Development of Single-Package 1.3/1.49 μm Bi-directional Device

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Optical access services are expanding quickly in Japan and North America. Passive optical network (PON) systems that allow one optical fiber to be shared between two or more users at low service prices have been adopted in optical access services. Sumitomo Electric is one of the manufacturers of Bi-directional transceiver devices used in PON systems. On the other hand, in the case of systems for supporting point-to-point communication schemes such as Ethernet where two optical fibers are generally used for transmission and reception, there is rising demand for transceivers that use one fiber in different wavelengths. In order to satisfy this market demand, Sumitomo Electric has developed a new transceiver device design. Compared to the conventional transceiver design composed of separate packages, the new "one package" design realizes a capacity reduction of about 30%. This paper reports on Sumitomo Electric's development of optical network unit (ONU) and optical line terminal (OLT) products for gigabit Ethernet communication systems using the new transceiver design.

1. Introduction

Optical access services are expanding quickly in Japan and North America. Passive optical network (PON) systems that allow a single optical fiber to be shared between two or more users at low service prices have been adopted in optical access services. Sumitomo Electric is one of the manufacturers of bi-directional transceiver devices used in PON systems [(1)-(5)].

On the other hand, in the case of systems for supporting point-to-point communication schemes such as Ethernet that generally uses two optical fibers, one for transmission and the other for reception, there is a rising demand for transceivers that use one fiber in different wavelengths. In order to satisfy this market demand, Sumitomo Electric has developed a new transceiver device design. Compared to the conventional transceiver design composed of separate packages, the new "single-package" design realizes a volume reduction of about 30%. This paper reports on Sumitomo Electric's new transceiver design for optical network unit (ONU) and optical line terminal (OLT) products for 1.25 Gbps Ethernet.

2. Fundamental structure of "single-package" transceiver device

The target specifications are listed in **Table 1**. **Photo 1** shows the appearance of the newly developed "single-package" transceiver device and that of the conventional one for comparison purpose.

All of the functional components, which are a LD on a heatsink, a detector PD on a submount, a TIA, a monitor PD, a WDM filter, and a CUT filter, are mounted in a compact 5.6-mm-diameter package as shown in **Fig. 1**.

Optical output into and optical input from a single mode fiber (SMF) are both directed through a ball lens mounted on top of the cap shell. This has realized the reduction of the size and cost of a transceiver device. The output and input functions and a WDM filter are assembled in a single package, so the number of packages and lenses are decreased and the space occupied by filters is reduced.

In the ONU device, a 1310 nm Fabry-Perot LD (FP-LD) is used as the transmitter and the wavelength of the receiver is around 1490 nm. In the OLT device, a 1490 nm distributed feedback LD (DFB-LD) is used as the transmitter and the wavelength of the receiver is 1310 nm.

Table 1. Target specifications

		ONU/OLT
Transmission rate	Transceiver	1.25Gbps
	Receiver	1.25Gbps
Output power		-3dBm @Ith+20mA
Minimum sensitivity		-23dBm

