Inverse-designed, normal incidence polarizing and polarization demultiplexing grating couplers for multi-core fiber

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***Abstract*—We experimentally demonstrate normal-incidence grating couplers designed using topology optimization to couple into multi-core fiber. The insertion loss of the polarizing and polarization demultiplexing gratings was –5.5 dB and –7.7 dB, which is within 0.8 dB of the performance obtained using a fiber array.**

Keywords—Inverse design, multi-core fiber, grating couplers

Multi-core fibers (MCF) provide increased resilience to environmental impacts such as vibrations and temperature changes between cores since each core experiences near identical effects compared to multi-fiber systems [1]. By suppressing differential-mode noise caused by environmental impacts, MCF enables highly sensitive interferometric integrated microwave photonics applications between chips. To enable such applications on commercial foundry integrated platforms, we designed compact, multi-layer grating couplers on the Global Foundries 45CLO process [4] compatible with a standard four core MCF from OFS [5]. The gratings were designed using topology optimization, a gradient-based design algorithm where the design region is divided into pixels that freely evolve between specified design materials to optimize the device performance [6]. MCF requires the grating couplers couple at normal-incidence, which heightens the difficulty of the design because of increased backreflections [7]. We designed two grating coupler variants: a polarizing grating coupler and polarization demultiplexing grating coupler. The polarizing grating coupler emits the fundamental TE waveguide mode into an optical fiber while simultaneously filtering the unwanted orthogonal polarization. Conversely, the polarization demultiplexing grating coupler demultiplexes light from the optical fiber into the fundamental TE mode of separate waveguides. We optimized both grating couplers from 1540 – 1560 nm and measured the amplitude, phase, and polarization data of the couplers in the complete Jones matrix to calculate the insertion loss, 1-dB bandwidth, and polarization dependent loss (PDL). Averaged across all devices, we measured –5.5 dB insertion loss and 33.5 1-dB bandwidth from the polarizing grating coupler and –7.7 dB insertion loss and 24.3 nm 1-dB bandwidth from the polarization demultiplexing coupler at the peak coupling wavelength. Furthermore, the PDL of the polarization demultiplexing grating coupler was less than 1.7 dB across c-band.

We fabricated the grating couplers in a square corresponding to the core separation of the MCF, Fig. 1(e). For the polarizing grating couplers, Fig. 1(a), we connected the loopbacks to diagonal cores of the MCF, Fig. 1(c). Since each polarization demultiplexing grating coupler, Fig. 1(b) has two outputs, we fabricated two loopbacks per grating coupler to separately measure each port of the device, Fig. 1(d). We independently determined the loss of the patch cords and the MCF fanout to directly assess the performance of the on-chip loopbacks. Using a red-light laser, we aligned the MCF, Fig. 1(f) with the grating couplers to maximize the power transmission through one of the loopbacks. Then, we measured the complete Jones matrix of this connection from 1525 – 1575 nm using the Luna OVA 5100. Without realigning the fiber, we performed the same measurement on the other core pairs.

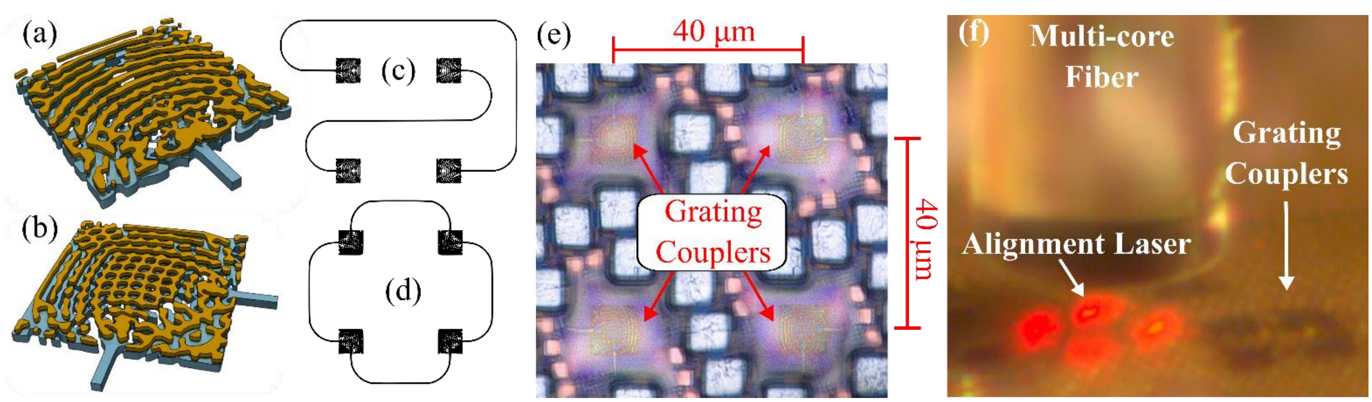

Fig. 1. Microscope image of the multicore fiber alignment process using a red-light laser (f). The grating couplers were in a square-shaped configuration of length 40 μm (e), corresponding to the core separation of the MCF. We fabricated loopbacks between the polarizing grating couplers (a) located on diagonal vertices of the square (c) and between polarization demultiplexing grating couplers (b) located on adjacent vertices of the square (d).

