Flexible, Multi-channel, Ultra-dense Optical Interface for Silicon Photonics

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Abstract We demonstrate an all-glass, 61-channel, flexible, two-dimensional optical fiber array with 37 inner channels matched to an array of vertical grating couplers of a multi-channel (16 Tx and 16 Rx) transceiver prototype occupying a chip area of only 0.16 mm².

Introduction

High density connections at optical interfaces are essential for photonic integrated circuits (PICs) with a large number of optical input and output channels. The channel density at the optical interface with a PIC can be increased beyond what has been accomplished with edge coupled linear fiber arrays by using a two-dimensional channel array. This saves valuable chip real estate and reduces waveguide propagation losses. The channel spacing of standard fiber arrays is limited by the fiber diameter, which is typically 125 μm, while the channel spacing of vertical grating couplers (VGCs) in silicon PICs is limited by the waveguide routing and can be smaller than 40 μm for a hexagonal arrangement.

Recently, IBM has developed a multi-channel, polymeric interposer based on adiabatic coupling¹ to achieve a broadband, dense optical input/output (IO), which does not require a diffractive element. Adiabatic interposers require a significant chip surface area, which for 12 channels exceeds the area required by a compact hexagonal array of 37 VGCs by more than an order of magnitude. While edge coupling, including adiabatic coupling, generally provides wider bandwidth per channel, both the coupling loss and the bandwidth of surface couplers have been improved significantly² while being compatible with a standard CMOS process³. Utilizing pitch reducing optical fiber arrays (PROFAs) allows the use of a compact array of 19 VGCs for probing⁴ or attaching a 37 channel fiber array to a passive PIC⁵. Packaging of active PICs requires the ability to add a heatsink and multiple electrical connections. These may not be compatible with a long rigid glass piece perpendicular to the PIC’s surface.

Here we demonstrate an all-glass, 61-channel, flexible optical interface for silicon photonics. It is based on a flexible two-dimensional optical fiber array matched to 37 vertical grating couplers of a multi-channel (16 Tx and 16 Rx) transceiver prototype with expected aggregate bandwidth of 1600 Gb/s. Further development of the PROFA enabled the combining of 61 optically isolated channels in a low-crosstalk, thin and flexible monolithic glass element (Fig. 1). The diameter of the flexible portion is less than 125 μm diameter, which is more flexible than standard SMF28 fiber.

![Fig.1: Flexible 61-channel PROFA attached to a 37 channel array of VGCs of a transceiver prototype. In the flexible section, all 61 channels are confined in a glass fiber of less than 125 μm diameter, which is more flexible than standard SMF28 fiber.](image-url)
less than 1 μm for all 37 channels. The large section of the coupler, which is mechanically uncoupled from the attachment point, is supported by a holder (Fig. 1). Since the coupler is bent, the untapered end of the flexible PROFA can be integrated into a low vertical profile package as-is or serve as a multicore fiber connector for a pigtailed or pluggable device.

**Design, fabrication, and results**

Packaging of PICs with low vertical profile is desirable for a variety of applications in optical communications and sensing. While this is easily achievable for edge couplers, surface couplers require substantial vertical length. The vanishing core approach used in the PROFA can be utilized in two steps to further reduce the outside diameter of the coupler by introducing a second outer core with index (n2) lower than the first outer core (n1) without compromising channel crosstalk (Fig. 2). In the flexible PROFA, the difference n3-n4 is larger than n2-n3 or n1-n2. This results in a high NA waveguide, which is insensitive to bending when the fiber is tapered to a small diameter and the light is guided by the second outer core (n3) (Fig. 2, flexible section). The calculated MFD versus channel spacing is shown in Fig. 3. The outer diameter of the coupling end is expanded to match both the 37-μm channel spacing and the MFD of the VGC array (Fig. 2, attachment point). The glass assembly: (1) is fused and drawn using a miniature draw tower, (2) has its flexible thin section polymer coated, and (3) is angle polished to match the 10 degree diffraction angle of VGCs. As shown in Fig. 2, this results in a structure which maintains low crosstalk between all channels while providing the flexibility necessary for a low-profile package. In addition, the flexible portion of the coupler provides mechanical isolation of the
PROFA-PIC interface from the rest of the PROFA. This increases stability to environmental fluctuations, including temperature variations and mechanical shock and vibration.

The PROFA tip was first aligned in series with each of five devices built on a 5x5 mm² chip, shown in Fig. 4. The devices are prototypes of compact multi-channel transceivers with modulators aiming for a bandwidth of 50 Gb/s and expected aggregate bandwidth of 1600 Gb/s. All devices are equipped with 37 channel VGC arrays and are designed for different spectral ranges. Only the inner 37 channels of the 61 channel PROFA were used for grating coupling. Two diagonally positioned VGCs are connected back-to-back for alignment of the PROFA and VGC array, 16 are used for Tx, and 16 are used for Rx. The coupling losses in different devices for the back-to-back connected reference channel pairs, measured at the 10 μm air gap before the PROFA attachment, are shown in Fig. 5. The packaging process was tested by attaching the PROFA to device # 5 via an index matching adhesive and bent into the PROFA holder as shown in Fig.1. The coupling loss measured after the PROFA attachment for the back-to-back connected reference channel pair is shown in Fig. 6. The maximum fiber-to-fiber coupling loss is ~ 7 dB, corresponding to less than 3.5 dB coupling loss per VGC. The crosstalk between PROFA channels after attachment was measured by launching light into channels neighboring the back-to-back connected pairs. The measured crosstalk was lower than -30 dB. The loss is stable with respect to movement of the untapered section of the PROFA. Such movement only flexes the thin section and does not affect the PIC attachment area.

Conclusion
We have designed and fabricated an optical IO interface for a prototype of a multi-channel (16 Tx and 16 Rx) transceiver with expected aggregate bandwidth of 1600 Gb/s with incorporated 37-channel array of VGCs occupying a chip area of only 0.16 mm². The fiber coupling is provided by the inner 37 channels of a 61 channel PROFA in which all 61 channels are part of a flexible, all-glass structure, which is even more compliant than a standard single core SMF. This opens a path to ultra-dense, multichannel optical interfaces for large port-count silicon photonics transceivers and switches.

References