Photo 1. Outside appearance of new and current products

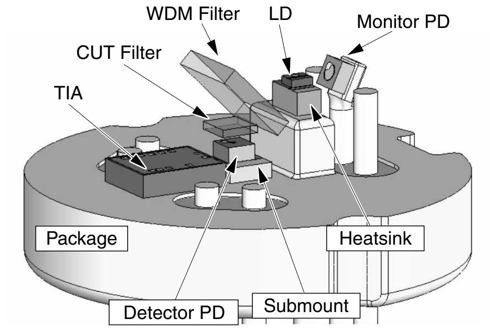

Fig. 1. Construction of one package

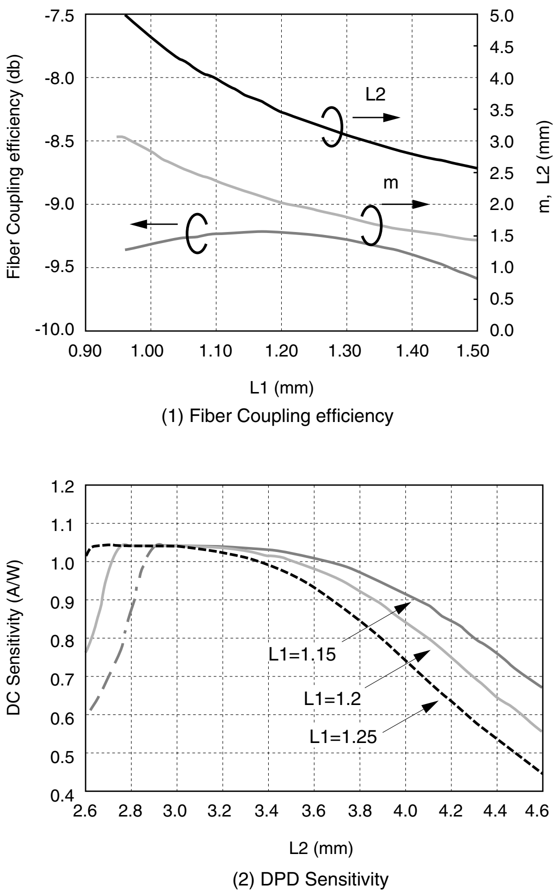

Fig. 3. Optical simulation

3. Optical design of "single-package" transceiver device

The output from the LD enters the WDM filter at an angle of 45 degrees and is reflected to the direction of the SMF. After the spot size of the said output is converted by a ball lens, it is then coupled into the core of the SMF. On the other hand, the input from the SMF is focused by the same ball lens, passes through the WDM filter and the CUT filter, and then is received by the detector PD as shown in **Fig. 2**.

The optical path from the SMF to the WDM filter surface through the ball lens is utilized for both the output and the input, so the layout of the parts can be simplified. The simulation results for optical lengths L1 and L2 are shown in **Figs. 3** (1) **and 3** (2), respectively.

The distance between the LD and the ball lens, which is represented as L1, needs to be more than 1 mm so that the WDM filter can be placed within this length. Thus L1 is designed to be 1.2 mm, and for achieving the target output power, it is determined that the fiber coupling efficiency is -9.0 dB and the optical magnitude of the lens (the m value) is 2.0. From **Fig. 3** (1), L2 is designed as around 3.5 mm. Even with the tolerances for L1 (1.15 to 1.25 mm) and L2 (3.3 to 3.7 mm) taken into consideration, it is found that the detector PD (DPD) obtains a DC sensitivity of more than 0.8 A/W and the AC sensitivity requirement of more than -23 dBm is satisfied.

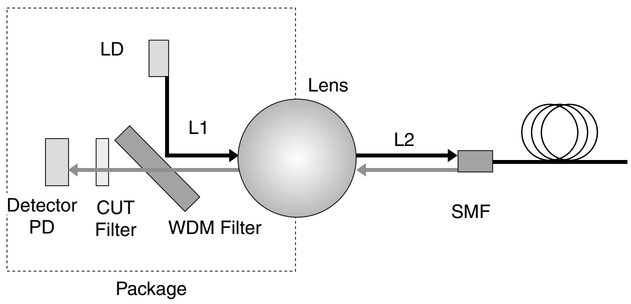

Fig. 2. Conceptual diagram of optical system

4. Crosstalk suppression design

One of the key challenges in developing bi-directional transceiver devices is to suppress crosstalk, because it affects the receiver's characteristics. There are two kinds of crosstalk, due to either an electrical or optical cause under full-duplex operation. In order to suppress crosstalk, both causes should be reduced. Especially in this "single-package" transceiver device, in which an LD and a DPD are mounted close to each other in the same package, crosstalk was one of the most serious problems to be solved.

4-1 Electrical crosstalk

The LD modulation current partly becomes the electric crosstalk in the DPD and raises its noise level, thereby causing the receiver sensitivity to deteriorate. Generally, this noise level should be suppressed to below the receiver sensitivity value of -12 dB. In this development work, the electrical crosstalk was simulated by calculating the electromagnetic field distribution of different package structures and different LD and DPD layouts. **Figure 4** shows the simulation results on two types of package structures (structure A and structure B). In these figures, electromagnetic field distribution is expressed by varying shades of color. The comparison between the results for structures A and B shows that a difference in the distributions of the electromagnetic field generated by the LD can be observed between structures with different ground pin (GND pin) positions. In package structure B that has two GND pins between the transmitter and the receiver, the electromagnetic field stays close to the LD and therefore its adverse effect to the DPD can be well reduced. The electrical signal from the DPD was converted to electromagnetic field through a resistance of 1 kilo-ohm, and the electromagnetic field difference between structures A and B was 27.3 dB.

