Development of 14 Gbit/s Uncooled TOSA with Wide Operating Temperature Range

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The authors have successfully developed new TOSAs (Transmitter Optical Sub-Assembly) which are operational for a wide operating temperature range from -40 to 90 degree C and at a high speed of 10 Gbit/s or more. The devices introduced multi-layer ceramic packages with a precisely controlled characteristic impedance and wide band width up to 23 GHz. In addition, an optical system using front facet monitoring technique has achieved stable tracking error characteristics within ±0.2 dB. A newly designed laser driver IC is also mounted in a package to ensure both high speed performance for 16GFC and low power consumption for high density aggregation of transmission systems.

Keywords: ceramics package, uncooled TOSA, XMD-MSA, 10GBASE-LR, 16GFC

1. Introduction

With the rapid increase of data traffic in recent years, the demand for large-capacity and high-speed transmission systems have been increasing. Nowadays, small products called XFP (10 Gbit/s Small Form-Factor Pluggable) and SFP+ (Small Form-Factor Pluggable Plus) are the mainstream of optical transceivers in the transmission systems, which transmit data at 10 Gbit/s or slightly more. To achieve large transmission capacity, the number of optical transceivers will be more increased in a transmission system such as network switch and router. Accordingly, optical transceivers must be capable of operating at a high temperature due to the increase of heat dissipation density. For high speed transmission, optical transceivers are expected to be operational for more than 10 Gbit/s. At the same time, low power consumption is also required to reduce the heat dissipation density. In particular, SFP+ must meet maximum power consumption less than 1 W. Consequently, development of TOSA (transmitter optical sub-assembly) with low power consumption is the significant and urgent issue.

This time, we have developed uncooled TOSA with DML (direct modulated laser diode) suitable for XFP and SFP+, targeting the transmission distance of 10 km or less. In this paper, we report the TOSAs, mentioning mechanical structure which introduces a new package for high-speed operation and circuit technique to achieve low power consumption.

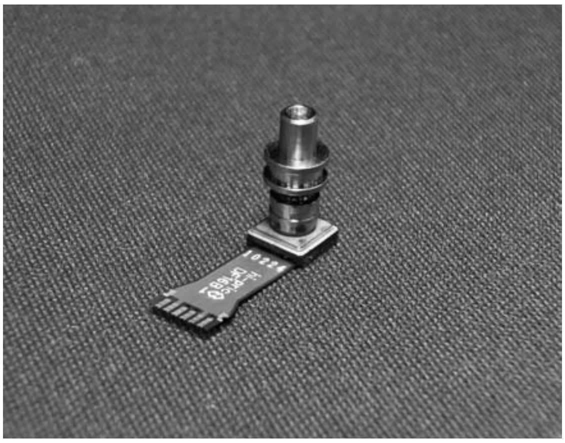

Photo 1. Appearance of TOSA

Table 1. Specifications of TOSA

Items	10GBASE-LR	16GFC
Specification	IEEE802.3ae	FC-PI-5
Mechanical Dimension	XMD-MSA Compliant	
Optical Interface	LC Receptacle	
Electrical Interface	8-PIN FPC	
Operation Case Temperature	-40～90 deg. C	-5～90 deg. C
Operating Bit Rate	10.3125Gbit/s	14.025Gbit/s
Transmission Distance	10km Max.	10km Max.
Wavelength	1260~1355nm	1295~1325nm
Optical Output Power	-8.2dBm Min.	-4.9dBm Min.
$RIN_{12}OMA$	-128dB/Hz Max.	-130dB/Hz Max.
Extinction Ratio	3.5dB Min.	3.5dB Min.
Tracking Error	±1.0dB	±1.0dB
Driving Method	By External IC	By Internal IC
Power Consumption	120mW Max.	300mW Max.

2. Structure of the TOSA

Photo 1 shows appearance of a TOSA. **Table 1** describes the specifications.

The mechanical structure is compliant with XMD-MSA (10Gbit/s Miniature Device Multi Source Agreement), and the electrical and optical specifications are compliant with 10 Gigabit Ethernet (hereinafter, 10GBASE-LR) and 16 Giga fiber channel (hereinafter, 16GFC) standards. The transmission distance is less than 10 km and the transmission rate is 10.3125 Gbit/s for 10GBASE-LR and 14.025 Gbit/s for 16GFC. The optical interface is LC receptacle and the electrical interface is 8-pin flexible printed circuit (FPC).

