Compact Integrated APD ROSA for QSFP28

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1. Background

The continuous increase in communication traffic requires faster, higher-capacity optical communication devices. The demand for high-speed optical transceivers that operate at 100 Gbit/s is growing. Currently, the industry-standard CFP transceivers(1) constitute the majority of the optical transceiver market; at the same time, development is underway on the QSFP28 (quad small form factor pluggable), which will be approximately one-fourteenth the volume ratio. CFP transceivers supporting transmission distance of the 40-km has a significant transmission loss due to long distance optical fiber transmission. Therefore, it is necessary to use a semiconductor optical amplifier (SOA) in front of a photodiode (PD) receiver optical subassembly (ROSA), hindering downsizing. Against this backdrop, a study was started on 40-km transmission using an avalanche photodiode (APD) ROSA alone, and was standardized by ITU-T for 4L1-9D1F in G.959.1. (2) Table 1 shows the specifications. This article describes the development of an APD ROSA that complies with the standard and is capable of being applied to a QSFP28 by speeding up the APD.

Table 1 Target specifications of the APD ROSA

Bit rates		27.95249 Gbit/s
Wavelength	Lane 0	1294.53 – 1296.59 nm
	Lane 1	1299.02 – 1301.09 nm
	Lane 2	1303.54 – 1305.63 nm
	Lane 3	1308.09 – 1310.19 nm
Minimum receiver sensitivity		−18.9 dBm

2. Configuration of the APD ROSA

Figure 1 shows a schematic view of the APD ROSA configuration. Received signals are optical signals multiplexed using four different wavelengths. An optical signal is converted to collimated light using a collimating lens, and is separated into four signals with different wavelengths by a demultiplexer. The separated optical signals are concentrated into the APD of each Lane by four lenses. In the APD, the optical signal is amplified and converted to an electric current, which is then converted to a voltage signal by a transimpedance amplifier (TIA) to be output from a ROSA.

3. Designing the APD

To achieve high receiver sensitivity, a wide bandwidth, high responsivity, and low dark currents necessary for operation at 28 Gbit/s even when using an APD alone are required. Figure 2 shows a schematic view of the APD configuration using a planar backside illumination structure. In the planar structure, a p-n junction is partially formed in the epilayer. As the structure can easily prevent the degraded p-n interface from being exposed to the outside, so that the dark currents can be reduced. Furthermore, the backside illumination structure light to enter from the back of the substrate to an absorption layer that formed on the substrate surface using epitaxy. Light that has passed through the absorption layer is reflected by the mirror on the outermost surface and then is absorbed again in the absorption layer, thus increasing the sensitivity.

When designing the device considering the receiver sensitivity and bandwidth, the thicknesses of the

