Silicon Photonics Coherent Optical Subassembly with EO and OE Bandwidths of Over 50 GHz

S. Yamanaka[1], Y. Ikuma[1], T. Itoh[1], Y. Kawamura[1], K. Kikuchi[1], Y. Kurata[1], M. Jizodo[1], T. Jyo[2], S. Soma[1], M. Takahashi[1], K. Tsuzuki[1], M. Nagatani[2], Y. Nasu[1], A. Matsushita[3], and T. Yamada[1]

[1]*NTT Device Innovation Center, NTT Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0198 Japan*
[2]*NTT Device Technology Laboratories, NTT Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0198 Japan*
[3]*NTT Network Innovation Laboratories, NTT Corporation, 1-1 Hikari-no-oka, Yokosuka, Kanagawa, 239-0847 Japan*
shogo.yamanaka.bd@hco.ntt.co.jp

Abstract: We present a silicon photonics coherent optical subassembly, which has electro-optic/ optic-electro bandwidths of 54 GHz/52 GHz for a transmitter/receiver. We also demonstrate up to 96 Gbaud polarization multiplexed 16QAM signal generation and detection.

OCIS codes: (130.0130) Integrated optics; (060.1660) Coherent communications

1. Introduction

Digital coherent technologies were originally deployed for long-haul systems, and have expanded application fields to metro and data center interconnect networks while increasing bit rate up to 400 Gb/s and reducing power dissipation and size to fit into QSFP-DD/OSFP module form factors. Recent research interests are further higher bit rates such as 800 Gb/s and more. Increasing baud rate is simpler and more OSNR tolerant approach than employing higher order modulation formats. We developed an in-phase/quadrature (IQ) modulator with an electro-optic (EO) bandwidth of 70 GHz based on indium phosphide (InP) technology, and demonstrated over 100 Gbaud optical signal generations [1]. Then, 100 Gbaud 32-ary quadrature amplitude modulation (32QAM) transmission experiment was reported, which also utilized InP photonic integrated circuits (PIC) combined with silicon germanium (SiGe) driver and transimpedance amplifier (TIA) ICs for both a transmitter and a receiver [2].

Silicon photonics (SiPh) technologies are also promising for coherent optics because they can monolithically integrate coherent transmission functions including modulators, coherent mixers, photodiodes (PDs), a polarization beam splitter/combiner and rotator (PBSR/PBCR) onto a single chip [3, 4]. Recently high bandwidth optical elements such as IQ modulators and germanium (Ge) PDs with SiPh platform have been reported separately. For transmitters, a SiPh IQ modulator with a 3dB bandwidth of ~ 35GHz was reported, and single polarization 100 Gbaud 32QAM signal generation was achieved [5]. Other SiPh modulators capable of 85 Gbaud 16QAM signal and 64Gbaud 64QAM were presented in [6]. For receivers, Ge PDs combined with TIAs with optic-electro (OE) response of 40 GHz and Ge PDs with 50 GHz bandwidth were reported [7, 8].

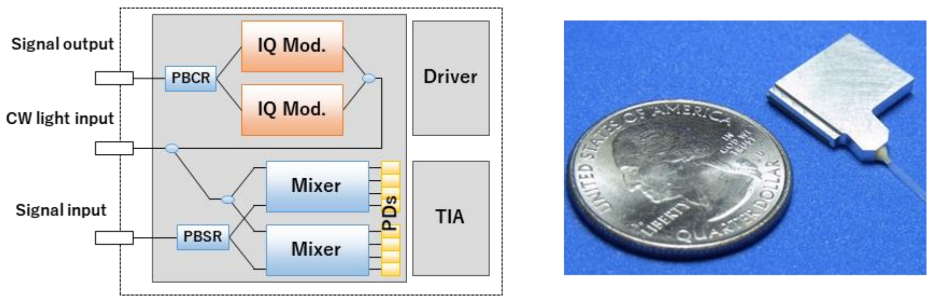
In this paper, we present a SiPh coherent optical subassembly (COSA), which has EO responses of 54 GHz and OE responses of 52 GHz including a package. It integrates a SiPh PIC that contains modulators and mixers, drivers, TIAs, and passive components such as resistors, decoupling and DC-block capacitors in a ball-grid array (BGA) package. Utilizing our COSAs, we have confirmed up to 96 Gbaud polarization multiplexed 16QAM optical signal generation and detection. To the best of our knowledge, these are the widest EO and OE bandwidths ever reported in SiPh based transmitter and receiver subassembly.

2. Devices and their frequency characteristics

Figure 1 (a) shows a block diagram of our COSA. Continuous wave (CW) light from a tunable laser is divided into two, and one portion is further divided and modulated by two IQ modulators and then multiplexed into a dual-polarization signal. The driver is a multiple stage amplifier with variable gain and peaking control, which is co-designed with the modulator. We employed open collector architecture for high power efficiency, and paid careful attention to the output stage layout optimized for flip-chip implementation on the package substrate. The other portion of divided CW light is interfered with received optical signal by coherent mixers and converted to electrical signals by Ge PDs. Following TIA amplifies and converts weak photo current signals into voltage signals with an appropriate amplitude.