In general, box-type packages are used for cooled TOSA and coaxial-type packages for uncooled TOSA. The box-type package consists of a ceramic part with transmission lines and a metal part forming outlines. It has an advantage of high-frequency characteristics by optimization of transmission lines, but disadvantages of complex structure with multiple components and high cost. On the other hand, the coaxial-type package has simple structure with a round-shaped metal part and some lead terminals sealed with glass. Therefore, it has an advantage of low cost but disadvantage of poor frequency performance insufficient to achieve high-speed operation more than 10 GHz, because the transmission lines cannot be optimized.

We have newly developed uncooled TOSAs introducing a new-type package with high frequency characteristic more than 10 GHz covering 16GFC and a simple structure to be manufactured at low cost. In **Fig. 1**, (a) shows a conventional TOSA (coaxial-type package) and (b) shows the new TOSA. The new TOSA introduces a multilayer ceramic package, which has been used in crystal oscillators, and enables optimization of transmission lines for high-frequency characteristics over 10 GHz. In the 5.4 mm sq package, an edge emitting laser diode (LD), a prism to reflect the emitted light to the vertical direction, photodiode (PD) to monitor split light through the prism, and heat sink of LD are mounted. Output light from the package is focused to optical fiber through a ball lens mounted in a lid. The package is hermetically sealed with the lid in order to protect the semiconductor components.

As to circuit configuration, we have adopted two ways; (1) external differential modulation signals directly drive LD, (2) an internal IC mounted in TOSA receives the differential signals and drives LD. Two different packages have been developed respectively. The characteristic impedance of transmission lines is differential 50 Ω for (1) and differential 100 Ω for (2).

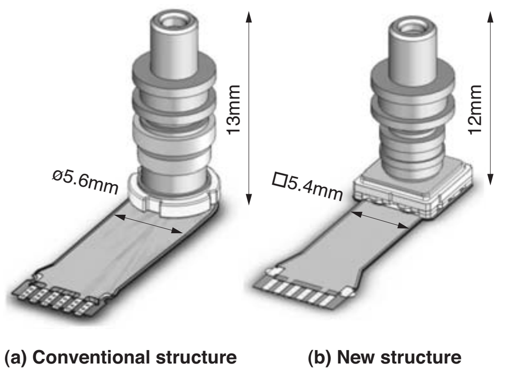

Fig. 1. Structure of TOSA

3. Design of Optical System

Figure 2 shows a sketch of the optical system. In the conventional structure (a), LD and heat sink are mounted to be perpendicular to the optical axis of TOSA, and PD is mounted with some angle to the optical axis. The front emitted light from LD, aligned with the optical axis, is focused to the optical fiber through a lens. In the new structure (b), LD, heat sink, prism, and PD are arranged on the same plane, which is perpendicular to the optical axis. The front emitted light of LD is reflected by a prism to the vertical direction and focused to optical fiber through a lens.

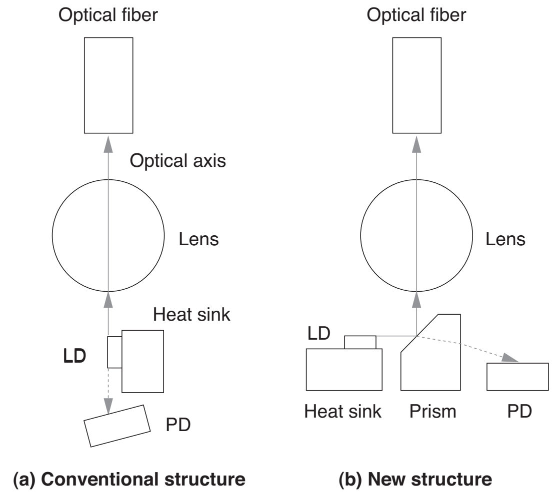

Fig. 2. Schematic diagram of optical system

3-1 Direct monitoring of optical output power

In conventional optical systems, the front emitted light is focused to optical fiber through a lens, and the rear emitted light is received by PD to monitor optical output power. The ratio of the front emitted optical power to the rear emitted optical power should be constant, but practically fluctuates with LD temperature. When APC (automatic power control) circuit stabilizes optical output power, LD current is generally controlled to keep the PD monitor current constant. However, the fluctuation causes deviation of ±1.0 dB in the optical output power, which is called tracking error characteristics.

