Low Insertion Loss 128-Gbaud HB-CDM with 3D-Printed Spot Size Converter Integrated InP-based Modulator

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Abstract: We demonstrate 128 Gbaud HB-CDM with InP-based modulator having 3D-printed SSCs on chip facet. Optical coupling loss of 1.1 dB and Telcordia compliant reliability promise practical usage of 3D-print technology based on two photon polymerization. © 2022 The Authors

1. Introduction

The amount of data traffic is rapidly increasing because of the development of internet services. With the increase of transmission speed, digital coherent communication will be widely used not only for long haul or metro, but also for inter-datacenter. Since the capacity is determined by baud rate and OSNR, it is essential to improve bandwidth and insertion loss of modulator. Silicon [1] and Lithium Niobate [2] Mach-Zehnder Modulator (MZM) are reported in recent years, but the former has a narrow bandwidth and large insertion loss, and the latter is too large to be mounted on a small package. InP MZM is the most suitable device for a high-speed transmitter module because of its wide bandwidth, low propagation loss, and miniaturization including optical circuits. Recently, High-Bandwidth Coherent Driver Modulator (HB-CDM) with an InP modulator has been reported, demonstrating 3 dB bandwidth over 80 GHz and 128 Gbaud 16QAM transmission [3]. In [3], the total insertion loss of 8.5 dB and coupling loss of 2.5 dB were achieved by monolithic integrated Spot Size Converter (SSC) into the modulator chip [4].

We have developed a unique SSC lens directly attached on the modulator edge facet and fabricated it by Two-Photon Polymerization (TPP) 3D-printing technology [5]. We can make modulator InP process simple because neither InP re-growth process nor dual core structure is necessary, which is needed to realize monolithic integrated SSC [6, 7]. Other benefits of this external SSC lens are reduced mode conversion loss and reduced chip size, and we can customize the SSC design for chip by chip during module assembly process. We have fabricated an OIF-compliant HB-CDM with SSC integrated InP modulator, and demonstrated good optical characteristics and 128 Gbaud transmission. Reliability of 3D-printed SSC was also tested, and there was no problem for Telcordia GR 468 standard. To our knowledge, this is the first demonstration of 3D-printed optical components integrated InP devices in commercial optical modules.

2. Module design

Fig 1 (a) shows the module outlook and (b) shows the block diagram. The module size is W11.6xL30.1xH4.45 mm and conforms to the OIF HB-CDM specification [8]. InP modulator, driver IC, and several optical components are mounted inside the module. We designed a narrow-pitch Flexible Printed Circuits (FPC) as the RF interface, because the SMT type lead-pin interface has a large drop-off around 80 GHz, making it unsuitable for 128 Gbaud modulation. The low-speed signals are connected via the lead pins on the side wall.

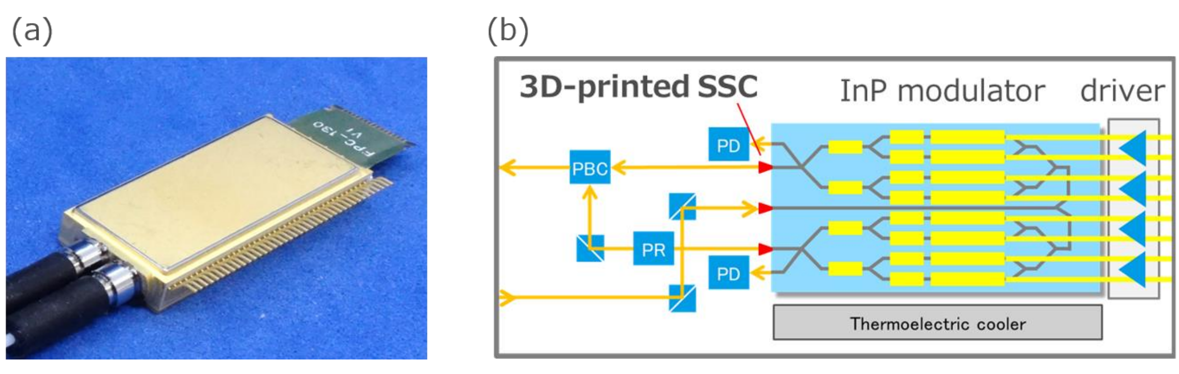

Fig. 1 (a) Outlook of HB-CDM module (b) Block diagram

As for the optical design, the output light from InP modulator is collimated by nearby glass lens, and coupled to fiber. MFD of modulator waveguide is as small as 1 μm, i.e., the NA of the output light is too large to couple with glass lens. 3D printing technology allows the SSC to be directly attached to the modulator output port, so the output light can be converted without waste. The SSC is in the form of a lens [9], and it expands output beam MFD from 1.0 μm to 2.7 μm. We can improve the coupling efficiency and alignment tolerance, while we do not have to change modulator chip and module design. Although the SSC surface has a large curvature, we have realized an aberration-free and low-reflection lens by our unique design method. The SSC was made of negative-tone photoresist. Liquid photoresist was dipped onto the modulator chip and cured by TPP, passively aligned to the modulator waveguide. After printing of SSCs, un-cured resist was removed and the modulator chip was mounted into a package with lead-free soldering.

