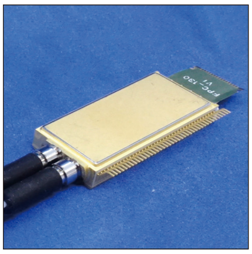


Low Insertion Loss, High Bandwidth Coherent Driver Modulator for 1 Tbit/s Fiber Transmission

Yasutaka MIZUNO*, Munetaka KUROKAWA, Naoki ITABASHI, Taichi MISAWA, Hiroshi UEMURA, and Manabu SHIOZAKI

With the increasing amount of internet traffic, there is a growing demand for high-capacity optical fiber communication not only for long-haul communication but also for inter-data centers communication. We have been developing InP modulators and driver ICs. Recently, we have developed a modulator module and successfully demonstrated 1 Tbit/s fiber transmission with a low power consumption of less than 3 W. We have also developed a spot size converter using 3D printing technology and achieved a low loss of 9.5 dB as part of the modulator module, confirming its reliability for Telcordia standards.

Keywords: optical fiber communication, coherent, modulator, 3D-print, HB-CDM

1. Introduction

Internet communication traffic has been increasing due to the widespread use of social media, a rapid increase in video streaming, and greater acceptance of telework in recent years. As data centers become larger and more decentralized, the increase in communication traffic between data centers has become a significant issue.

In optical fiber communication, the intensity modulation protocol, in which the optical intensity is used to transmit signals, was commonly used. The coherent optical transmission protocol, in which both the intensity and the phase are used to carry information, has also come into use to meet the need for higher capacity. Coherent optical transmission enables long-haul communication over thousands of kilometers with digital signal processing technology, in combination with dozens of wavelengths division multiplexing in a single optical fiber. Due to these characteristics, coherent optical transmission was mainly used on trunk line networks of over 100 km. In recent years, however, demand for inter-data-center connections of 100 km or less, which is a relatively short distance, has been growing rapidly due to the limit of long-haul transmission by intensity modulation as well as the miniaturization and lower power consumption of coherent devices.

Such inter-data-center connections require a transmission speed equivalent to or higher than that of intra-data-centers, so high-speed optical modules of 400 Gbit/s or more are required. It is also necessary to reduce the insertion loss and power consumption of optical modules to meet the recent trend of "going green."

Previously, we developed a modulator[1] and a receiver[2] using InP-based materials as well as a module[3] that mounted the modulator and receiver. Through further development of these technologies, we have developed a coherent modulator module (HB-CDM*1), which achieves ultra-high-speed operation over 1 Tbit/s and ensures both low insertion loss and low power consumption.

2. Module Design

2-1 Module structure

The appearance of the HB-CDM is shown in Photo 1. We achieved miniaturization and low profiling by our matured assembly technology. The package size of W 11.6 mm × L 30.1 mm × H 4.45 mm conforms to OIF*2 specifications[4], which are the industry standard. Regarding the interface of electrical signals, the OIF specifications stipulate both the lead pin type and the FPC type. We used the FPC type because it would be suitable for high-speed operation.

