet PCs, high-quality internet content has become commonplace. Communication traffic is rapidly increasing with the expansion of IoT*1 in various fields, and the diversification and enhancement of the services provided. Recently, a shift from 4G to 5G has been underway, and the demand for higher communication speeds and capacity is increasing.

The interface between antennas and base stations in the transmission network (mobile fronthaul) is connected by optical fibers. 25 Gbps optical communication is introduced with the shift to the 5G system, and for optical transceivers, one of its key components, compact products such as SFP28*2 modules are widely used. In addition, wavelength division multiplexing (WDM), which multiplexes optical signals of different wavelengths through a single optical fiber for transmission, is widely used to expand transmission capacity.

Sumitomo Electric Device Innovations, Inc. has already developed a CAN-type optical receiver[1] and an edge-illuminated waveguide APD chip[2],[3] for C-Band.*3 Combining these techniques, we have developed a new optical receiver for 25 Gbps DWDM*4 SFP28. This paper describes the design and performance of the new receiver.

2. Target Specifications

Photo 1 shows the appearance of an SFP28 module. Since the optical transmitter and receiver are installed side by side in an SFP28 module with a width of 13.8 mm, the target width of the receiver is set to 6 mm, half the width of an SFP28 module, or less.

The target specifications set for developing the optical receiver are shown in Table 1. Based on the IEEE*5 standards and the MSA,*6 and considering market demand, we have set our target specifications.

Since the mobile fronthaul is normally installed outdoors, it is necessary to operate in the industrial temperature (I-Temp) range from -40 to +85°C.

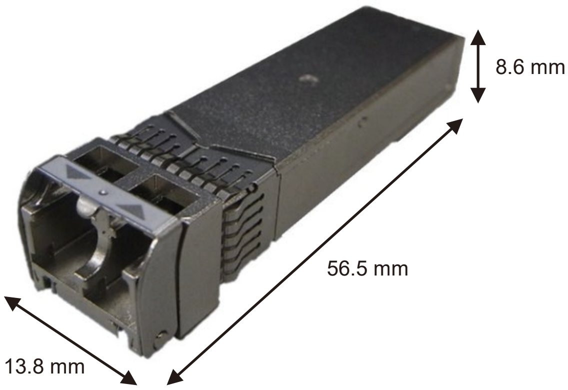

Photo 1. SFP28 module

Table 1. Target specifications

Parameter	Specification	Unit
Operating temperature	-40 ~ 85	°C
Data rate	25.78125	Gbps
Modulation method	NRZ	-
Transmission distance	2 m ~ 10 km	-
Wavelength	1528 ~ 1567	nm
Receiver sensitivity†	< -19	dBm

† Average optical input power with a bit error rate of 5×10^{-5}

3. Structure of APD

As shown in Fig. 1, photodiodes used for optical communications are generally divided into two types according to their shape: surface-illuminated and edge-illuminated.

The surface-illuminated type easily achieves high responsivity by forming a large-diameter photo-detection area; while it is subject to a tradeoff between the bandwidth and responsivity due to an increase in the junction capacitance of photodiode (PD). On the other hand, since the edge-illuminated type has a structure in which the direction of incident light is different from the traveling direction of the optical current, it has a great advantage in that the length and thickness of the absorption layer can be independently designed from both electrical and optical viewpoints—in other words, the responsivity and bandwidth can be independently designed.

However, the edge-illuminated type has a structural disadvantage in that it is difficult to achieve high optical coupling efficiency because the photo-detection area is inevitably small. We have achieved both the wide bandwidth and high responsivity by integrating a waveguide with a spot-size converter (SSC)*7 into the light-receptive part of the edge-illuminated APD, expanding the mode field diameter (MFD) on the plane of incidence, and improving optical coupling tolerance.

