European Conference on Optical Communication (ECOC) 2022 © Optica Publishing Group 2022

2-dimensional Low-profile Fiber Coupler for Co-packaged Optics

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Abstract *2-dimensional low-profile fiber coupler (2D-LPC) with 64-SMFs and 8-PMFs is demonstrated for co-packaged optics. The fabricated 2D-LPC shows high density of 24 fibers/mm, total height of 5.5 mm, low insertion loss of < 0.5 dB, and high polarization extinction ratio of > 20 dB.*

Introduction

Continuous growth of internet traffic requires increasingly higher bandwidth for data transmissions from and to the servers in datacenters (DCs). In DC switches, signalling from a switch application-specific integrated circuit (ASIC) to a pluggable optical transceiver (TRx) on the front panel is performed electrically through a printed circuit board (PCB) as shown in Fig. 1(a). However, high-speed electrical connections are approaching their fundamental limitations in terms of data rate and energy consumption. Co-Packaged Optics (CPO) is attracting attention as a technology for overcoming limitations [1]. As shown in Fig. 1(b), the CPO is enabled by Silicon photonics (SiPh) technology and the SiPh chip is placed close to the switch ASIC for shortening the electrical wiring interconnect, thus reducing the overall energy consumption while keeping the data rate.

Grating coupler (GC) is a technology widely applied for SiPh [2] and recognized as a cost-efficient fiber coupling technique. However, as shown in Fig. 1(b), fiber coupling to GCs are made vertically to the chip surface in limited space. Furthermore, as CPO module will support 3.2 Tb/s total bandwidth or more, fiber coupling solution must have features such as high-density, low-profile, and fiber count scalability. In this paper, we demonstrated a two-dimensional low-profile fiber coupler (2D-LPC) as a proof-of-concept for the CPO. The low loss, high channel density and heat durability are achieved by combining glass plates with bent fibers.

Design strategy

Assuming a 51.2 Tb/s total switch bandwidth supported by 16 × 3.2 Tb/s CPO modules, consisting of 8 × 400GBASE-DR4, each CPO module needs to couple with 64 single-mode fibers (SMFs). In addition, polarization-maintaining fibers (PMFs) are necessary for supplying light from remote light source (RLS) to SiPh chip as shown in Fig. 1(b). Assuming one laser chip supplying light to one 400G transmitters, 8 PMFs are also required. Hence, 72 fibers (64 SMFs and 8 PMFs) are required in total.

From CPO document [3], maximum width for the fiber coupler part is 16 mm. Thus, the density more than 4.5 (=72/16) fibers/mm is required. However, as shown in Fig. 2, conventional optical fiber array with one dimensional (1D) arrangement with 0.25-mm pitch is insufficient, because density is limited less than 4.0 fibers/mm. The 1D fiber array with 0.127-mm pitch (double-density) can be used for 51.2 Tb/s generation, however, it cannot support 102.4 Tb/s generation. From the Fig. 2, the coupler technology with density more than 20 fibers/mm would be a rational and sustainable choice as it can support at least 409.6 Tb/s with DR4 200G/lane.

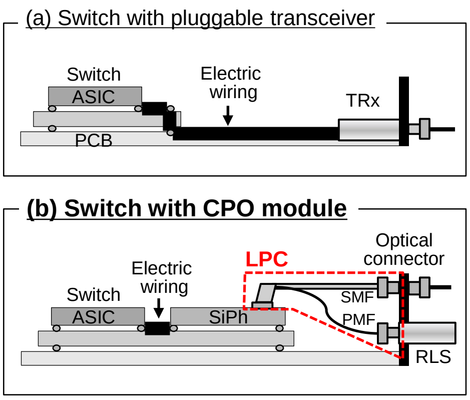

Fig. 1: Schematic of switch with (a) pluggable transceiver and (b) CPO module.

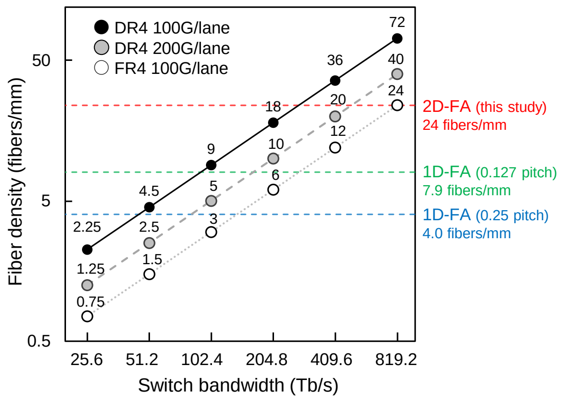

Fig. 2: Estimation of density with necessity with respect to switch bandwidth.

Therefore, we studied fiber array with 2-dimensional (2D) arrangement having density of 24 fibers/mm by using 2D glass plate (2D-GP) with high-precision holes [4]. By employing a glass plate as a fiber position aligner, glass will be the interface material to the SiPh chip. This is beneficial as it offers CTE-matching with the SiPh chip, while its UV transparency enables the bonding between the fiber array and SiPh chip using UV-curable resin. The high thermal durability of glass is also suitable for use around switch ASIC, where ambient temperatures can reach 110°C [5].