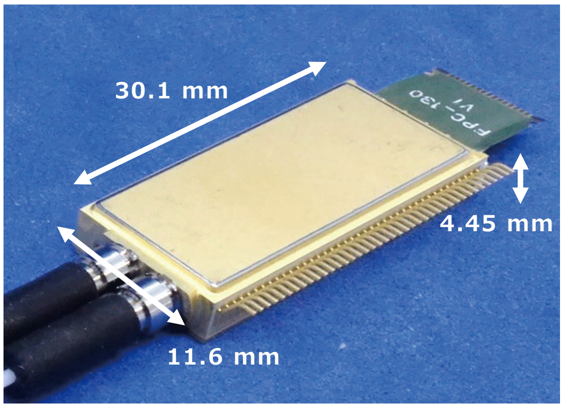
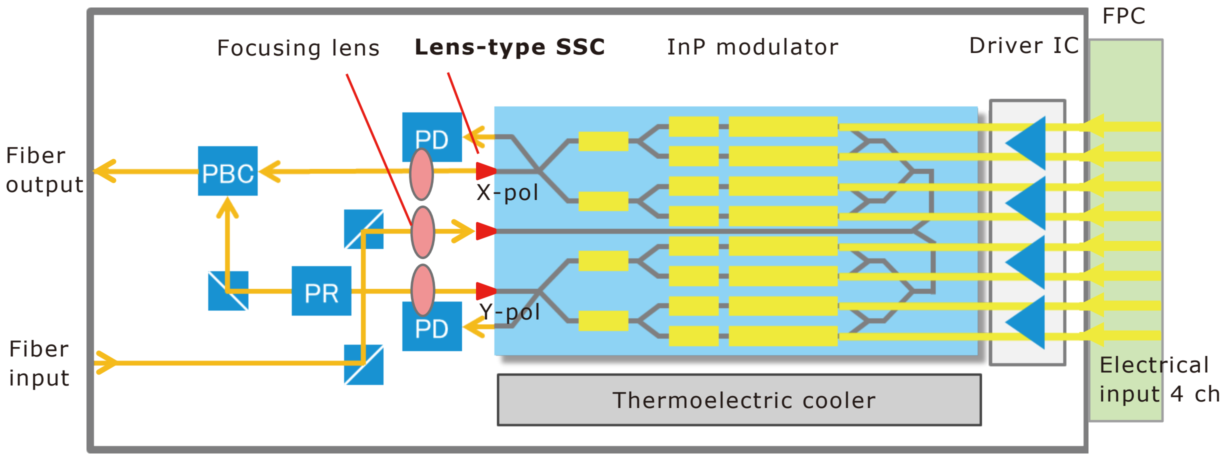


Photo 1. Appearance of the HB-CDM package

Next, Fig. 1 shows the block diagram inside the module. An InP modulator, a driver-IC, various optical parts, and a thermoelectric cooler are mounted inside. The operation principle is as follows. First, continuous wave light is input via a fiber and enters the InP modulator. Similarly, electrical signals are input via the FPC, amplified by the driver-IC, and input into the InP modulator. The InP modulator can add signals to the light by changing the



PBC: Polarization Beam Combiner
PR: Polarization Rotator
PD: Photo Detector

Fig. 1. Block diagram of the HB-CDM

phase state of light according to the electrical signals. The generated signal light goes out from the InP modulator and is coupled with the output fiber. In this way, the input electrical signals are converted to optical signals and transmitted externally via the fiber.

2-2 Optical design

As a new technology, we introduced a lens-type spot size converter (SSC)*3 at the input and output ports of the modulator, utilizing 3D printing technology. In the InP modulator, the waveguide width should be narrower to improve the modulation efficiency. This results in the beam diameter of 1.0 µm, which is smaller than the diffraction limit and generates a large coupling loss with the fiber. To cope with the problem, the waveguide-type SSC is commonly used to expand the output beam.(5) However, it posed two issues, SSC's inherent mode conversion loss and the larger chip size.

To solve these issues, we devised a lens-type SSC as shown in Fig. 2. Unlike a waveguide-type SSC, the lens-type SSC converts beam diameter by optical refraction, making it possible to shorten the SSC size to 1/10 smaller than that of a waveguide-type SSC. Expansion of the beam diameter improves coupling loss with the fiber, and also relaxes the alignment tolerance of an optical system, which is expected to improve module reliability.

To realize such SSC, we focused on nano-scale 3D printing technology(6) using two-photon polymerization*4. The lens-type SSC could be directly formed on the end face of the InP modulator by 3D-printing technology. After forming the SSC, we assembled the HB-CDM module and measured various characteristics.

