Optical Engineering

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Abstract. We propose a novel, low-cost bidirectional optical subassembly (BOSA) that uses a single glass-sealed conventional transistor-outline (TO)-CAN package for passive optical network application. In this BOSA, optical transmitting and receiving functions are incorporated into a silicon optical bench and in a TO-CAN package, respectively. With these features, the optical and electrical crosstalk is efficiently suppressed. The single TO-CAN BOSA has an extinction ratio of 11.69 dB and output power of 2.93 dBm for 1.25 Gb/s operation. The penalty of optical dispersion is 1.2 dB after 20-km single-mode fiber transmission. The receiver sensitivity is less than −30 dBm at a bit error rate of 10^{-3} for 10.3 Gb/s operation and the signal crosstalk penalty of a single TO-CAN BOSA is 0.8 dB. [DOI: 10.1117/1.OE.52.1.010501]

Subject terms: bidirectional optical subassembly; single transistor-outline package; silicon optical bench; avalanche photo diode.

Paper 121210L received Aug. 22, 2012; revised manuscript received Nov. 29, 2012; accepted for publication Dec. 4, 2012; published online Jan. 7, 2013.

1 Introduction

Passive optical network (PON) architecture has been considered a promising solution for providing high-bandwidth demands in access networks.[1] For a next-generation passive optical network (NG-PON), 10 Gigabit Ethernet passive optical network (10G-EPON), and 10-Gigabit-capable passive optical network (XG-PON), data rates of up to 10 Gb/s are required.[2–4] Moreover, all of these network architectures could meet the requirements of having the lowest possible cost. In order to realize the economical fiber-to-the home system, the cost reduction of the bidirectional optical subassembly (BOSA), which is the key element of the optical transceiver as the major portion of the optical network unit (ONU), is the most important.

In previous studies, conventional BOSA structures for the ONU application have been proposed by combining two transistor-outline (TO)-CAN packages with a transmitter optical subassembly (TOSA) and a receiver optical subassembly (ROSA).[5] The BOSA structure, which is based on a single TO-CAN, has been developed by adopting a silica-based planer lightwave circuit (PLC)[6] and coaxial TO-CAN structure,[7] in order to greatly reduce costs compared to the conventional two TO-CAN configurations.

In this letter, we introduce a low-cost, coaxial, single TO-CAN BOSA composed of a single glass-sealed conventional TO-CAN package and one silicon optical bench (SiOB), which have been adopted as the design of low-optical and electrical crosstalk for asymmetric 10G-EPON applications.

2 Design and Fabrication of the Proposed BOSA

Figure 1(a) shows a schematic diagram and the bidirectional optical coupling processes of the proposed BOSA. This BOSA is composed of a TO-stem and a SiOB platform for the receiving and transmitting functions. In this BOSA, it is important to suppress the signal crosstalk with a good receiver performance under the full duplex operation because a laser diode (LD) and a photo diode (PD) are integrated into a single TO-CAN package. To suppress the electrical and optical crosstalk from the transmitter part to the receiver part, the transmitter part is attached on the SiOB platform and the receiver part is attached in a TO-stem cavity separately. The 1310-nm distributed feedback (DFB) LD and the monitor photo diode (mPD) for the transmitter are attached on the SiOB platform by using flip-chip bonding technology with a placement accuracy of $\pm 1\ \mu$m. A focusing lens is integrated on the V-groove of the SiOB platform by using flip-chip bonding technology and a UV epoxy resin. The SiOB is fabricated to the high-resistivity silicon (HRS) of 10 k$\Omega \cdot$ cm to achieve a low crosstalk structure. The avalanche photo diode (APD) (bandwidth: 10.7 GHz with multiplication gain of 9 at bias voltage of a 27 V), transimpedance amplifier (TIA) (differential transimpedance gain: 4 kΩ, bandwidth: 8 GHz, input-referred RMS noise: 1 μA_{rms}), and capacitor for the receiver are integrated in the cavity of the 10-pin TO-stem, which has a diameter of 6.4 mm. This is done with a die bonding process using flip-chip bonding technology and silver epoxy. The only path that the aggressive optical signal passed the receiver by is a very tiny through hole of a SiOB platform, as shown in Fig. 1(a). An upstream, 1310-nm optical signal of the LD is passed through the focusing lens and is reflected on a 45-deg surface of the wavelength division multiplexing (WDM) filter and then coupled into the single-mode fiber (SMF). A downstream, 1577-nm optical signal is passed through the WDM filter and is then coupled to the APD chip via the hole in the SiOB platform. The half-ball lens is attached to the bottom of the WDM filter in order to focus on the APD, which has an active area of 80 m. To further suppress the optical crosstalk, a blocking filter is placed under the hole in the SiOB platform. The WDM filter is aligned with and attached to the SiOB platform at the position that has a maximum output power of LD and a maximum photocurrent of APD. All components, such as the APD, TIA, mPD, LD, capacitor, and microlens, are hermetically sealed in the TO-CAN. Figure 1(b) shows the images of a fabricated pigtail-type of the single TO-CAN BOSA module, which is aligned and attached by laser welding technology.