From ref. 3, maximum height for the fiber coupler part is 6 mm and the fiber is necessary to be bent sharply to meet this requirement. A bent fiber with bending radius of around 2.5 mm is subjected to a strong stress of around 1.8 GPa, which is two times higher than the screening stress in general fiber production. Hence, there is significant risks in terms of product life for using the bent fiber such a severe bending condition. In order to overcome this issue, we employed a stress-free bending technique [6]. By using this technique, the fiber is free from stress even when it was bent to radius R = 2.5 mm, thus high reliability guaranteed.

Sample preparation

Based on above design strategy, 72-fiber 2D-LPC was prepared. Figure 3 shows the schematic of the 72-fiber 2D-LPC. The sample consists of the 2D-GP, bent fiber ribbons (with bending radius R = 2.5 mm), fiber supporting part, and 24-fiber MT ferrules [7]. The glass plate has 12 × 6 array with the pitch of 0.25 × 0.3 mm. The holes are tilted by 8 degrees to suppress the return loss. Six 12-fiber ribbons were stacked and the fiber ribbons were connectorized to the 24-fiber MT ferrules. The total height of the prepared sample is 5.5 mm, which meet requirement in ref. 3. The 72 fibers are placed within 3 mm width, thus, the density is 24 (= 72/3) fibers/mm. This is 6 times higher than a conventional 0.25-mm pitch 1D fiber array and it is scalable by increasing number of column or row as occupied area is small enough.

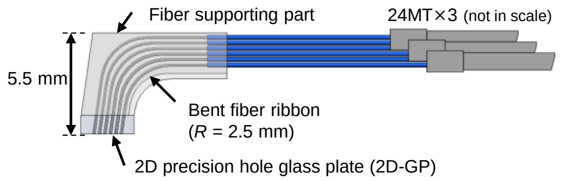

Fig. 3: Schematic of the 72-fiber 2D-LPC.

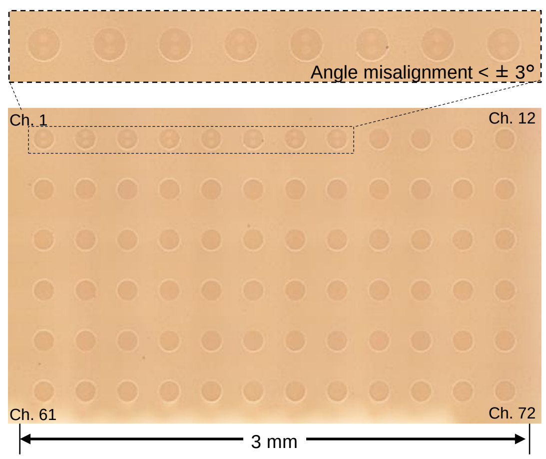

Fig. 4: Picture of end-face of 2D-LPC. Channel 1 – 8: PMFs. Channel 9 – 72: SMFs.

Figure 4 shows the end-face of fabricated 2D-LPC with 64 SMFs and 8 PMFs. The misalignment of rotational angle of the PMFs, which leads to excessive loss due to polarization mismatch to GC, are < ± 3°. The misalignment angles of the PMFs in MT ferrule are also < ± 3°.

Evaluation of optical characteristics

Because we do not have master 2D-LPC with perfect position accuracy yet, insertion loss (IL) and fiber core position error were measured for estimation of loss when 2D-LPC couples with the SiPh chip with the identical channel positions.

Figure 5 shows the result of measured IL. The inset of Fig. 5 shows a setup for the measurement. In this measurement, a SMF actively aligned to the end-face of 2D-LPC and powers at the MT ferrules side were detected by power meter (PM). IL of all of channels were less than 0.5 dB, and average value was 0.33 dB.

Next, in order to estimate the coupling loss (CL) with GC, fiber core position error from designed position was measured. Figure 6 shows histogram of the measured core position error. The average and maximum core position errors were 0.5 μm and 2.1 μm, respectively. The CL (dB) was estimated by following equation [8]:

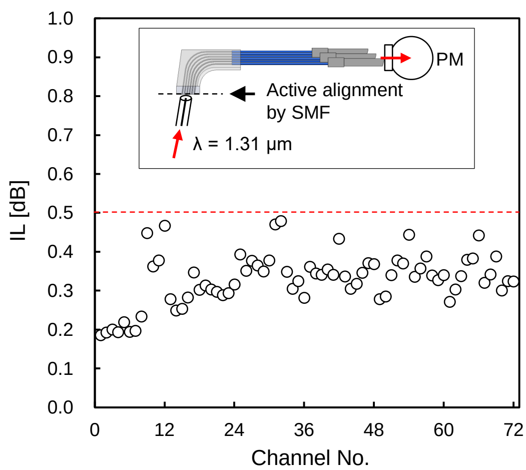

Fig. 5: Result of IL measurement. (Inset: setup for active alignment with SMF).