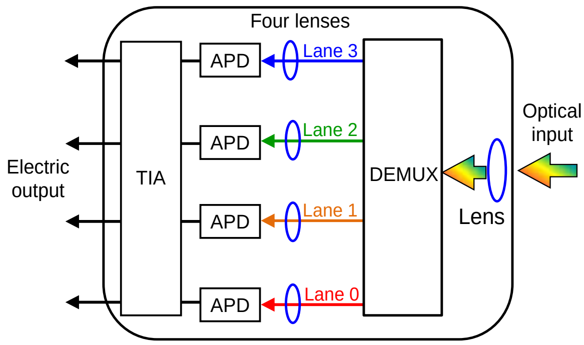

Fig. 1 Components of the APD ROSA

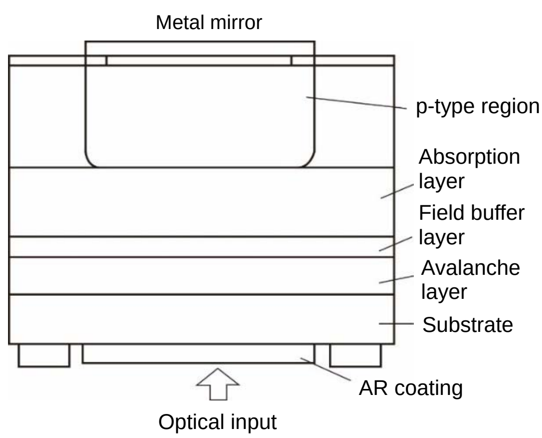

Fig. 2 Structure of the APD

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avalanche layer and absorption layer are important. The drift velocity of holes is slow compared with that of electrons, and thus the multiplication of holes deteriorate the bandwidth. When the avalanche layer is made thinner, the multiplication of holes can be suppressed, thereby improving the bandwidth. This means that a thin avalanche layer is desirable for broadening the bandwidth. However, the thin avalanche layer has the disadvantage that the dark currents increases. For the avalanche layer of the APD, a thickness that can balance the properties between the bandwidth and dark currents has been chosen. Figure 3 shows the calculation results of the absorption layer thickness and the 3-dB frequency bandwidth at a multiplication factor of 10. The absorption layer thickness was determined to be 600 nm, which maximizes the bandwidth, to 18.5 GHz. With this thickness, a favorable responsivity at approximately 0.8 A/W can be achieved.

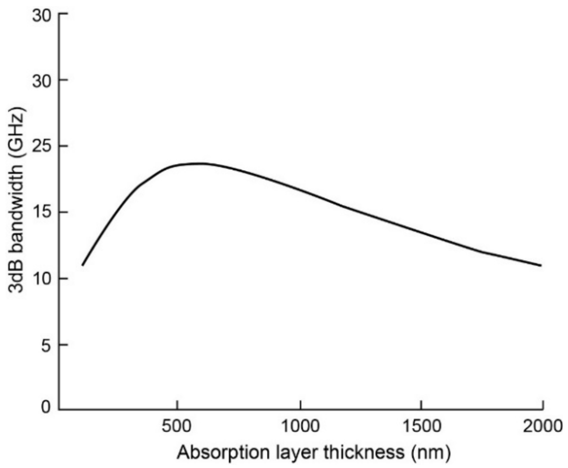

Fig. 3 3-dB down bandwidth versus absorption layer thickness

4. Design of the APD ROSA

To achieve the desired minimum receiver sensitivity, it is important to reduce the optical loss of the ROSA and to secure the optical isolation of adjacent lanes, which are both largely dependent on the demultiplexer. The optical loss should be as small as possible. Therefore, the target value was set to 1.0 dB or less. It is necessary to reduce the optical isolation to a level at which the receiver sensitivity does not deteriorate due to the effects from an adjacent lane. Figure 4 shows a graph of the penalty calculation results for optical isolation. If the optical isolation is 27 dB, the penalty is 0.05 dB or less. Based on these considerations, we used an optical filter with an optical loss of 1.0 dB and optical isolation of 27 dB. The demultiplexer has a structure in which four optical filters were attached to a glass prism.

Figure 5 shows a graph of the calculation results of the demultiplexer spectrum properties. The shaded areas represent the regions with the optical loss at 1.0 dB and optical isolation at 27 dB in the wavelength bandwidth of each lane. For each lane, the filter loss did not exceed 0.6 dB, and the optical isolation from adjacent lanes was at least 30 dB, satisfying the target.

5. Properties of the APD and APD ROSA

Figure 6 shows a graph of the frequency response properties of the APD. With 10 as the multiplication factor, 18 GHz, which is close to the calculated value, was

