Compact bidirectional optical subassembly vertically stacked with 1.25-Gbps transmitter and 10-Gbps receiver for passive optical networks

Jong Jin Lee
Kwon-Seob Lim
Seihyoung Lee
Hyun Seo Kang
Electronics and Telecommunications Research Institute,
1110-6 Oryong-dong, Buk-gu, Gwangju 500-480,
Republic of Korea
E-mail: jongjin@etri.re.kr

Abstract. A compact bidirectional optical subassembly (BOSA) for a 1.25/10-Gbps passive optical network is developed. A vertically stacked 1.25-Gbps transmitter based on a silicon optical bench, and a 10-Gbps receiver based on a low temperature cofired ceramic are implemented to realize low-cost manufacturing and miniaturization for single package application. The proposed BOSA delivers an extinction ratio more than 10 dB at 1.25-Gbps modulation, optical output coupling efficiency is more than 60%, rise and fall time is under 300 ps, and the side mode suppression ratio is more than 35 dB for the transmitter part. For the receiver part, responsivity is more than 0.6 A/W, and sensitivity is lower than –17 dBm at a 10-Gbps bit error rate 10^{-12} and –21 dBm at BER 10^{-3} without forward error correction. The cross talk between receiver and transmitter is less than –53 dB up to 10 GHz, and optical isolation is 33 dB. [DOI: 10.1117/1.3506718]

Subject terms: passive optical network; optical network unit; bidirectional optical subassembly; bidirectional optical alignment; single package.

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1 Introduction

With the rapidly growing demand of high data traffic, the passive optical network (PON) will be adopted much earlier as a fiber to the home (FTTH) access network. To reduce the FTTH implementation cost, the cost of an optical network unit (ONU) is another big matter of concern. A bidirectional optical subassembly (BOSA) with an optical transmitter and receiver takes away the majority of the ONU cost.[1]

In this work, we introduce a novel compact BOSA composed of a 1.25-Gbps transmitter part provided with a 1310-nm distributed feedback (DFB) laser diode (LD) and 10-Gbps receiver provided with a 1577-nm PIN photodiode (PD) and transimpedance amplifier (TIA) for 1.25/10-Gbps PON application.

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The conventional two-TO-CAN based BOSA is composed of many mechanically machined precision metal fixtures that have tight machining tolerance, thus are very dependent on labor capacity and machining skill. This limitation has been a main obstacle for mass production for a long time. We adopted a silicon optical bench (SiOB) and low temperature cofired ceramic (LTCC) as a substrate. Both technologies have been well proven for a long time and are very suitable for large volume production because of their high repeatability and high yield production capability.

We introduce the structure of the proposed compact 10-Gbps BOSA structure, the fabrication and assembly process, and the experimental result.

2 Structure and Fabrication of Compact Bidirectional Optical Subassembly

Figure 1 shows the fully assembled proposed compact BOSA. This BOSA is vertically stacked with a SiOB-based transmitter and LTCC-based receiver, which reduces the footprint area very effectively compared with traditional planar light wave circuits (PLCs), TO-CAN, and fiber-based devices.[2] Total volume is $4 \times 6 \times 2.5$ mm^3, which is the size the BOSA can be integrated into as a single package, like a miniflat package or TO-CAN.

The SiOB substrate is fabricated using a high resistivity silicon (HRS) wafer that has thickness of 0.65 mm and a diameter of 8 in. The V-grooves for lens assembly are fabricated by a 400-μm-deep wet etching process. The signal lines are integrated with 20Ω matching resistance on them. The measured 3-dB bandwidth of the signal line was higher than 10 GHz. We designed the signal line to satisfy the higher bit rate for a 2.5-Gbps transmitter, which is applied to a 10-gigabit-cabable PON (XG-PON).[3]

On the V-groove adjacent to the LD, the collimating lens, usually called the first lens, has a 1-mm diameter and is integrated with flip-chip bonding. The repeatability of placement accuracy is smaller than ± 2 μm, and the collimated beam size is around 550 μm. The focusing lens, called the second lens, is integrated at the other end of the V-groove to focus the collimated beam to the 8-deg angled fiber.

In the middle of the SiOB, between the collimating and focusing lens position, a small window of diameter 1.3 mm is fabricated with a deep reactive ionized etching (DRIE) process. The input beam changes the direction of propagation reflected by a cubic-type edge filter that has a 45-deg reflection angle, aims for the PD of the receiver, and passes through this window. The bottom of the cubic filter is coated with a blocking filter to pass only a 1577-nm input beam. The optical isolation of the cubic filter according to the 1310- and 1577-nm beam is more than 33 dB. To focus the input beam on the PD, a half-ball lens is attached to the bottom of the cubic filter. The beam size focused by the half-ball lens is around 10 μm.