In the new optical system, the front emitted light is split with a prism, which has an angled plane coated with reflective film; the most part is reflected to the vertical direction and focused to optical fiber through a lens, the rest part passes through the angled plane and is received by PD for monitoring. In this way, the ratio of optical output power to monitored power by PD is theoretically constant and independent from temperature. This enables stable output power control against temperature change.

Figure 3 shows measurement results of the tracking error characteristics of a new TOSA. In a wide temperature range from -40 deg. C to 90 deg. C, stable output power within ± 0.2 dB has been achieved.

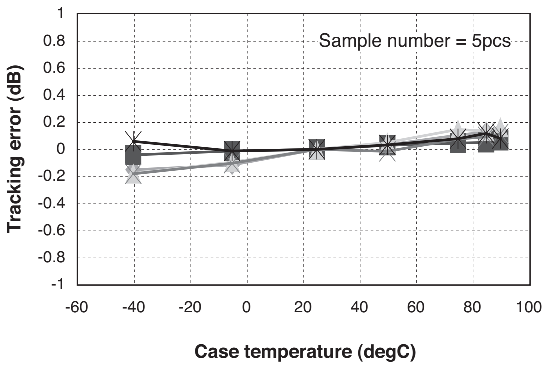

Fig. 3. Characteristic of tracking error

3-2 Suppression of optical reflectance

If reflected light from outside incidents on LD in TOSA, relative intensity noise (RIN) degrades. As the degradation makes signal quality worse, it is necessary to suppress the reflected light before it incidents on LD. In general, an isolator is used in the optical system to interfere the reflected light. However, it causes high cost.

We have devised a structure to suppress the reflected light with no isolator, using reflective film of the prism instead. The LD used in our uncooled TOSA is capable of emitting optical output power of about 1 dBm under normal driving conditions, which is sufficient to meet specification requirements of TOSA. In the conventional design, when the product of LD optical output power multiplied by coupling efficiency of the lens is smaller than the standard value of TOSA output power, incident optical power on optical fiber is reduced by defocusing, namely moving the optical fiber away from a focus point. However, we have carefully selected a small value for prism reflectance, so as to reduce the incident optical power but still obtain sufficient TOSA output power. The light passing through the prism incidents on PD placed in front of the prism, and monitoring current corresponding to the optical power is outputted.

On the other hand, the reflected light going back through optical fiber from outside of TOSA is finally focused to LD by a lens in the conventional optical system. In our structure, the prism is placed in the middle of the optical path to LD and most of the reflected light passes through the prism because of low reflectance of the reflective film, so that the reflected light can be suppressed without an isolator.

Figure 4 shows characteristics of $RIN_{12}OMA$ at -12 dB reflected light. $RIN_{12}OMA$ characteristics obtained are less than -130 dB/Hz, which meet the requested specifications of -128 dB/Hz, meaning that the structure successfully suppresses the reflected light.

4. RF Design

We designed the new package to have differential signal transmission lines of 50 Ω characteristic impedance. The frequency characteristics were compared with those of the conventional coaxial-type package. The following describes the results.

4-1 Frequency characteristic

In conventional packages, an external differential input signal reaches LD through three parts: (1) transmission lines on FPC, (2) lead pins sealed by glass, and (3) transmission lines on a heat sink substrate mounted in the package. For each part, transmission lines can be designed to obtain specific characteristic impedance, but matching the characteristic impedance between (1) and (2), and also (2) and (3) is rather difficult. Therefore, conventional coaxial-type packages fail to achieve transmission rate over 10 Gbit/s. For the new package, the input signal path to LD consists of three parts: (4) transmission lines on FPC, (5) transmission lines within the package, and (6) transmission lines on a heat sink substrate mounted in the package. As all parts have transmission lines, the characteristic impedance can be matched flexibly by adjusting the width of the transmission lines formed on ceramics and compensating impedance mismatches at a junction of neighboring two parts. This makes it possible to achieve much better high frequency characteristics.