3. Results of the Module Evaluation

3-1 Optical characteristics

Figure 3 shows the alignment tolerance of the focusing lens at the input and output ports of the modulator. While the curve is very steep without the SSC (1 dB tolerance: ±0.4 µm), the tolerance is wider with the SSC (±0.8 µm). The estimated beam diameter is 1.0 µm without the SSC and 2.7 µm with the SSC, indicating that the SSC

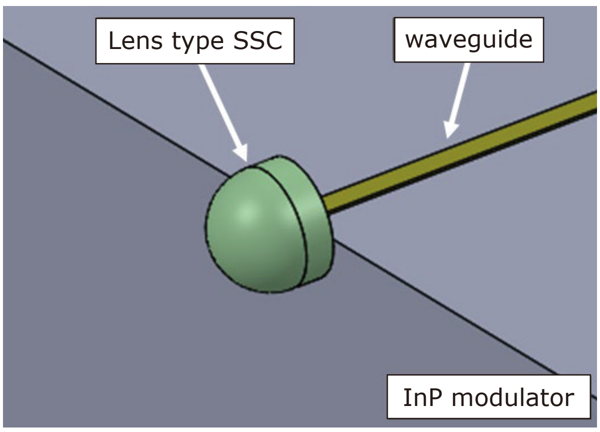


Fig. 2. Lens-type SSC (image)

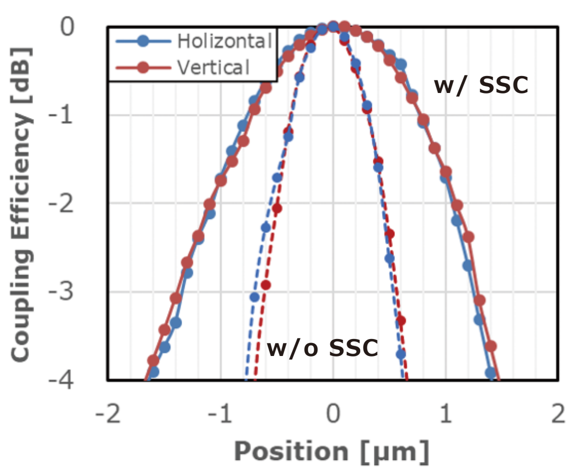


Fig. 3. Alignment tolerance of focusing lens

made the beam diameter three times larger. We confirmed that the coupling efficiency between the InP modulator and fibers improved significantly from 55% to 78% with the SSC.

Next, the wavelength dependence on the insertion loss of the HB-CDM module is shown in Fig. 4. The values include the transmission and separation loss in the InP modulator and the coupling loss between the modulator and the fibers. The insertion loss of our conventional module was as large as 13.5 dB due to the large coupling loss, but it was improved to 9.5 dB at 1550 nm by introducing the SSCs. The absence of wavelength ripples indicates that the influence of reflection by the SSCs is small. In addition, the loss of X polarization (X-pol) completely matched the loss of Y polarization (Y-pol) in Fig. 4, showing that polarization dependence is also small. From these results, we confirmed good optical characteristics by introducing the SSCs.

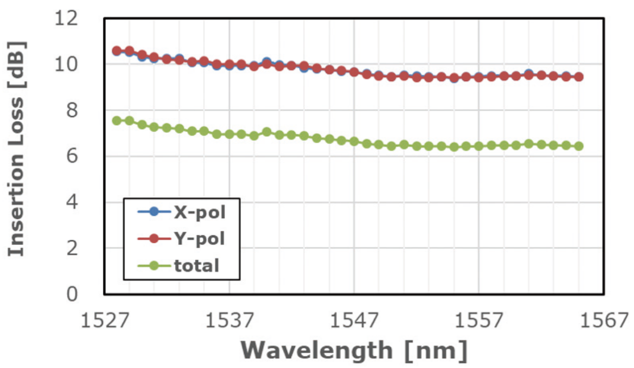


Fig. 4. Wavelength dependence on the insertion loss of HB-CDM

3-2 Electro-optical frequency response

The responsiveness of the modulator module to high-speed signals (the frequency response characteristics) is determined by the multiplication of the characteristics of components that transmit electrical signals, including the modulator chip, driver-IC, package, and FPC. We design these parts in-house, so optimized electrical property has been achieved through the coordinated design of the respective parts. Figure 5 shows the electro/optical (E/O) frequency response characteristics of the HB-CDM. A 3 dB bandwidth of > 75 GHz is necessary for 1 Tbit/s transmission, which is above the dotted line. Our HB-CDM meets these requirements and achieves a bandwidth of 80 GHz. As shown in the figure, the same characteristics are attained in all four channels, indicating that the difference among the channels is small.