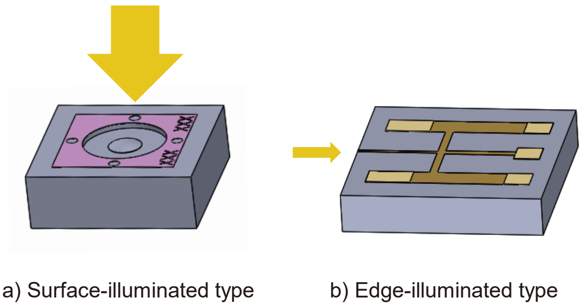

Fig. 1. Type of photodiode

The appearance of the APD chip we have developed is shown in Fig. 2, and the structural cross-section is shown in Fig. 3.

This APD includes the waveguide, which propagates the incident optical signal to the APD absorption layer, and the APD chip, which converts light into electricity. They are integrated on a single chip using InP-based monolithic integration technologies.[4] We have achieved high responsivity by directly connecting the waveguide and the APD absorption layer with a butt-joint growth technique.

We have also achieved wide bandwidth through the reduced capacitance due to the downsized p-n junction region and the reduced carrier transit time in the thinner absorption layer. The voltage required for APD multiplication can be lowered, contributing to lower power consumption.

In addition, the edge-illuminated type can secure a sufficient absorption layer length and it is difficult to concentrate the electric field in the layer, leading to high input breakdown voltage.

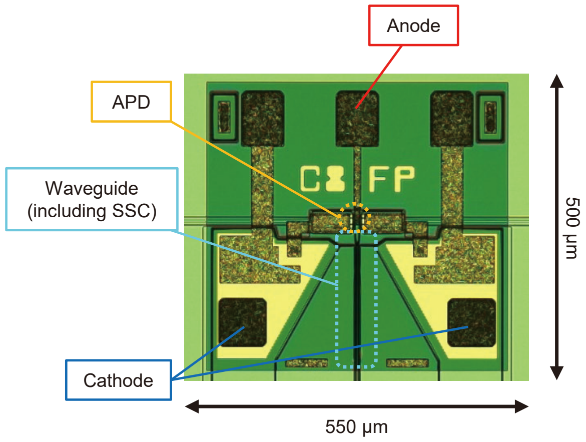

Fig. 2. APD chip appearance

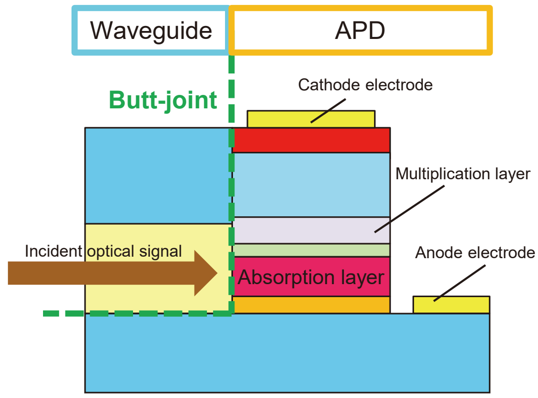

Fig. 3. Structural cross-section of APD

4. Structure of Optical Receiver

Photo 2 shows the appearance of the optical receiver. Its diameter of 5.6 mm and length of 14.8 mm are small enough to be implemented in a small optical transceiver SFP28.

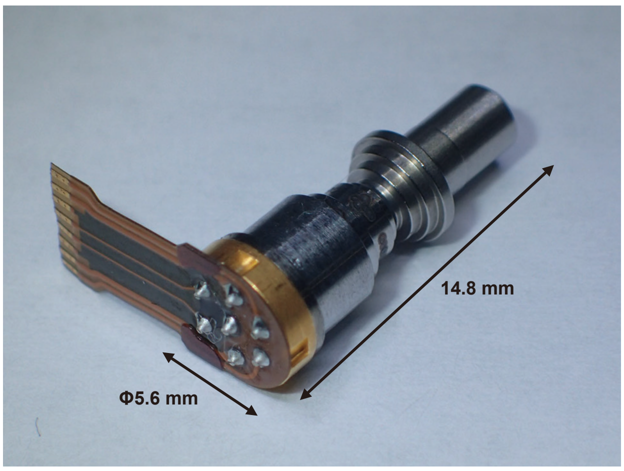

Photo 2. Optical receiver

The structure of the optical receiver is shown in Fig. 4. It consists of an LC receptacle equipped with a single mode fiber (SMF) stub, flexible printed circuits (FPC) that provide an electric connection with a transceiver, and package equipping chip components such as APD and a trans-impedance amplifier (TIA), as well as lenses.