We analyzed the frequency characteristics by electromagnetic simulation for both conventional and new packages. **Figure 5** shows the models used for the analysis. They

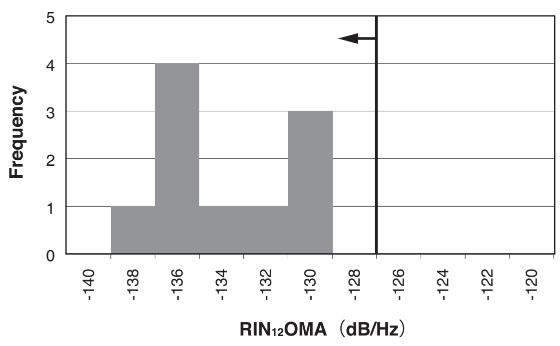

Fig. 4. Characteristic of $RIN_{12}OMA$

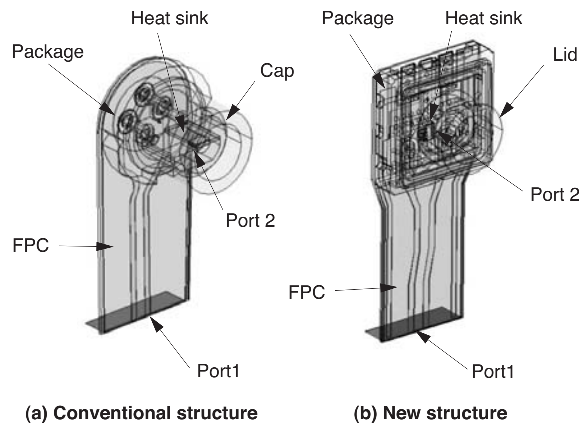

Fig. 5. Analysis models of frequency characteristics

consist of FPC, package, heat sink, and cap (conventional package) or lid (new package). The two ports for electromagnetic simulation were selected as Port 1 on transmission lines of FPC and Port 2 at the symmetrical surface on transmission lines of a heat sink.

Figure 6 shows simulation results of transmission frequency characteristics (S21) of the conventional and new packages. For the conventional package, the band width is about 9 GHz because of reflections caused by impedance mismatches. Reversely, the new package has the band width more than 23 GHz by optimizing the impedance matching.

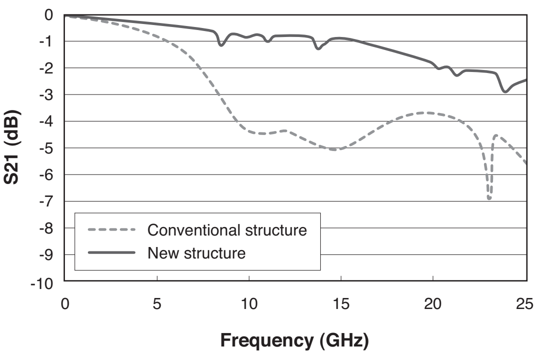

Fig. 6. Frequency characteristics of packages

4-2 Characteristic impedance

Figure 7 shows measurement results of the characteristic impedance by the time domain reflectometry (TDR). The samples used consist of FPC, package, heat sink and LD. The results indicate the characteristic impedance from the edge of FPC. The transmission lines are designed to have the characteristic impedance of 50 Ω for the differential input signal.

The horizontal axis of **Fig. 7** is time, corresponding to the point that the signal reaches at the time, namely, (1) from 0 to 50 ps shows the pad connected to the FPC and circuit board, (2) from 50 to 150 ps shows the transmission lines on FPC, (3) from 150 to 200 ps shows the package, and (4) from 200ps to more shows the LD. The vertical axis is the differential characteristic impedance by TDR measurement.

The conventional package has mismatches of the characteristic impedance after 150 ps with the maximum of about 59 Ω. For the new package, the characteristic impedance is well controlled and the deviation is less than 3 Ω after 50ps. This indicates that the new package has very good impedance matching for the whole signal path.

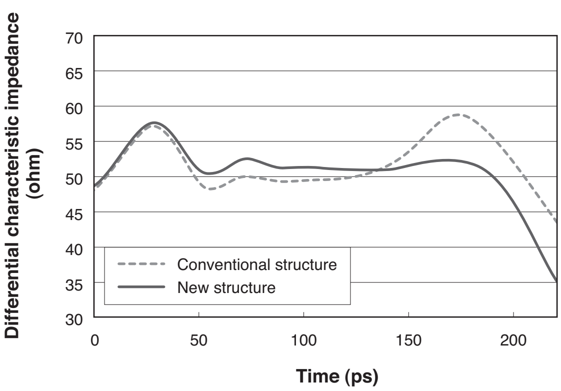

Fig. 7. Differential characteristic impedance

5. Low Power Consumption Design

We have developed a shunt-driver IC to be mounted in TOSA for low-power-consumption optical transceiver such as SFP+ [(2)-(4)].