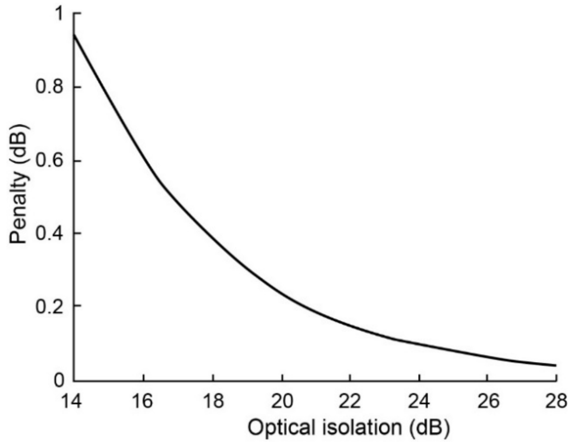

Fig. 4 Penalty versus optical isolation

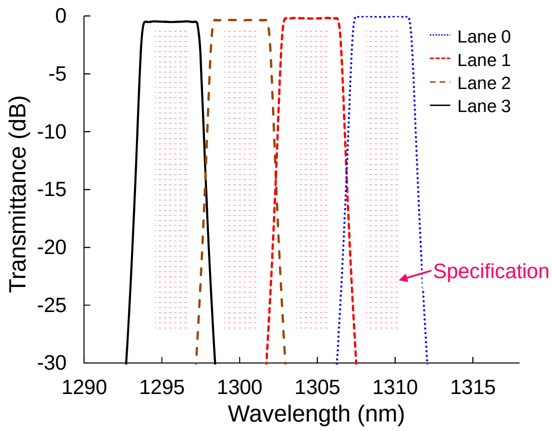

Fig. 5 Spectrum characteristics of the demultiplexer

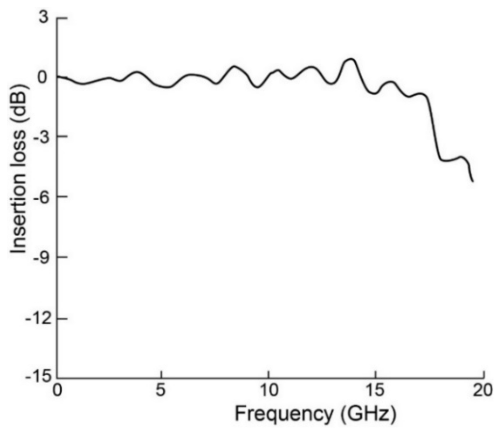

Fig. 6 Insertion loss versus frequency

achieved in the 3-dB bandwidth.(3)

Figure 7 shows a graph of the evaluation results of the demultiplexer transmission spectrum. The loss at the demultiplexer did not exceed 0.5 dB, and the optical isolation was at least 30 dB, showing that the designed properties were obtained.

Figure 8 shows a photo of the APD ROSA. The external dimensions are 24.6×6.55×5.1 mm, allowing the device to be mounted on a QSFP28.

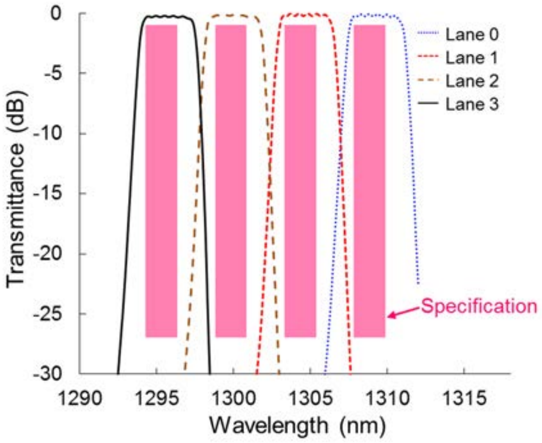

Fig. 7 Spectrum characteristics of the demultiplexer

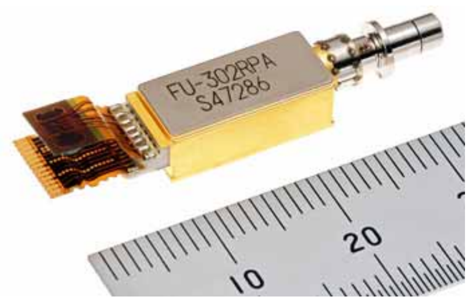

Fig. 8 Photograph of the APD ROSA

Figure 9 shows a graph of the bit error ratio (BER) when the ROSA temperature was 25°C. The light source was modulated at a rate of 27.95249 Gbit/s and with the PRBS2^{31}-1 pattern. The optical signal extinction ratio for Lanes 0 to 3 is 8.9, 10, 9.2 and 9.6 dB, respectively. The APD voltage was set to 19 V for all lanes. The minimum receiver sensitivity at an error ratio of 10^{-6}, making an allowance for error correction, was −23.7, −24.6, −24.5 and −24.4 dBm for Lanes 0 to 3, respectively. This satisfied the standard specification.

