

7 × 100 Gb/s Multicore Fiber Link Enabled by an Inverse-Designed Dual-Polarization Coupler

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Abstract: We present the first integration of an array of seven freeform dual-polarization SOI couplers with a seven-core fiber featuring a 125 μm cladding diameter, achieving a 7 × 100 Gb/s error-free multicore link. © 2025 The Author(s)

Spatial division multiplexing (SDM) is a promising technology for addressing bandwidth bottlenecks and reducing the number of parallel fibers, thereby lowering power consumption in data center interconnects [1]. Multicore fibers (MCFs), in particular, have been extensively explored for their ability to increase transmission capacity while maintaining the same footprint as single mode fibers (SMFs) [2]. To fully harness these benefits, efficient MCF-to-chip couplers are essential [3–5]. Furthermore, these MCF-to-chip couplers must support both polarizations and exhibit low polarization-dependent loss (PDL) to enable advanced modulation formats exploiting polarization diversity. For MCFs with small core pitches, such couplers must also be ultra-compact to fit within the limited space and effectively route signals from each channel without introducing significant crosstalk.

In this study, we demonstrate an error-free multicore link using a 200 m long seven-core fiber and an array of compact silicon dual-polarization couplers with a footprint of only 100 μm². The dual-polarization freeform coupler was achieved through inverse design and features a 0-degree coupling angle, enabling wafer-level testing and simplifying alignment. Previously, Hayashi et al. demonstrated a multicore link using a 4 × 2 fiber with four dual-polarization and two single-polarization gratings. However, due to the larger footprint of the dual-polarization gratings, they were unable to fit a coupler for each core, even when using a fiber with a diameter of 180 μm and core spacing of up to 45 μm [6]. Our design reduces the footprint by half compared to the previously published 10° dual-polarization coupler designed for a similar seven-core fiber [7], while maintaining comparable efficiency. To realize the multicore link, we employed a commercial single-wavelength Wavelogic 3 (WL3) transceiver from Ciena, transmitting a dual-polarization quadrature phase-shift keying (DP-QPSK) 100 Gb/s data stream in the 1566.72 nm channel in each core of the fiber, resulting in a net data rate of 700 Gb/s. The average optical loss per channel was −12.3 dB, and the average bit error rate (BER) across all channels was 1.67058×10^{-4} , which is below the forward error correction threshold.

The dual-polarization coupler was designed for an silicon-on-insulator (SOI) platform with a 250 nm-thick silicon layer, a 3 μm-thick bottom cladding layer, and a 1 μm-thick top cladding. During the design process, the silicon layer was divided into two sections: a fixed 130 nm-thick bottom layer, which remained unetched, and a 120 nm-thick top layer, which was optimized using the Lumerical software. This two-layer structure resulted from several 2D optimizations, where the etch depth varied from 50 nm to 200 nm in 5 nm increments, with 120 nm yielding the best results. Notably, the device was designed for 0-degree coupling, enabling vertical alignment. This design avoided potential issues related to different coupling heights between the seven cores of the MCF and eliminated the need for fiber polishing at specific angles or for tilting the fiber, thereby simplifying the alignment process. Although no symmetry conditions were applied during optimization due to software limitations, symmetry was enforced in the final geometry obtained from the process. As a result, the simulation showed identical coupling efficiencies of −3.8 dB for both polarizations, with a 3 dB bandwidth of 59 nm [8]. The multicore fiber used in this demonstration was fabricated by Corning and has a length of 200 m and a standard cladding diameter of 125 μm. It consists of seven identical cores arranged in a triangular lattice with a center-to-center spacing of 32 μm between adjacent cores. Each core has a modal diameter of 8 μm at 1550 nm, and the measured crosstalk (XT) over a length of 10 km was −43 dB.

The devices were fabricated by Applied Nanotools (ANT) through a custom fabrication run using electron-beam lithography (EBL) and reactive ion etching (RIE) processes. Although the fabrication process is capable of achieving a minimum feature size of 60 nm, a minimum feature size of 100 nm was chosen for the design to ensure compatibility with 193 nm lithography processes, which are widely available for large-scale manufacturing. Figure