The optical signal entering the receptacle is converted to collimate light by the 1st lens integrally molded in the cap, and then concentrated into the APD chip by the 2nd lens, which is placed close to the APD chip. The optical signal is converted into electrical current by APD, then converted into a voltage signal and amplified by the TIA. After passing through the package and high-frequency line on the FPC, the signal is transmitted to the optical transceiver.

This receiver adopts a two-lens coupling system consisting of 1st and 2nd lenses to suppress the decrease of coupling efficiency due to fixed misalignment of the lenses. The calculation results of the 1st lens tolerance are shown in Fig. 5. The peak coupling efficiency is about 98%, and a high coupling efficiency of about 90% is achieved even at a lens offset of 40 µm. This not only suppresses the decrease in coupling efficiency due to the misalignment of the lenses but also is effective in reducing fluctuations of coupling efficiency against ambient temperature changes.

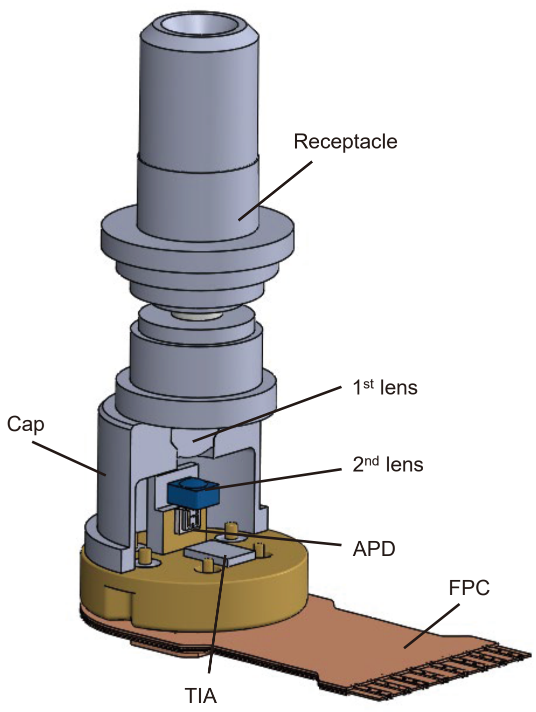

Fig. 4. Structure of optical receiver

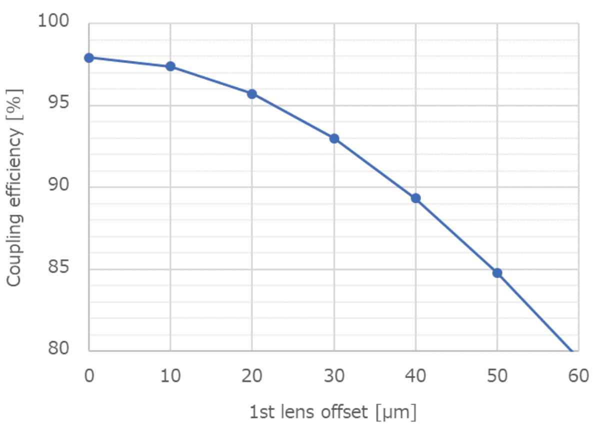

Fig. 5. Calculation results of 1st lens tolerance

5. Characteristics of Optical Receiver

5-1 Dark current and photocurrent

Figure 6 plots dark current and photocurrent at a temperature of 25°C, at an optical input power of 10 µW, and at an optical input wavelength of 1.55 µm. Its breakdown voltage was about 22 V, and it achieves low dark current characteristics of 2 nA or less at an applied voltage of about 19 V, equivalent to 90% of the breakdown voltage. In addition, the responsivity was 0.8 A/W at an applied voltage of about 9 V corresponding to a multiplication factor of 1.