Figure 10 shows the minimum receiver sensitivity when the ROSA temperature was changed from −5°C to 80°C. While the receiver sensitivity dropped to the lowest at 80°C, Lanes 0 to 3 were −22.8, −23.6, −23.8 and −23.7 dBm, respectively, showing that favorable results satisfying the standard specification were obtained. The maximum power consumption was 0.42 W, which is low enough for the device to be applied to a QSFP28.

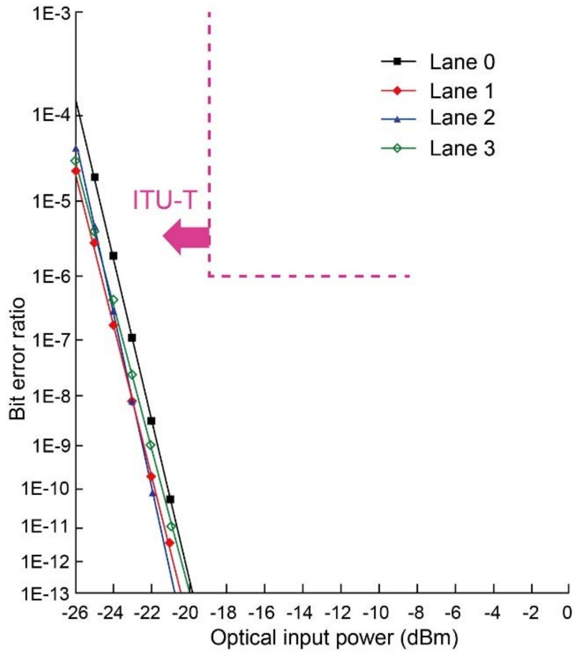

Fig. 9 Bit error ratio

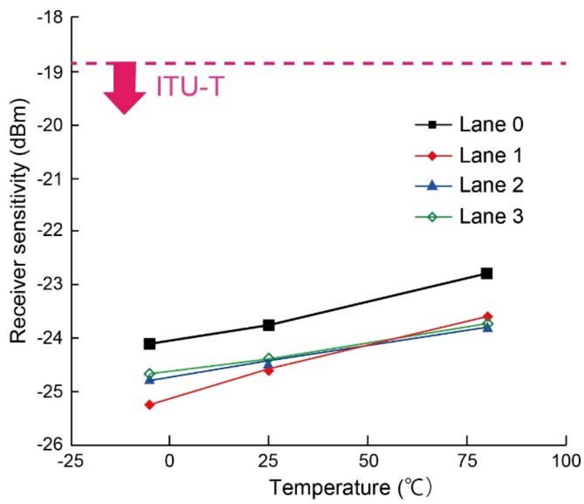

Fig. 10 Minimum receiver sensitivity versus temperature

6. Conclusion

We have developed a 100 Gbit/s integrated APD ROSA for 40-km transmission. With downsized external dimensions of 24.6×6.55×5.1 mm and very low maximum power consumption of 0.42 W, the device is suitable for applying to a QSFP28. The minimum receiver sensitivity of achieved −22.8 dBm when the ROSA temperature was changed from −5°C to 80°C, satisfy the ITU-T standard specification.

References

(1) CFP-MSA: http://www.cfp-msa.org
(2) ITU-T G.959.1: http://www.itu.int/en/ITU-T
(3) Takemura, R., et al.: "Resonant Cavity 25Gbps APD for high responsivity and low dark current," IEICE General Conference C-4-2 (2016)