From the polarization, amplitude, and phase characterization of each loopback contained in the complete Jones matrix, we calculated the insertion loss, bandwidth, and PDL of the grating couplers. Specifically, we define the insertion loss as the difference between the total input power and the total output power. At the peak coupling wavelength, the polarizing loopbacks demonstrated average insertion loss of –11.0 dB, and the polarization demultiplexing loopbacks averaged an insertion loss of –15.4 dB. Since the insertion loss is the sum of the insertion loss of the two grating couplers and the waveguide loss, we assumed that the grating couplers had equal insertion loss and the waveguide was lossless. Therefore, we report –5.5 dB and –7.7 dB insertion loss for the polarizing and polarization demultiplexing grating couplers respectively, Fig. 2(a-b). The 1-dB bandwidth of the single polarization grating couplers ranged from 22 – 45 nm. Conversely, the 1-dB bandwidth of the polarization demultiplexing grating couplers ranged from 21 – 28 nm. Furthermore, we define the PDL as the difference between output power of each arm of the polarization demultiplexing grating coupler in the intended polarization. Therefore, we again assumed that each grating coupler in the loopback had equal loss to estimate the loss of a single grating coupler. Then, we subtracted the output powers of each arm of the grating coupler and found PDL less than 1.7 dB for all four grating couplers from 1525 – 1575 nm, Fig. 2(c). The Fabry-Perot resonances apparent in the loss measurements are due to backreflections in the silicon waveguide between the two grating couplers. Comparing our measurements to the measured data using a fiber array, we found that the insertion loss and PDL were within 0.8 dB. We attribute the slight performance decrease to imperfect alignment because of the increased difficulty in aligning the MCF, particularly the rotation of the fiber relative to the grating couplers.

Grating couplers designed for MCF based I/O to integrated platforms are a fundamental requirement of systems that require the density and noise resilience of MCF. Future measurements will use index matching get between the MCF face and chip surface to improve the insertion loss and bandwidth. To reduce the Fabry-Perot resonances in the transfer functions, our future design will explicitly minimize the backreflections of the grating couplers while simultaneously maximizing the coupling efficiency. Finally, we plan to use our grating couplers to design an integrated optical phase locking loop across a span of MCF.

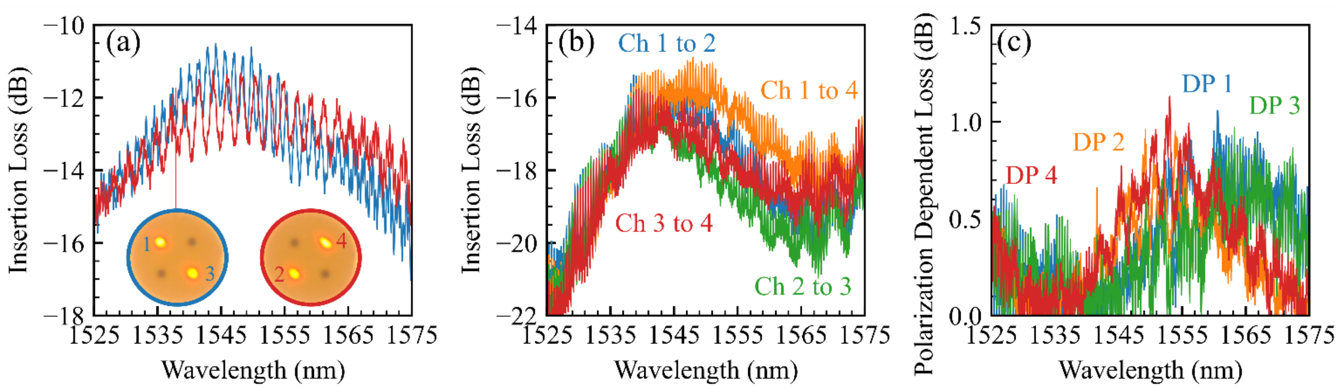

Fig. 2. Experimental validation of the manufactured loopbacks consisting of two grating couplers and a silicon waveguide. The loopbacks connected diagonal cores for the polarizing grating couplers (a) and adjacent cores for the polarization demultiplexing grating couplers (b). The PDL of the polarization demultiplexing grating couplers (labeled DP) (c) was calculated using the Jones matrix for each loopback and assuming equal loss between the input and output grating couplers. For all measurements, the MCF was aligned to maximize transmission for one loopback and the other loopbacks were measured without realigning the fiber.

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References

[1] B. J. Puttnam *et al.*, "Self-homodyne coherent detection in multi-core fiber links," *2014 IEEE Photonics Conference*, 2014, pp. 522-523, doi: 10.1109/IPCon.2014.6995480.

[2] C. G. Bottenfield *et al.*, "High Performance Microwave Photonic Downconversion in a Commercial InP Platform," *2021 Optical Fiber Communications Conference and Exhibition (OFC)*, 2021, pp. 1-3.

[3] A. M. Zin, M. S. Bongsu, S. M. Idrus and N. Zulkifli, "An overview of radio-over-fiber network technology," *International Conference On Photonics 2010*, 2010, pp. 1-3, doi: 10.1109/ICP.2010.5604429.

[4] M. Rakowski et al., "45nm CMOS — Silicon Photonics Monolithic Technology (45CLO) for Next-Generation, Low Power and High Speed Optical Interconnects," 2020 Optical Fiber Communications Conference and Exhibition (OFC), 2020, pp. 1-3

[5] "Optical Fiber Cable and Connectivity Solutions," OFS. https://www.ofsoptics.com/multicore-optical-fiber/

[6] A. M. Hammond, A. Oskooi, M. Chen, Z. Lin, S. G. Johnson, and S. E. Ralph, "High-performance hybrid time/frequency-domain topology optimization for large-scale photonics inverse design," *Opt. Express,* vol. 30, no. 3, pp. 4467-4491, 2022/01/31 2022, doi: 10.1364/OE.442074.

[7] D. Taillaert, P. Bienstman, and R. Baets, "Compact efficient broadband grating coupler for silicon-on-insulator waveguides," *Opt. Lett.,* vol. 29, no. 23, pp. 2749-2751, 2004/12/01 2004, doi: 10.1364/OL.29.002749.