Figure 8 shows the simplified circuit diagram of an optical transmitter using a shunt-driving system, which is composed of a VCSEL driver and a shunt-driver IC. The shunt-driver IC is composed of a transistor (FET) placed in parallel with the LD and can output modulated current. The LD current can be modulated and converted into the optical signal. The shunt-driving system can reduce driving current from the VCSEL driver outside the TOSA because the FET amplifies the driving current with a trans-conductance gain gm. In order to reduce the total power consumption of SFP+ to 1 W or less, power consumption of the TOSA should be reduced to 300 mW or less, which has been achieved with the shunt-driving system.

We developed a new driver IC for 16 GFC applications. A push-pull-driving system, which is more appropriate for high-speed operation than the conventional shunt-driving system, is adopted. The new driver IC contains two transistors in the output stage; one is placed in parallel with the LD and pulls current from the LD, and the other is in series with the LD and pushes current to the LD. These transistors are switched alternately and the LD current can be modulated to be converted into the optical signal. The load current of each transistor in the push-pull-driving system is

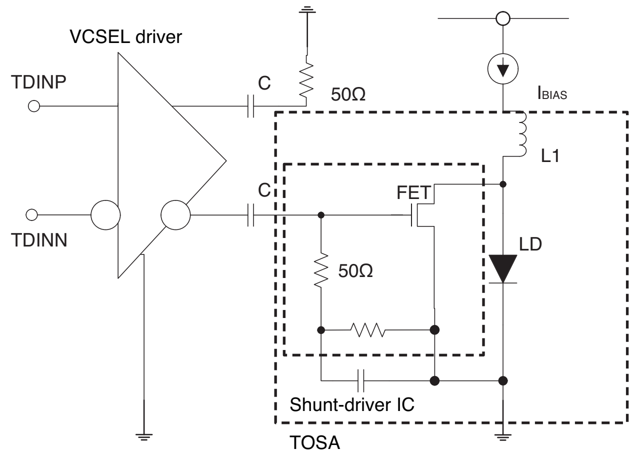

Fig. 8. Simplified circuit diagram of optical transmitter using shunt-driving system

smaller than that of a transistor in a shunt-driving system.

Figure 9 shows the simplified circuit diagram of an optical transmitter using a push-pull-driving system, which is composed of a VCSEL driver and a push-pull-driver IC. The push-pull-driver IC is driven from the VCSEL driver IC with a differential voltage signal through 100 Ω transmission line. A differential terminating resistor (R1) is in the push-pull-driver IC to adjust the input impedance to 100 Ω and matches the differential transmission line. A buffer circuit (AMP) is a current source controlled by differential voltage signals from the VCSEL driver. Bias current to the LD is supplied from the current source (Ibias). A ferrite bead inductor L1 is connected to the LD anode and the two transistors (Q1, Q2) to the current source (Ibias) to prevent modulated current leakage.

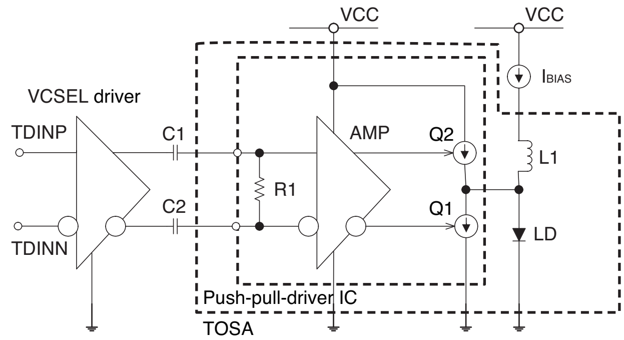

Fig. 9. Simplified circuit diagram of optical transmitter using push-pull-driving system

6. Optical Eye-Diagram

6-1 Characterization for 10GBASE-LR

Figure 10 shows optical output waveforms of the newly developed uncooled TOSA, which were evaluated under the driving conditions corresponding to 10GBASE-LR applications. The bitrate is 10.3125 Gbit/s, the extinction ratio is 5.0 dB, and the case temperature of TOSA is -40 deg. C to 90 deg. C. The pulse mask margin (PMM) at 25 deg. C and -40 deg. C is more than 50% and even under high temperature at 90 deg. C is more than 30%. It obtains a good eye opening.