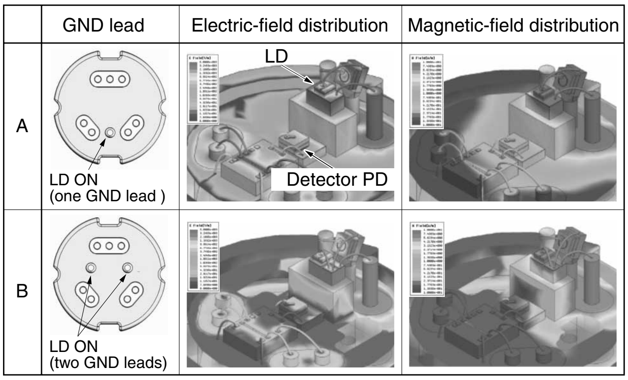

Fig. 4. Electromagnetic field simulation

Based on the results above, **Fig. 5** shows the output of the transimpedance amplifier (TIA) plotted against varying frequencies. At from 1.5 to 2.0 GHz, a maximum TIA output of -90 dBm is obtained with two GND pins, while -75 dBm is obtained with one GND pin. This result indicates that some of the LD modulating current is converted through the package to cause electric crosstalk at the receiver. The GND pins located between the transmitter and receiver areas can effectively change the electro-magnetic field generated by some of the LD modulating current and reduce the electrical noise.

4-2 Optical crosstalk

Optical crosstalk also becomes a kind of receiver noises, when some LD lights which were not coupled into the SMF are received by the DPD. The LD emits

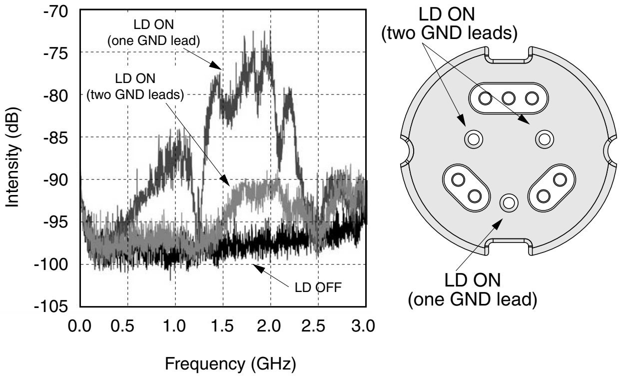

Fig. 5. Electrical crosstalk

light at a divergence angle of 30 to 35 degrees. It is found that the light emitted at a relatively large angle is either not to be reflected at the surface of the WDM filter or reflected to the direction other than that of the lens. In both cases, the light strays in the package.

For the purpose of reducing and absorbing the stray light, two measures were taken. One is that the filter carrier on which the WDM filter and the CUT filter are mounted is placed over the DPD, and the other is that the inner surface of the cap shell is coated with a light absorbing film.

It is confirmed that optical crosstalk is suppressed by 10 dB. As a result of the adoption of filter carrier and coating, an average optical crosstalk of -39 dB and a deviation of σ = 2.6 dB are obtained (in **Fig. 6**).

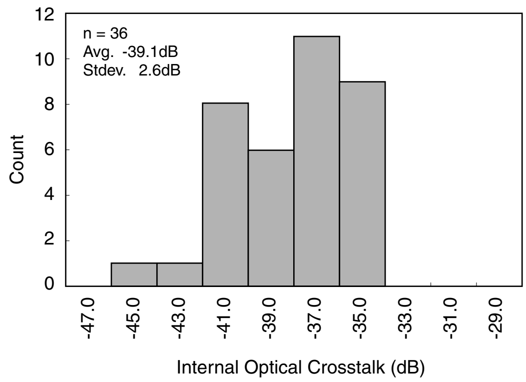

Fig. 6. Optical crosstalk

5. Manufacturing process

First, an LD mounted on a heatsink and a DPD mounted on a submount are soldered with AuSn on a 5.6 mm diameter package. Since both an LD and a DPD are precision mounted using the center of the package virtually estimated from the package's outline as a positioning standard, these two parts can be maintained in their designed relative positions. Next, a monitor PD and a TIA are mounted on the package with resin. Then, all parts are connected electrically with an Au wire to the pin of the package. A filter carrier on which a WDM filter and a CUT filter are mounted is positioned properly with respect to the LD and the DPD, and then fixed using a UV curable resin. After the package is hermetically sealed with a lens cap, a receptacle that guides a ferrule is aligned to the lens cap under SMF coupling power monitoring, and fixed to the outside of lens cap with the UV curable resin.