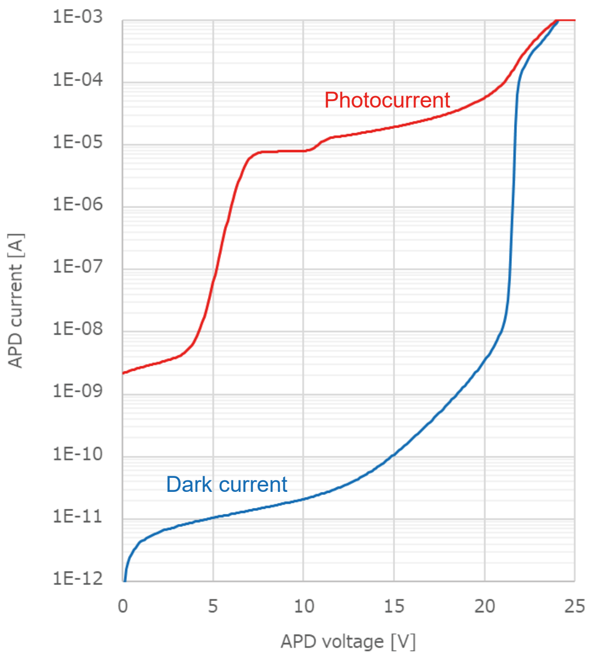

Fig. 6. Dark current and photocurrent

5-2 Frequency response

Figure 7 plots the frequency response of optoelectronic conversion gain at a temperature of 25°C, at an optical input power of 10 μW, and at an APD multiplication factor of 5. The 3 dB bandwidth (BW) was about 14 GHz, which is sufficient for receiving NRZ-modulated signals at a symbol rate of 25 Gbps.

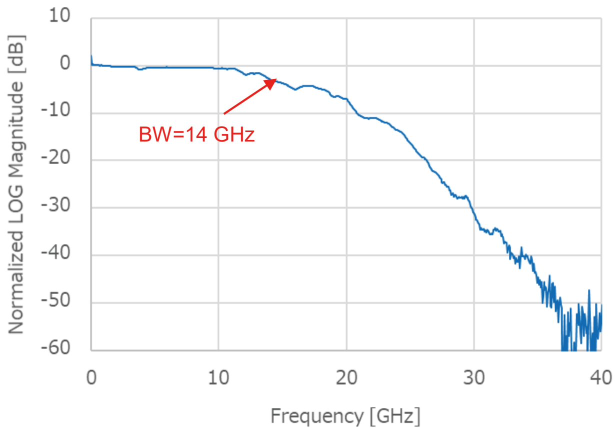

Fig. 7. Frequency response of optoelectronic conversion gain

5-3 Receiver sensitivity characteristics

Figure 8 plots the bit error rates (BER) for 25.78125 Gbps PRBS31*8 NRZ signal after transmission over 0 and 10 km at a temperature of 25°C. As a light source, we used an in-house 25 Gbps optical transmitter module employing an electro-absorption modulator integrated into laser diode.(5) The receiver sensitivity at a bit error rate of 5×10^{-5} was measured to be -24 dBm or less after transmission over both 0 and 10 km with a margin of 5 dB or more for the target value of -19 dBm. The deterioration of the receiver sensitivity (transmission penalty) after transmission over 10 km was 0.7 dB, exhibiting favorable characteristics.