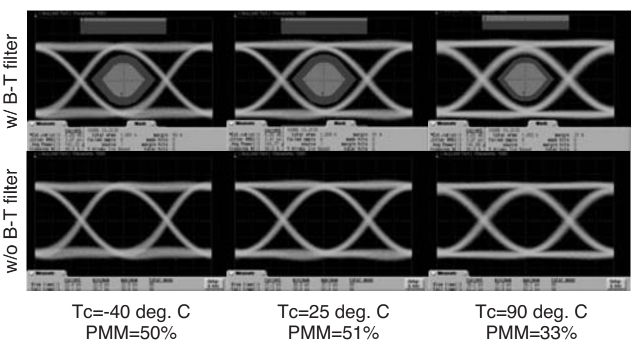

Fig. 10. Optical eye diagrams for 10GBASE-LR

6-2 Characterization for 16GFC

Figure 11 shows the electro-optical characteristics of TOSA mounting the newly developed driver IC. The band width is about 14 GHz, ensuring the band width for operation at 14 Gbit/s.

Similarly, the waveform was evaluated under the driving conditions for 16GFC applications. **Figure 12** shows the optical output waveforms. The bitrate is 14.025 Gbit/s, the ex-

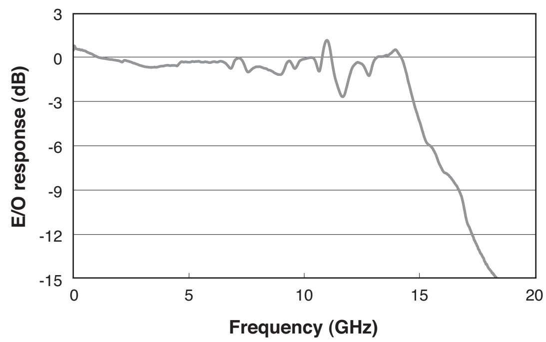

Fig. 11. E/O response

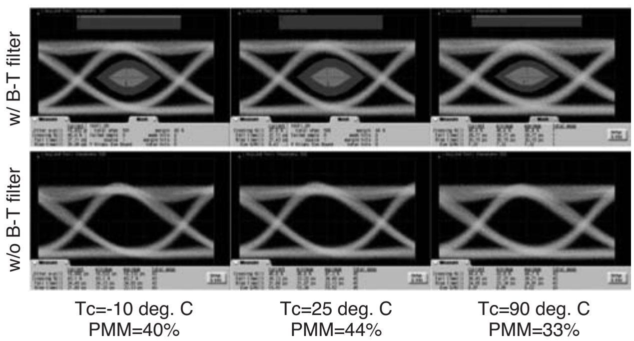

Fig. 12. Optical eye diagrams for 16GFC

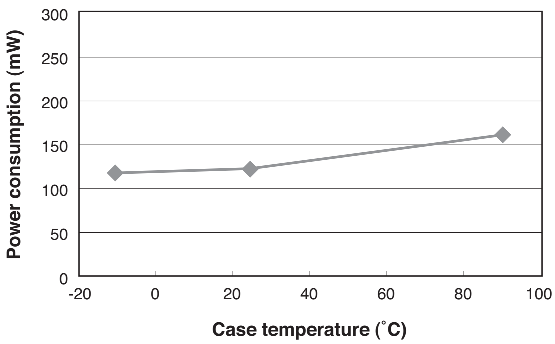

Fig. 13. Power consumption of TOSA

tinction ratio is 5.0 dB, and the case temperature of TOSA is -10 to 90 deg. C. The PMM between -10 and 90 deg. C is more than 30%. Good eye diagrams are obtained. **Figure 13** shows the power consumption of TOSA. Target specifications of 300 mW are satisfied even in high temperatures.

7. Conclusions

We have developed uncooled TOSA corresponding to 10GBASE-LR and 16GFC applications. It can operate in high temperature environments at 90 deg. C and obtain a sufficient pulse mask margin at 14Gbit/s. Furthermore, the newly developed internal driver IC enables an optical transceiver to reduce the power consumption, and therefore can contribute to the power saving of transmission systems.

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