3 Simulation and Experimental Results

The optical output power of the single TO-CAN BOSA was more than 2.9 dBm, and the side mode suppression ratio (SMSR) was 42.26 dB. The 3-dB bandwidth of the

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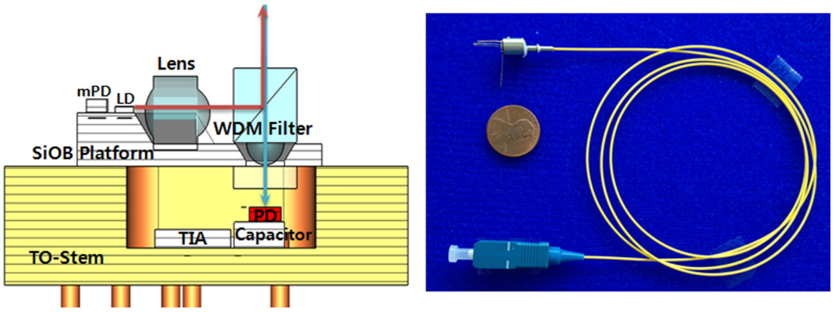

Fig. 1 Images of the proposed single TO-CAN BOSA. (a) Structure and optical signal path of the proposed single TO-CAN BOSA; (b) manufactured Single TO-CAN BOSA.

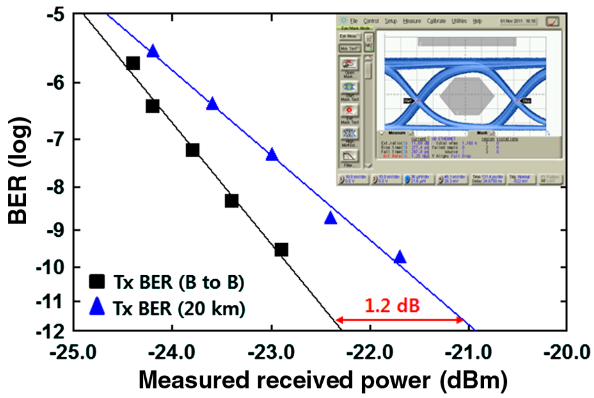

Fig. 2 The BER characteristic of the transmitter of the single TO-CAN BOSA at 1.25 Gb/s.

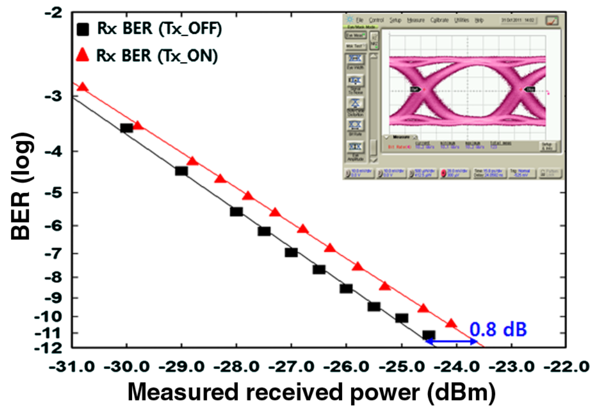

Fig. 3 Sensitivity test results of the receiver of the single TO-CAN BOSA at 10.3 Gb/s.