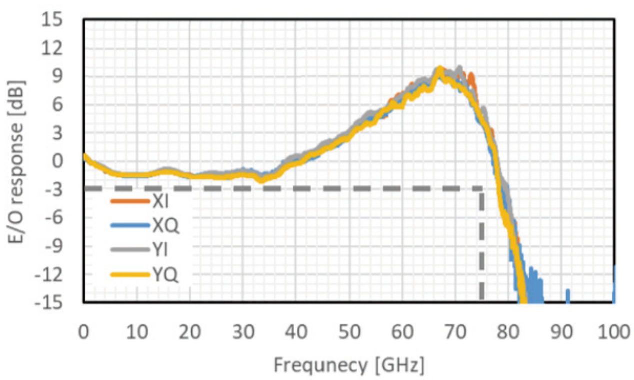


Fig. 5. HB-CDM's E/O frequency response

3-3 Power consumption

The faster the operation speed of the modulator module, the higher the power consumption. According to OIF specifications, the upper limit for class 80 HB-CDM is 6.5 W. Although our conventional HB-CDM had sufficient capacity to meet the specification, we have further reduced the power consumption by optimizing the design of the driver-IC and the thermoelectric cooler. The power consumption of the HB-CDM module at different temperatures is shown in Fig. 6. Because the thermoelectric cooler in the module is set to 50°C, power consumption reaches its maximum at −5°C and 75°C. Based on these results, we could demonstrate the power consumption of 3 W or less in the entire operation temperature range, which was half or less than the OIF specifications.

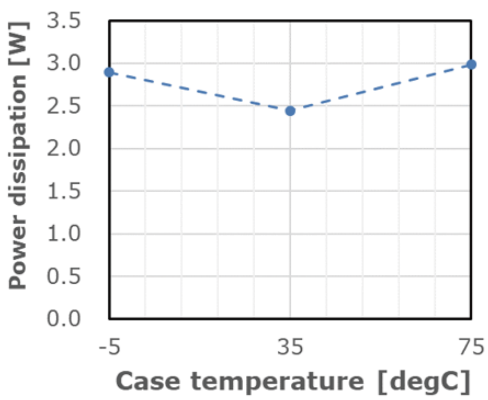


Fig. 6. HB-CDM's power consumption

3-4 Fiber transmission characteristics

We conducted a fiber transmission test to demonstrate that our HB-CDM could be used for actual data transmission. Figure 7 shows the evaluation system for the transmission test. 128 Gbaud electrical signals generated by an arbitrary waveform generator (AWG) were input into the HB-CDM, and the unmodulated light of 1550 nm was also input into the HB-CDM. The generated signal light was received by an optical modulation analyzer (OMA) to evaluate the waveform and the bit error rate (BER). The constellation*[5] of 16QAM*[6] modulation is as shown in Fig. 8. Clear signals with small waveform distortion were confirmed. The error vector magnitude (EVM), which indicates the difference from ideal signals, was as small as 9.8%. A BER of 1.04×10^{-3} was confirmed to be sufficiently smaller than the FEC limit*[7] of 2×10^{-2}. Based on these results, we demonstrated that our HB-CDM met 128 Gbaud 16QAM, namely, 1 Tbit/s transmission.