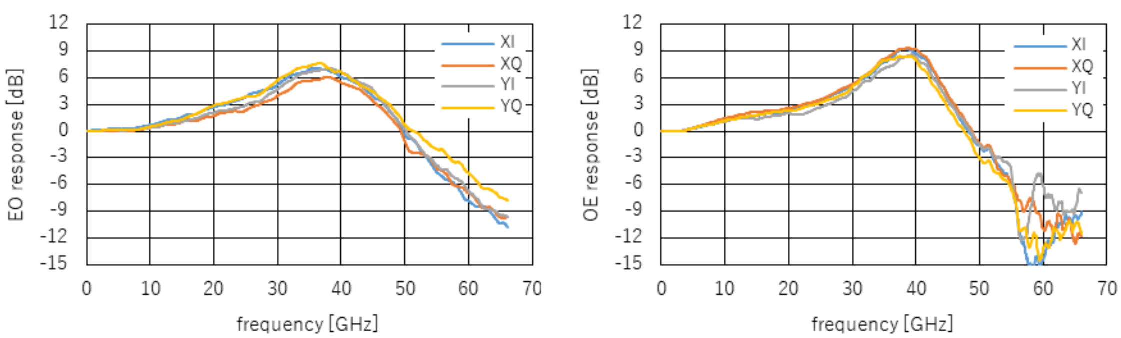
For fabrication, solder paste was printed on one side of a ceramic substrate, and resistors, decoupling and DC block capacitors were mounted and reflow processing was performed. Then, SiPh PIC, driver, and TIA chips were flip-chip bonded, and an underfill was injected into the gap between the substrate and each chip. Next, solder paste was printed on the other side of the substrate and solder balls were mounted to form BGA. A fiber array assembly was attached to SiPh waveguides. Finally, a lid covered the inside chips contacted by thermal interface material for heat dissipation. Figure 1 (b) shows a picture of the COSA.

For testing frequency characteristics, COSAs were soldered on printed circuit boards (PCBs) which had mini-SMP connectors for connecting coaxial cables. To de-embed the PCB loss, we measured frequency response of the test PCB that had two connectors at both edges, and the length of traces between connectors was twice as length from mini-SMP connector to solder ball pad for COSA. We applied this test PCB trace loss to de-embed measured COSA frequency responses. Figure 2 (a) shows EO responses of the COSA transmitter side. An average 3-dB bandwidth was 54 GHz with maximum gain and peaking setting for four channels, and they were consistent performances. Figure 2 (b) represents OE responses of the COSA receiver side. It has an average bandwidth of 52 GHz bandwidth for channels.



(a) (b)

Figure 1. (a) Schematic configuration and (b) picture of fabricated COSA



(a) (b)

Figure 2. (a) EO responses of transmitter side and (b) OE responses of receiver side

3. High baud rate signal generation and detection experiments

We conducted high baud rate signal generation and detection experiments by using two fabricated COSAs for a transmitter and a receiver. The COSA for the transmitter was connected to a four-channel arbitrary waveform generator (AWG) operating at a sampling rate of 120 GS/s. The COSA for the receiver was connected to a digital storage oscilloscope (DSO) with a sampling rate of 240 GS/s. Although we connected each COSA test board to AWG/DSO by coaxial cables as short as possible to minimize loss, PCB traces and cables introduced about 5 dB additional loss at 50 GHz.

Transmitted signals were calculated by offline processing and uploaded to the AWG. We applied digital calibration scheme that compensate for linear frequency responses of the transmitter and the receiver including COSAs, test boards, coaxial cables, and DSO/AWG. Training sequences were transmitted and received to calculate tap coefficients of linear equalizers that compensate for frequency amplitude and phase responses of the transmitter and the receiver [9]. We did not employ any optical pre-compensation. After tap coefficient optimization, we performed 80 Gbaud and 96 Gbaud polarization multiplexed 16QAM optical signal generation and detection. Figure 3 shows the constellations in back-to-back configuration. We obtained Q-factor of 7.6 dB and 6.6 dB calculated from a bit error rate (BER) at an optical signal-to-noise ratio (OSNR) of 26 dB for 80 Gbaud and 96 Gbaud, respectively. Assuming 20 % overhead forward error correction (FEC) with a pre-FEC Q-factor limit of 5.7 dB, we achieved the net rates of 527.15 and 632.58 Gb/s excluding FEC overhead and 1.17 % pilot symbol.

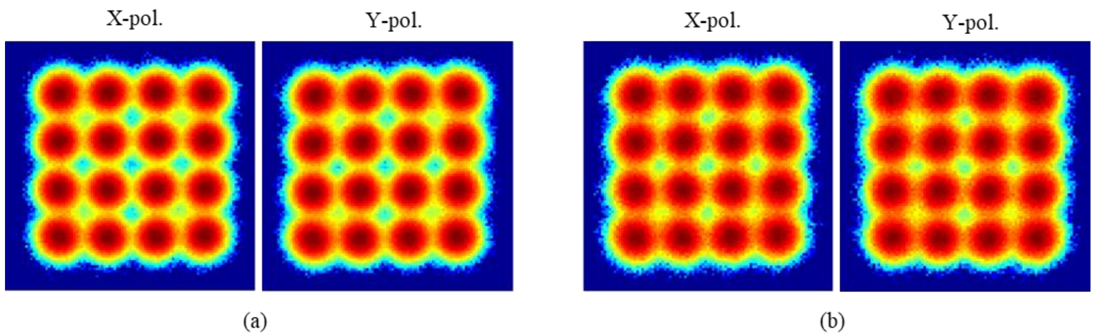


Figure 3. (a) 80 Gbaud and (b) 96 Gbaud polarization multiplexed 16QAM constellations

4. Conclusion

We described a SiPh COSA with the widest EO and OE bandwidths of 54 GHz and 52 GHz. We also demonstrated up to 96 Gbaud polarization multiplexed 16QAM optical signal generation and detection. These results show feasibility of SiPh technologies for beyond 100 Gbaud coherent systems.

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