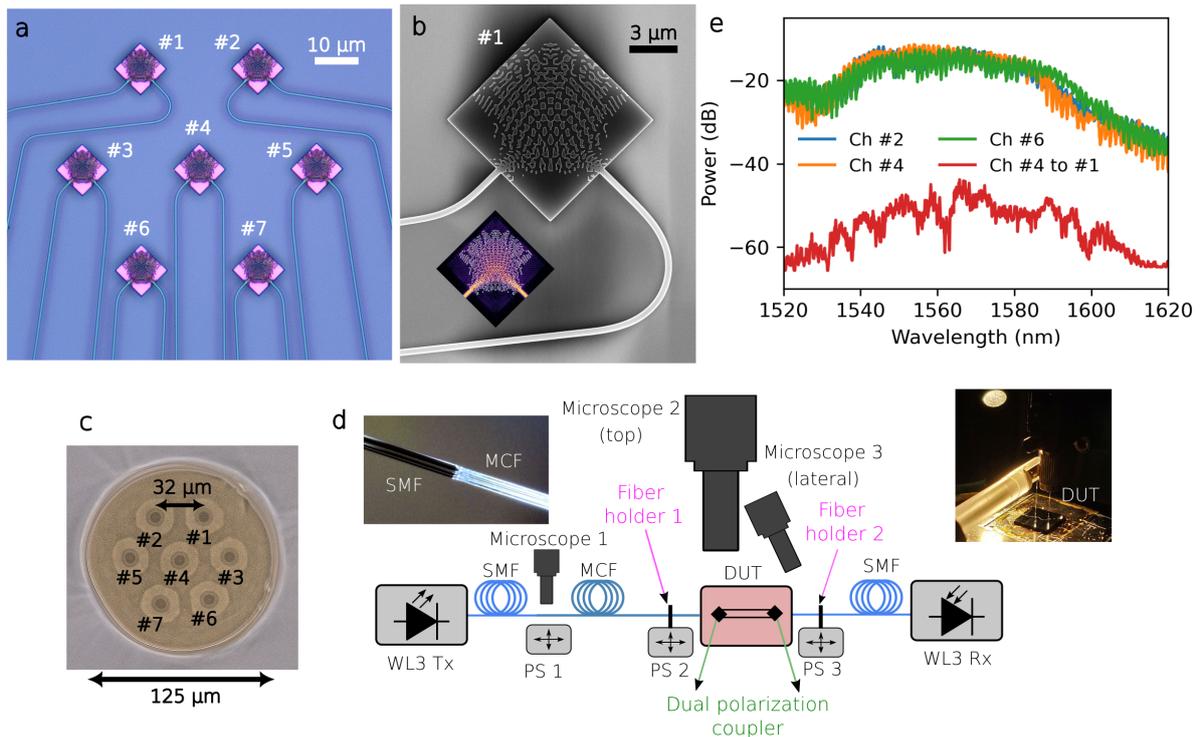


Fig. 1: Dual-Polarization MCF-to-Chip Coupler Array and Link Characterization Setup. a) Top-view image of the array of seven dual-polarization couplers along with their input/output waveguides. b) scanning electron microscopy (SEM) image of dual-polarization coupler #1, with an inset showing a simulation of the electric field magnitude at 1550 nm. c) Cross-section of the MCF, displaying the cladding and pitch dimensions, as well as the numbering of the cores corresponding to the couplers. d) Schematic of the link characterization setup, where a WL3 transceiver is used to transmit and receive a DP-QPSK 100 Gb/s data stream through each core of the multicore fiber and the device under test (DUT), along with two insets showing the connection between the SMF and the MCF, as well as the fibers coupling to the dual-polarization coupler array. e) Transmission efficiency of channels #2, #4, and #6, as well as the XT from #4 to #6, spanning from 1520 nm to 1620 nm.

1a shows an image of the array of seven freeform dual-polarization couplers. Due to their compact footprint of only $100\ \mu\text{m}^2$, the two input/output waveguides for each coupler can be easily routed, as seen in the array image. Achieving such routing with dual-polarization grating couplers would be significantly more challenging, if not impossible, due to their larger footprint.

Figure 1b presents an SEM image of coupler #1, with an inset showing the simulated electric field magnitude at 1550 nm. The SEM image shows a high degree of fidelity between the fabricated device and the inverse-designed structure, clearly showcasing the distinctive and complex features obtained through the optimization process. The link characterization setup is illustrated in Figure 1d. In this experiment, a DP-QPSK 100 G signal was transmitted through the seven cores of the MCF, shown in Figure 1c, and the device under test (DUT), which consists of two interconnected arrays of seven couplers. At the output of the WL3 transmitter, the DP-QPSK data stream was launched into a SMF, which was aligned with each core of the MCF using a piezo stage. The MCF was then aligned with one array of seven freeform dual-polarization couplers at the input of the DUT. At the output of the DUTs, the second array was aligned with an SMF, which was directly connected to the WL3 receiver. For optical characterization, an EXFO TC100S-HP tunable laser was used instead of the transmitter, and an EXFO CPT440 tester was used to measure the optical power. Due to setup limitations, an SMF was used at the output instead of an MCF and was aligned with the corresponding coupler during both transmission and optical characterization. Figure 1e presents the results of the optical characterization for channels #2, #4, and #6, showing link efficiencies of $-11.9\ \text{dB}$, $-11.3\ \text{dB}$, and $-12.0\ \text{dB}$, respectively, after discounting the measured loss at the interface between the SMF and MCF, which is around 1.2 dB. This shows that the efficiency of each freeform coupler ranges between $-5.6\ \text{dB}$ and $-6.0\ \text{dB}$. It is important to note that one side of the coupler array was connected to an SMF, which increased losses, as the coupler was designed for an MCF with a mode field diameter of $8\ \mu\text{m}$, whereas the SMF has a mode field diameter of $10.4\ \mu\text{m}$. Simulations indicate that using an SMF instead of an MCF increases losses by approximately 1.1 dB, suggesting that the coupler loss could be below $-5\ \text{dB}$. Additionally, the crosstalk between channel #1 and channel #4 was observed to be below $-30\ \text{dB}$ across the entire C-band.