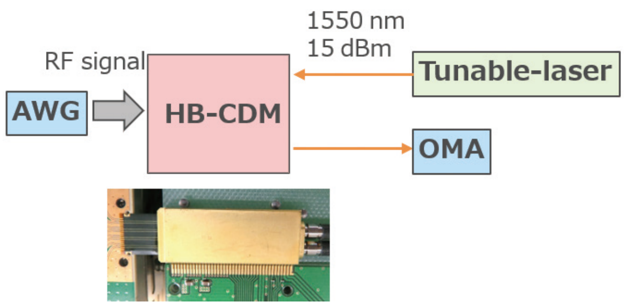


Fig. 7. Evaluation system for fiber transmission characteristics

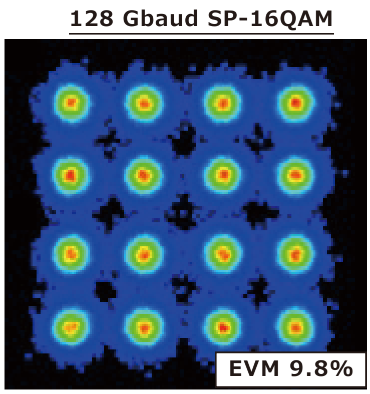


Fig. 8. Evaluation results of fiber transmission characteristics

3-5 Reliability

More rigorous reliability is required for telecommunication optical modules compared to general consumer equipment. Telcordia GR-468[7] is established as the industry standard for reliability requirements, and reliability tests based on it were conducted on the prototype HB-CDM module. The fiber output power of HB-CDM was evaluated after each test. Figure 9 shows the changes in fiber output power. The standard requires the changes to be within ±0.5 dB, and the test results showed that the changes were 0.1 dB or less. Notably, there was a concern about the reliability of the newly introduced 3D-printed SSCs, but no problem was found even after the temperature cycle or mechanical shock.

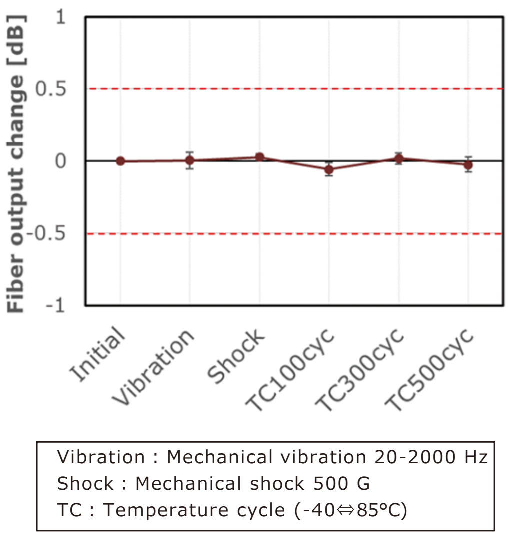


Fig. 9. HB-CDM reliability test results

4. Conclusion

To cope with growing Internet communication traffic in recent years, we have developed an HB-CDM that can operate for ultra-high-speed transmission of 1 Tbit/s. We have achieved a bandwidth of 80 GHz based on the coordinated design of the components, and demonstrated fiber transmission of 1 Tbit/s. We have introduced our proprietary SSCs by using 3D printing technology and significantly improved the coupling efficiency. We also demonstrated that the reliability of HB-CDM could meet the Telcordia standard.

Technical Terms

*1 HB-CDM: Abbreviation for "High-Bandwidth Coherent Driver Modulator." This is a coherent modulator module incorporating a modulator and driver-IC.

*2 OIF: Abbreviation for "Optical Internetworking Forum." This is an industrial organization responsible for standardizing optical network technologies.

*3 Spot size converter (SSC): Functions to convert the optical beam diameter.

*4 Two-photon polymerization: A technology to locally cure resin by non-linear optical effect with irradiated laser.

*5 Constellation: A diagram that shows received signals on the IQ phase coordinate plane.

*6 16QAM: A transmission protocol with $2^4 = 16$ patterns in the optical intensity and phase state. A single signal has 4-bit information, and combination with polarization multiplexing enables transmission of 8-bit information.

*7 FEC-Limit: Abbreviation for "Forward Error Correction Limit." This is the upper limit of errors that can be restored by forward error correction. Error-free transmission can be achieved at this value or less.

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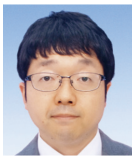

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