3. Experimental results

3.1 Optical characteristics

Fig. 2 (a) shows tolerance curves of first collimation lens at the modulator output port. The tolerance curve without SSC was steep, and the SSC expanded 1 dB tolerance from 0.7 μm to 1.6 μm. Fig. 2 (a) also shows symmetrical curves on horizontal and vertical directions, indicating that a perfectly circular beam is obtained by the SSC. Fig. 2 (b) shows insertion loss of the HB-CDM module. It was measured when the parent and child modulators are driven under maximum transmission. The insertion loss of HB-CDM was 9.4 dB/pol at 1550 nm, and was less than 10 dB in most of C-band wavelength. Measured coupling loss per port was improved from 2.6 dB to 1.1 dB by the SSC, even though it included 0.2 dB Fresnel reflection loss on SSC surface. This result means that total insertion loss of HB-CDM was improved by 3.0 dB thanks to the SSCs. Polarization dependent loss was less than 0.1 dB, and optical reflection loss was -35dB. The ripple-less curve in Fig. 2 (b) indicated that the influence of the reflection by SSC is small.

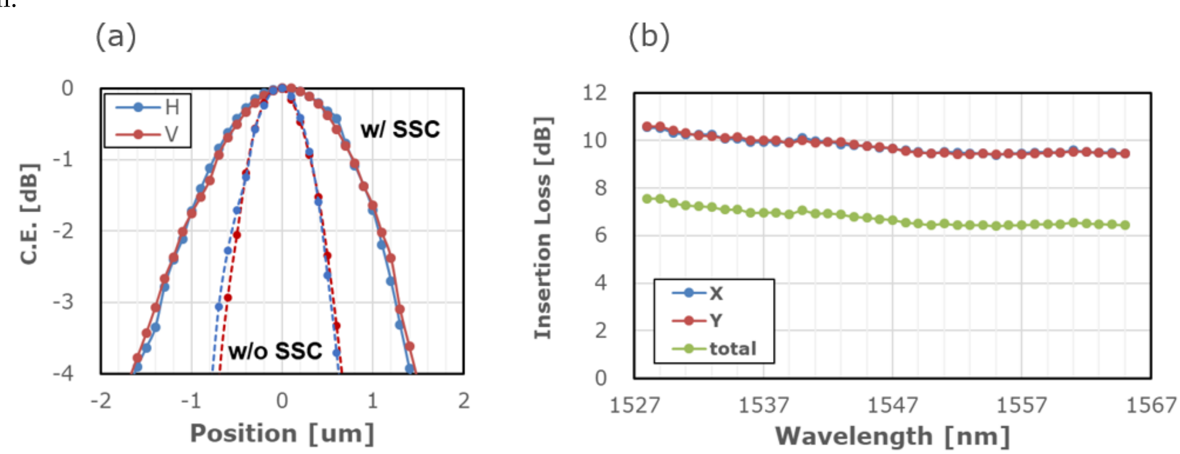

Fig. 2 (a) Tolerance curves at the modulator output port with and without SSC H: Horizontal, V: Vertical
(b) Wavelength and polarization dependence of insertion loss on HB-CDM

We have also tested the reliability of 3D-printed SSCs separately. No degradation has been observed in temperature cycles from -40 to 85 °C up to 500 cycles under hermetic condition. No problems has been observed in mechanical vibration from 20-2000 Hz and mechanical shock up to 1500 G, as specified in the Telcordia GR-468-CORE. The SSC is attached to the modulator edge facet, but we think it is robust against mechanical load because of its small size and low weight. We have also tested long-term operating test as large as 200 mW optical output, and no degradation of resin has been observed over 3,000 hours. Furthermore, no change in SSC properties has been observed even after a die bonding process at 320°C. Based on these results, 3D-printed optical components fabricated with TPP have sufficient capability for practical use to optical modules.

3.2 Electrical characteristics

Fig. 3 (a) shows the frequency characteristics of E/O response. Loss of an evaluation board and connection cables was separately evaluated using a test coupon, and was de-embedded from the evaluation result. As can be seen from the graph, similar characteristics were obtained on all 4 channels. Flat frequency characteristics without large dips were obtained thanks to careful impedance designs of transmission lines. 3 dB bandwidth reaches to 78 GHz and satisfies the HB-CDM Class-80 specifications except for peaking around 70 GHz.