We adopted a high resistive LTCC substrate whose electric resistivity of 10^{13} $\Omega \cdot$cm, which is around 10^8 times larger than that of silicon, we used to build the receiver part. The LTCC substrate is prepared using a low temperature cofiring process. As shown in Fig. 2, we fabricated the cavity structure, which is easily made by punching a green sheet to integrate the receiver part, which is very sensitive to external noise. A transimpedance amplifier (TIA) that has a bandwidth of 9 GHz, sensitivity of –21 dBm, gain of 4 KΩ,

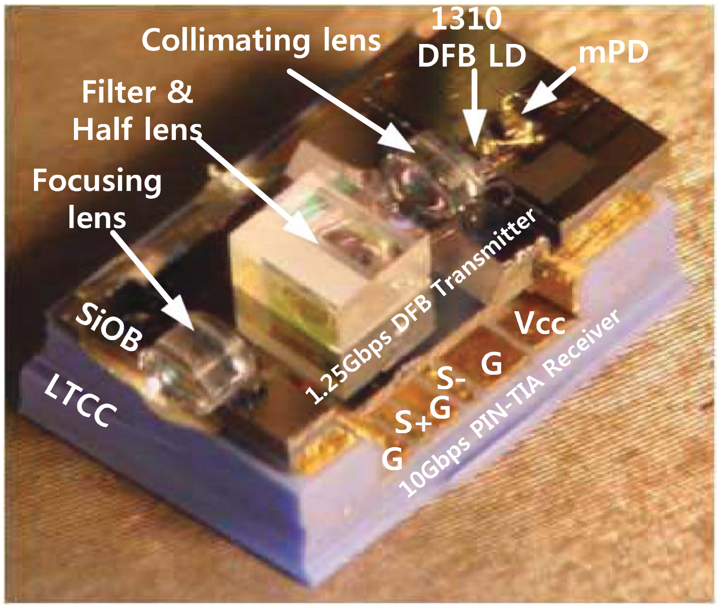

Fig. 1 Compact BOSA stacked transmitter and receiver for small footprint ($4 \times 6 \times 2.5$ mm^3).

input noise of 10 pA/(Ha)$^{1/2}$, and a PD whose responsivity is 0.95A/W and active area is 32 μm are integrated inside the cavity with a SMT-based die bonding process.

The LTCC has low thermal conductivity of 3 W/mk. To enhance the LD heat dissipation, we fabricate a total of 33 thermal vias around the cavity wall. The thermal vias are filled with high thermal conductive silver paste. As shown in Fig. 2, thermal via provides the good thermal path from the LD to the heat sink.

To couple the output beam, the optical fiber is actively aligned and attached to the package using a laser welder. The LD output beam is tilted 4 deg to maximize the fiber coupling efficiency. After, the cubic filter is inserted in SiOB using a flip-chip bonder. We coarsely align the PD active area and the center of the half lens using an image overlap of the flip chip bonder. After that, as shown in Fig. 3, we actively aligned the 1577-nm input beam to the PD with fine adjustment of the cubic filter while monitoring the PD photocurrent output and transmitter optical power output at the same time. This simultaneous bidirectional optical alignment makes single-packaged BOSA possible.

The measured alignment tolerance of the filter is ± 4 μm in the lateral direction, smaller than ± 6.5 μm in the axial direction, considering 0.5-dB misalignment loss. Because the lateral direction of alignment deviated from the input beam path, axial alignment follows the input beam path direction.

3 Experimental Result

Transmitter coupling efficiency was more than 60% by adapting a microaspheric lens precisely aligned, positioned on V-grooves, and tilted 4 deg according to the 8-deg angled fiber axis. At 25°C ambient temperature with Ith + 20 mA current input, the output power was more than 4 mW, and the side mode suppression ratio (SMSR) measured with an optical spectrum analyzer (OSA) showed more than 35 dB. The rise and fall time was shorter than 300 ps at 1.25-Gbps modulation measured using a rf probe system and a digital oscilloscope. The extinction ratio was more than 10 dB.

The responsivity of the receiver part was around 0.6 A/W, and as shown in Fig. 4, we achieved sensitivity of –17 dBm at a bit error rate (BER) of 10^{-12}, and –21 dBm at BER 10^{-3} without forward error correction (FEC). As shown in

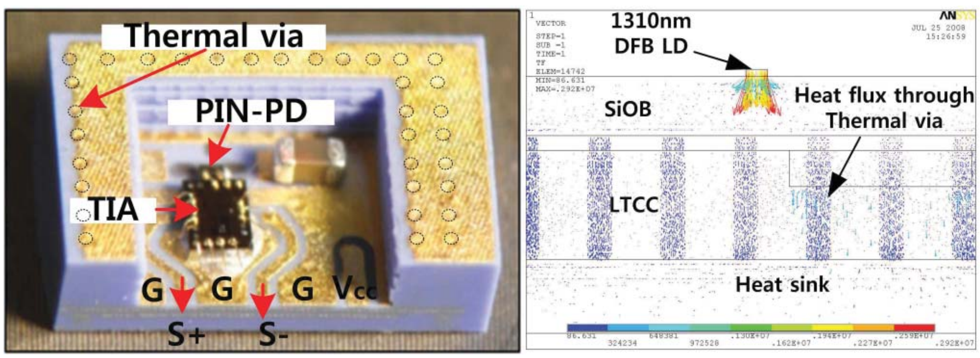

Fig. 2 High resistance LTCC substrate for noise sensitive 10-Gbps PIN-TIA receiver and heat flux vector through thermal via.