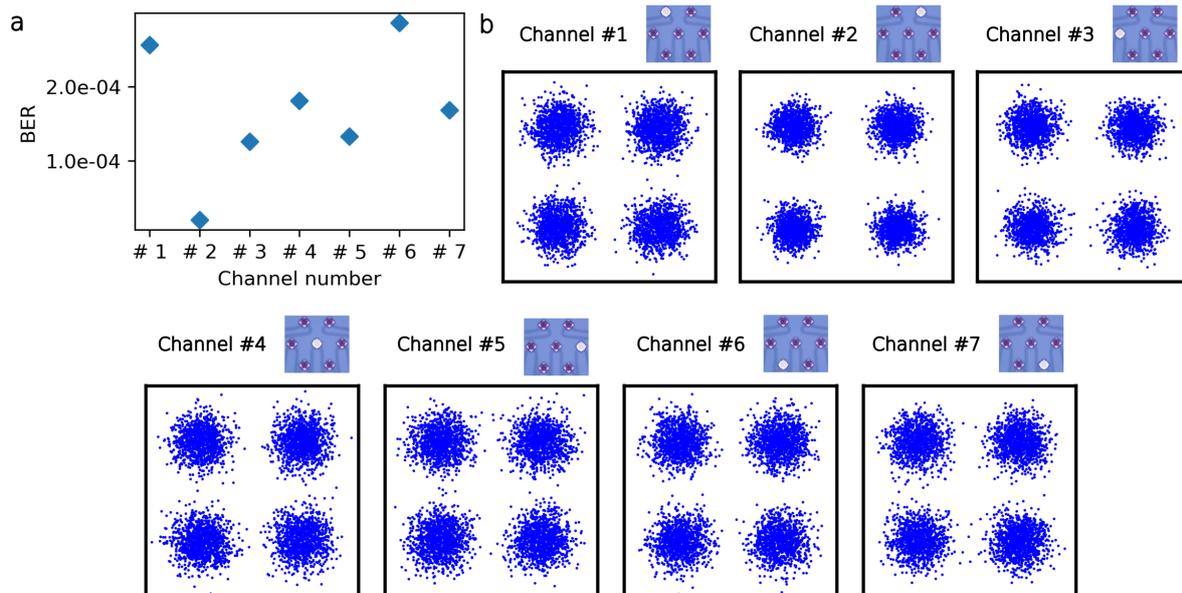


Fig. 2: **Link Performance.** a) Measured BER for the seven channels in the link, which is composed of the 200 m seven-core fiber and the interconnected dual-polarization SOI coupler array. b) Image of the seven dual-polarization coupler array, indicating the coupler in use, along with the recovered constellations of one polarization for each channel.

Figure 2a presents the recorded BER values of the 100 Gb/s data stream transmitted through each core of the multicore optical fiber and the DUT. The BER for each channel remains below the pre-FEC threshold. The constellations of the recovered signals, including one polarization for the different channels, are shown in Figure 2b. A net data rate of 700 G is achieved with a single wavelength by utilizing seven parallel channels, each carrying 100 Gb/s DP-QPSK signals. The constellation diagrams clearly show four clusters, indicating low phase noise and minimal polarization dispersion losses for each channel, thereby confirming the high performance of the freeform dual-polarization couplers.

In conclusion, we successfully demonstrated a free-error 700 Gb/s multicore link using a seven-core fiber and ultra-compact dual-polarization couplers fabricated on an SOI platform. The link's error-free performance indicates low XT and PDL. Additionally, the low average loss of -12.3 dB makes the freeform dual-polarization coupler a strong candidate to support communication links of up to 7×800 Gb/s.

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