Fig. 3 (b) shows the power dissipation from -5 to 75 ℃. Thermo electric cooler in the module was fixed at 50 ℃, and the evaluation was done by changing the ambient temperature. We do not need to integrate SOA into modulator, so temperature dependence is small, and maximum power dissipation is less than 3W.

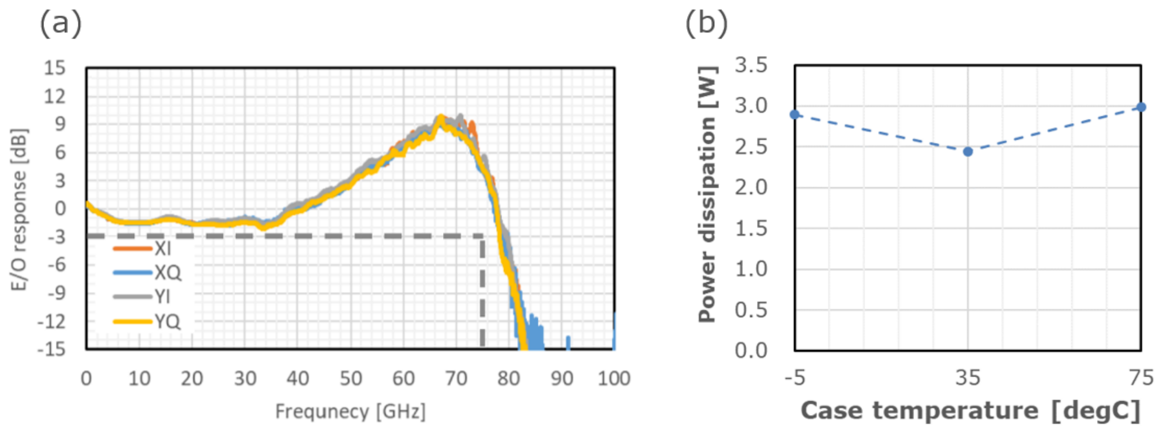

Fig. 3 (a) Frequency dependence of E/O response on HB-CDM (b) Power dissipation on each temperature

3.3 Transmission characteristics

Fig. 4 (a) shows the measurement setup for transmission evaluation. The CDM module was driven by the RF signal generated by an Arbitrary Waveform Generator (AWG), and the modulated light was evaluated using the Optical Modulation Analyzer (OMA) supporting 128 Gbaud. Fig. 4 (b) shows the transmission test results about 128 Gbaud 16QAM modulation, where a clear constellation was confirmed and EVM of 9.8% was obtained. 1.0E-3 BER was obtained with OMA, indicating that the performance is sufficient for practical use.

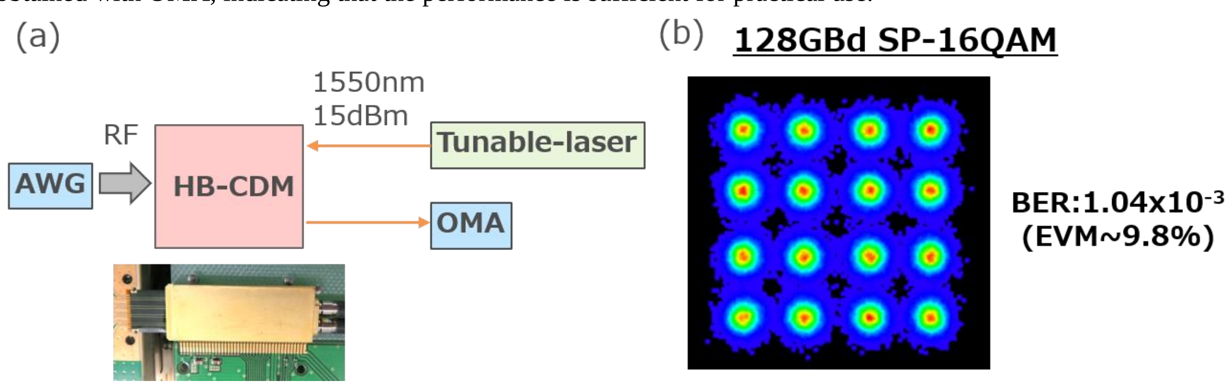

Fig.4 (a) Measurement setup of transmission test (b)Constellation on 128 Gbaud 16QAM modulation

4. Conclusion

We have demonstrated 128 Gbaud HB-CDM with InP-based modulator having 3D-printed SSCs. Module integration and Telcordia compliant reliability of 3D-printed SSCs were also shown, indicating the capability of TPP 3D-printed optical components for practical usage.

5. Reference

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