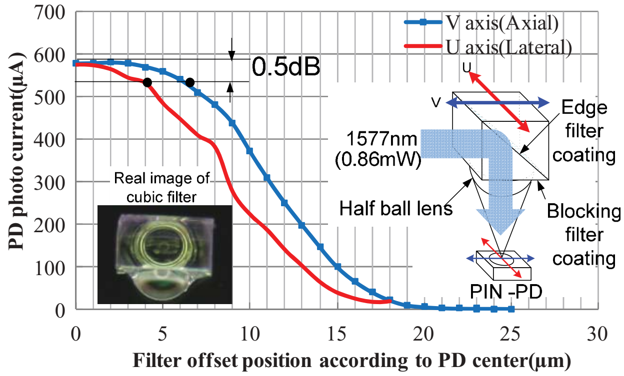

Fig. 3 Measured PD photocurrent output according to filter offset from the center of the PD.

Fig. 5, we calculated minimum electrical cross talk requirements according to sensitivity referring to the previous study.[4] To achieve error-free –17 dBm at a BER of 10^{-12} at responsivity of 0.6 A/W, the minimum required cross talk is around –52 dB. We achieved cross talk performance under –53 dB at 10 GHz.

The measured optical filter isolation was 33 dB and insertion loss of the cubic filter was 0.2 dB.

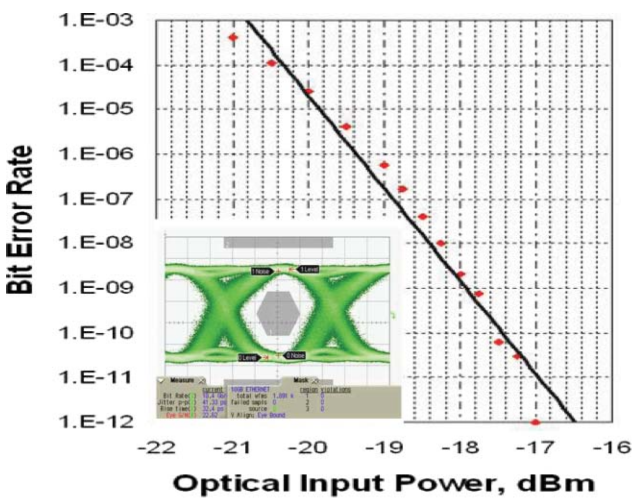

Fig. 4 Measurement results of the receiver's 10-Gbps sensitivity and eye diagram of limiting amp output at PRBS 2^{31}–1, 10.3125 Gbps.

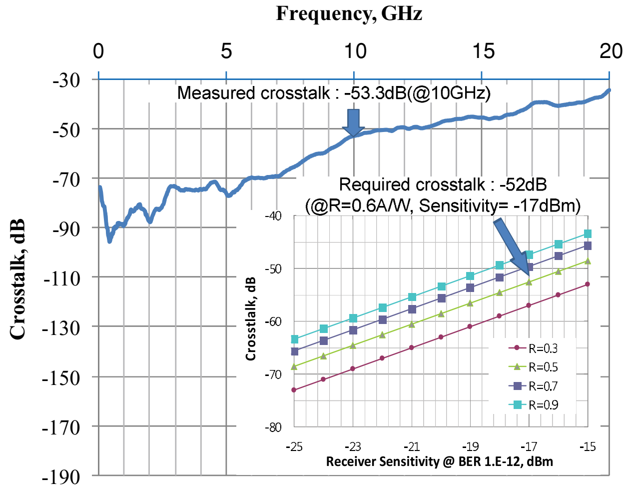

Fig. 5 Minimum required transmitter-receiver electrical cross talk for TIA and measurement results.

4 Conclusion

We successfully develop a novel compact BOSA for 1.25/10-Gbps PON application. We stack a SiOB-based transmitter and LTCC-based receiver to realize a small footprint, minimize electric cross talk, and enhance the LD heat dissipation for single package applications.

We achieve an extinction ratio more than 10 dB at 1.25-Gbps modulation with 60% coupling efficiency. The rise and fall time is under 300 ps, and the SMSR is more than 35 dB for the transmitter part. The responsivity of the receiver part is around 0.6 A/W, and sensitivity is –17 dBm at BER of 10^{-12}, and –21 dBm at BER 10^{-3} without FEC. The electrical cross talk is lower than –53 dB, up to 10 GHz, and optical isolation is 33 dB.

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