6. Characteristics

Figure 7 shows the fiber output power distribution of the ONU devices at an operating current 20 mA higher than the threshold current (Iop = Ith + 20mA) and at a temperature of 25 deg. C. The average fiber output power for 30 pieces was -2.9 dBm and its deviation (σ) was 0.12 dBm, while the target fiber output power in the specifications is -3 dBm.

The distribution of DC sensitivity is shown in **Fig. 8**. The average and the deviation were 0.85 A/W and 0.08 A/W, respectively.

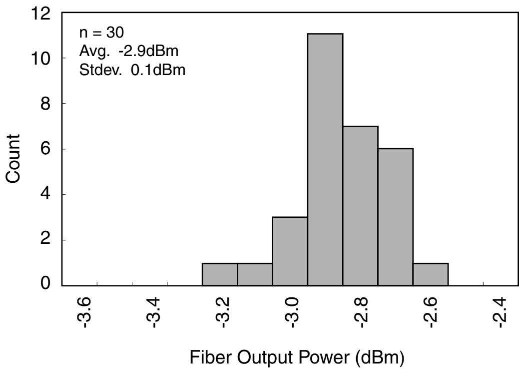

Fig. 7. Output power distribution

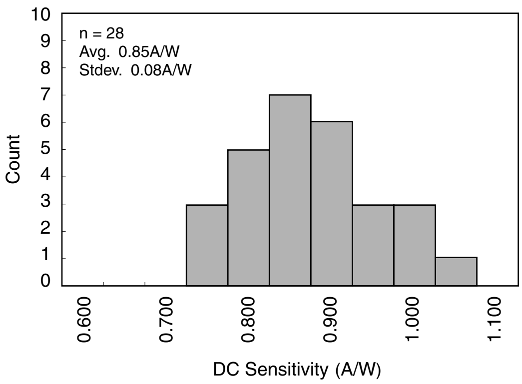

Fig. 8. DC sensitivity

These parameter results confirm that the deviations of the relative mounting positions of the LD and the DPD from the design values have been less than +/-20 μm.

Figure 9 shows the temperature dependence of the central wavelength emitted from the LD when the TIA bias current supply is turned on or off. The wavelength differences between the two cases were around 2 nm, corresponding to the temperature difference of about 4 deg. C. **Figure 10** shows the fiber output power curves. Even in a condition where the TIA is under a bias current, the fiber output power reaches more than 0.5 mW (-3 dBm) in a temperature range from -40 to +85 deg. C.

Tracking error was also measured to confirm whether or not the dislocation of optical axis due to temperature changes is within an acceptable level. The results in **Fig. 11** show that the tracking error, which represents the temperature dependence of output power, was within +/-1 dB in a temperature range of -40