$$\mathrm{CL} = -10\log\left(\frac{2w_1w_2}{w_1^2+w_2^2}\right)^2 \exp\left(-\frac{2s^2}{w_1^2+w_2^2}\right) \quad (1)$$

where, $2w_1$ and $2w_2$ are mode field diameters (MFDs) and we assumed as 8.6 µm for both $2w_1$ and $2w_2$, since MFD of GC is generally designed to match with that of SMFs. The *s* is position error between the optical fiber and GC. As the position error of GC is considered as almost zero, the value of *s* is assumed as values of the measured fiber core position error. Based on the above assumptions, the CLs are calculated and shown on the secondary axis in Fig. 6. At *s* of 0.5 µm, which is measured average core position error, CL is 0.06 dB. For the worst-case *s* of 2.1 µm, CL is 1.04 dB. The major origin of core position error is due to glass hole diameter deviation and inaccurate hole position. Further CL reduction can be expected by advance of the 2D-GP fabrication process.

Then, the polarization extinction ratio (PER) is measured to evaluate polarization-maintaining performance of PMF in the fabricated 2D-LPC. Generally, GC of SiPh chip can receive only one polarized light, polarization mismatch leads to the excessive loss (EL) at fiber-GC coupling interface. By using the PER, the EL (dB) can be estimated by a following equation:

$$\mathrm{EL} = 10\log\left(1 + 10^{-\mathrm{PER}/10}\right). \quad (2)$$

Assuming target EL of less than 0.1 dB, PER more than 16 dB is necessary. The setup of cross-polarizer measurement method [9] and results of the PER measurement are shown in Fig. 7. The results show that PER of all 8 PMFs exceeds 20 dB, and it indicates that 2D-LPC has high polarization-maintaining performance even at bending radius of 2.5 mm.

Results of reliability tests

In order to verify basic reliability of the 72-fiber 2D-LPC, we performed heat cycling test from −45°C to 85°C for 100 cycles and dump heat test at 85°C/85%RH for 100 hours as an acceleration test and confirmed no fiber breakage. The thermal durability for use around switch ASIC was tested by 110°C continuous operating test for 168 hours. As shown in Fig. 8, the power variation is less than ± 0.4 dB. More longer-term test is on-going.

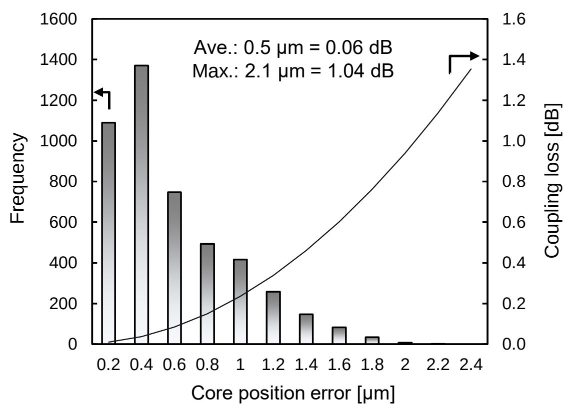

Fig. 6: Histogram of core position error. Estimated coupling loss due is described in secondary axis.

Conclusions

We demonstrated 72-fiber 2D-LPCs as a high-density and low-profile fiber coupler for CPO. The fabricated 2D-LPCs show insertion loss of less than 0.5 dB, core position error of 0.49 µm in average, and PER of more than 20 dB, while achieving the required compactness. The results of reliability test also indicate robustness of the 2D-LPC structure. Therefore, the developed 72-fiber 2D-LPC offers robust, space-efficient, and scalable fiber coupling application for surface coupling type CPO module.

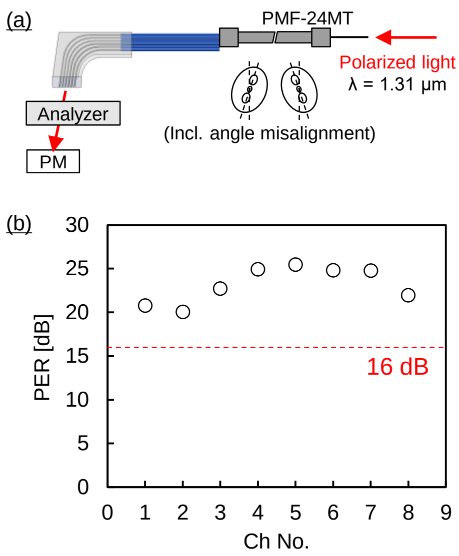

Fig. 7: (a) Setup and (b) result of PER measurement.

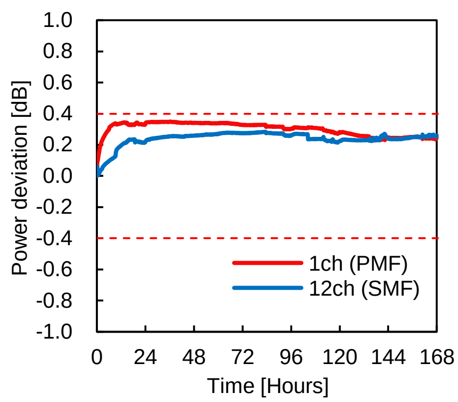

Fig. 8: Result of 110°C continuous operating test.

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