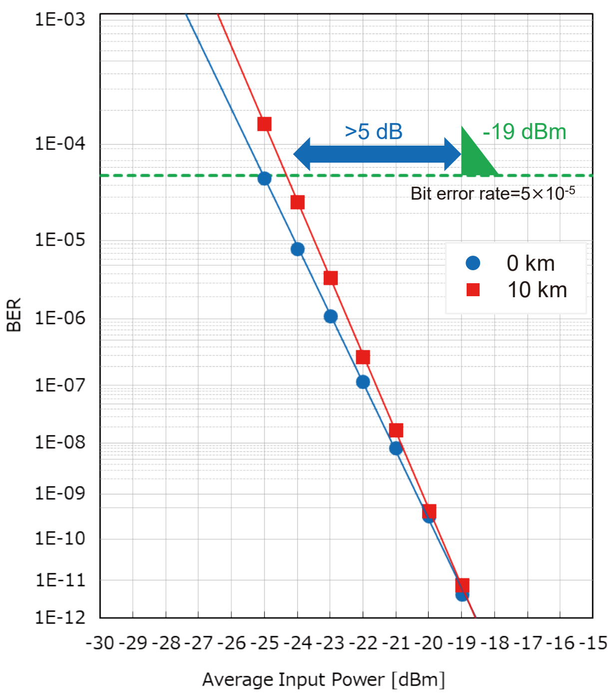

Fig. 8. Bit error rate

5-4 Temperature characteristics of receiver sensitivity

Figure 9 plots the temperature characteristics of receiver sensitivity at temperatures from -40 to 85°C. The receiver sensitivity was -23 dBm or less after transmission over both 0 and 10 km, securing a margin of 4 dB or more for the target value of -19 dBm with temperature fluctuations taken into account.

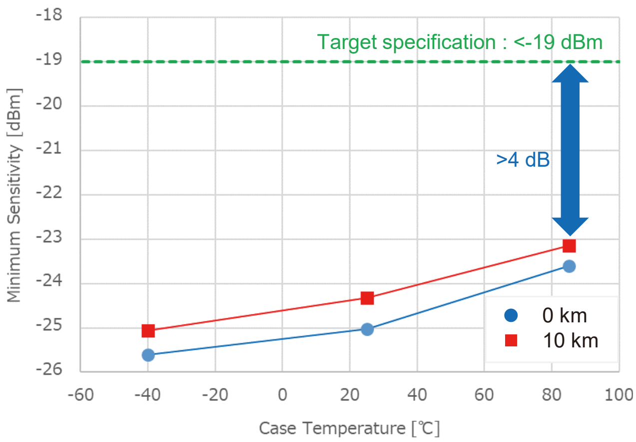

Fig. 9. Temperature characteristics of receiver sensitivity

6. Conclusion

We have developed an optical receiver for 25 Gbps DWDM that can be mounted in SFP28 modules. Equipped with our edge-illuminated waveguide APD chip, the receiver has achieved both the wide bandwidth and high responsivity. The receiver sensitivity for 25.78125 Gbps NRZ signals after transmission over 10 km is -24 dBm or less, and -23 dBm or less even at temperatures from -40 to 85°C, exhibiting favorable characteristics.

Technical Terms

∗1 IoT (Internet of Things): A system of internet-connected objects (Things) that exchange information and interact and cooperate with each other.

∗2 SFP28 (small form-factor pluggable 28): A multi-source agreement of small optical transceivers compatible with 25 GbE. The data transmission rate is 25 Gbps.

∗3 C-Band (conventional band): A wavelength band used for optical communications. Its bandwidth ranges from 1,530 to 1,565 nm.

∗4 DWDM (dense wavelength division multiplexing): A subset of wavelength division multiplexing. It uses the 1.5 µm band (C-Band) and the wavelength spacing is about 0.4 nm.

∗5 IEEE (The Institute of Electrical and Electronic Engineers): An organization that makes standards for electrical and electronic engineering.

∗6 MSA (multi-source agreement): An agreement among vendors to manufacture parts which are compatible across vendors.

∗7 SSC (spot-size converter): A waveguide structure that has a function to convert the input/output light beam shape.

∗8 PRBS31 (pseudo-random bit sequence 31): A pseudo-random bitstream with a sequence length of 2^{31}-1.

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