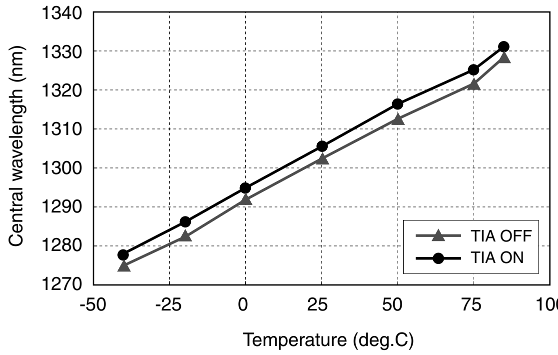

Fig. 9. Central-wavelength at -40 to 85 deg. C when TIA is OFF/ON

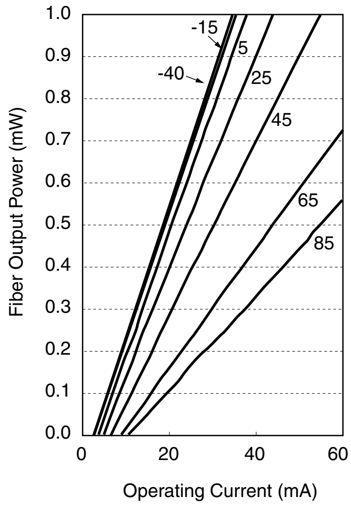

Fig. 10. I-L Characteristics at -40 to 85 deg. C

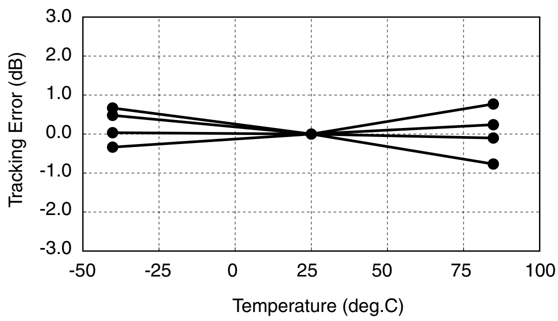

Fig. 11. Tracking error

to +85 deg. C. This indicates that the product whose parts are fixed using a resin can provide a level of performance equivalent to that provided by products made using the YAG welding method over a wide temperature range.

Figure 12 shows the eye diagram of the ONU device with 2^7-1 PRBS at 1.25 Gbps. A good eye opening was observed.

In **Fig. 13**, the bit error rate (BER) curves of the receiver of the ONU device at a DC sensitivity of 0.8 A/W are shown. White circles are the AC sensitivity results when the LD was Off (not operating) and black squares are the data for when the LD was On (operating). In the case of the LD turned Off, the minimum sensitivity at BER = 10^{-10} was -30.4 dBm, while in the case of the LD turned On (full duplex condition) it was -30 dBm The crosstalk penalty which corresponds to the difference between the two values was 0.4 dB. This small crosstalk penalty indicates that the developed single-package bi-directional device suppresses crosstalk well.

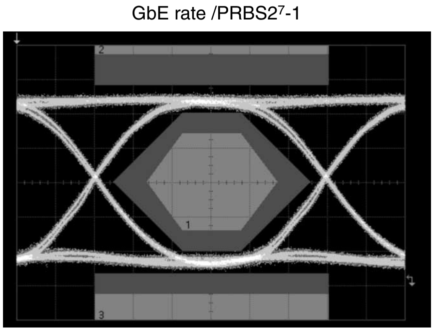

Fig. 12. Transmitter output waveform

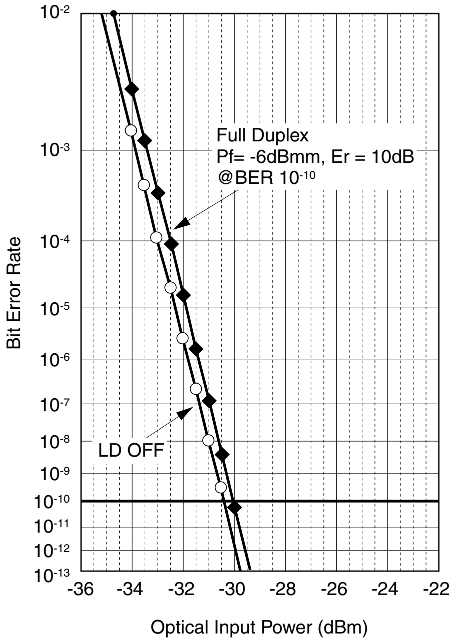

Fig. 13. Bit error rate

7. Conclusion

The authors succeeded in developing a single-package 1.3/1.49um bi-directional device that has an LD and a DPD mounted in a single package and is fixed with a resin. It was confirmed that crosstalk is suppressed well. The stability of optical axis with temperature changes was also confirmed to be at the same level as that of products produced by the YAG welding method. As a result of this development work, a bi-directional transceiver device of the world's smallest size and reduced cost is developed.

References

(1) ITU-T Recommendation G983.1, "Broadband optical access systems based on passive optical networks (PON)" (1998)

(2) T. Kurosaki et al., "Full duplex 1300/1500-nm-WDM optical transceiver modules for ATM-PON systems using PLC-hybrid-integration and CMOS IC technologies", ECOC '98, Technical Digests vol. 1, pp. 631-632 (1998)

(3) H. Nakanishi et al., "A 1.3/1.55μm bi-directional optical transceiver module using a simple straight optical waveguide structure", ECOC '99, pp. 312-313 (1999)

(4) Y. Kuhara et al., "Design and Analysis of A Novel Bi-Directional Transceiver with -40dBm Full-Duplex Sensitivity for ATM-PON ONU", OHAN/FSAN2001, April (2001)

(5) H. Nakanishi et al.,"Development of Bidirectional 1.3/1.55-μm Optical Transceiver Module Compliant with Ethernet Standard", SEI TECHNICAL REVIEW No.54 June (2002)

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