transmitter was measured to be 2.13 GHz with a 2.5 Gb/s DFB LD. Figure 2 shows the bit error characteristic and optical eye diagram of the transmitter of the single TO-CAN BOSA. The transmitter performances were measured by a 1.25 Gb/s nonreturn-to-zero (NRZ) pseudorandom binary sequence (PRBS) with a pattern length of $2^{31} - 1$. The eye diagram was measured with Gigabit Ethernet. The optical output waveform shows a sufficient margin for 1.25 Gb/s transmission. The extinction ratio was 11.69 dB, and the penalty of optical dispersion was 1.2 dB after a 20-km SMF transmission. We also observed an extinction ratio of 10.70 dB using the same BOSA for 2.5 Gb/s operation.

We calculated the maximum acceptable electrical crosstalk from the transmitter to the receiver to achieve the specific receiver sensitivity at bit error rate (BER) of 10^{-3}. In order to achieve a receiver sensitivity of less than −30 dBm at BER of 10^{-3} when the receiver optical coupling efficiency is 0.3 A/W, the electrical crosstalk should be below −80.4 dB.[8] We also calculated the electrical crosstalk from the transmitter to the receiver by using a three-dimensional electromagnetic solver of the CST microwave studio to verify the suppression of the electrical crosstalk with the proposed single TO-CAN BOSA structure. The calculated electrical crosstalk was less than −100 dB from DC to 40 GHz, with a through hole of $0.3 \times 0.3\ \text{mm}^2$ and the metallization for the ground on the bottom of the SiOB platform. With these features, the optical and electrical crosstalk can be effectively suppressed.

The 3-dB bandwidth of the receiver was measured to be 13.67 GHz, with 10.3 Gb/s APD and TIA. Figure 3 shows the BER performances of the receiver at the "on/off" conditions of the transmitter of the single TO-CAN BOSA. The receiver was driven by a 10.3 Gb/s NRZ PRBS with a pattern length of $2^{31} - 1$. When the transmitter was disabled, the receiver sensitivity was −31 dBm at a BER of 10^{-3}, which sufficiently satisfied the requirements of the IEEE 802.3 av PRX 30 standards of −28.5 dBm without forward error correction. The receiver sensitivity of −24.4 dBm at BER of 10^{-12} was achieved. When the transmitter was driven using a 1.25 Gb/s NRZ PRBS with a pattern length of $2^{31} - 1$, the receiver sensitivity was −30.6 dBm at BER of 10^{-3} and −23.6 dBm at BER of 10^{-12}. The DFB LD was driven by the LD driver evaluation board and the bias current and modulation current of the DFB LD was 19.5 mA and 55 mA, respectively. The signal crosstalk penalty of the single TO-CAN BOSA was 0.8 dB, which was achieved by comparing the receiver sensitivities of BER of 10^{-12} at the "on/off" conditions of the transmitter.

4 Conclusions

We developed a single TO-CAN BOSA where the optical transmitter and receiver were incorporated into a single TO-CAN for 10G-EPON applications. A highly simplified, low-cost feature of the single TO-CAN BOSA was realized by implementing passive alignment technologies, the single TO-CAN package, and the SiOB platform. The transmitter output power was 2.93 dBm, and the extinction ratio was 11.69 dB for 1.25 Gb/s operation. The penalty of optical dispersion was 1.2 dB after a 20-km SMF transmission. The receiver sensitivity was −31 dBm at a BER of 10^{-3}

for 10.3 Gb/s operation, and the sensitivity penalty due to the signal crosstalk was 0.8 dB.

The optical and electrical crosstalk was efficiently suppressed by separating the transmitter and receiver components using the HRS SiOB platform and TO-stem. The performance of the single TO-CAN BOSA was good enough to satisfy the requirements of the IEEE 802.3av PRX 30 standards. This proposed single TO-CAN BOSA is a candidate to be a low-cost BOSA for 10 G-EPON, as well as XG-PON application.

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