Demonstration of 1.28-Tb/s Transmission in Next-Generation Nanowires for Photonic Networks-on-Chip

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Abstract: **We transmit 1.28-Tb/s wavelength-parallel optical data through a 4.3-cm long low-loss Si_3N_4 nanowire, comprising 32 40-Gb/s wavelength channels. We confirm error-free transmission and show negligible crosstalk, validating this medium for high-performance silicon photonic interconnection networks.**

Introduction

As chip-scale computing systems continue to scale toward increased processor parallelism, electrical on-chip interconnection networks are increasingly becoming the performance bottleneck for both power consumption and bandwidth. Moreover, limited pin count and high energy dissipation associated with electrical buffer stages also limit the off-chip bandwidth using electrical interconnects. Optical networks-on-chip (NoCs) based on silicon photonic devices have the potential to meet next-generation bandwidth and power requirements of chip multiprocessors, leveraging dense wavelength parallelism to route optical signals encoded with terabit-scale data rates.

Silicon photonics presents an enabling technology for photonic NoCs due to small device footprint, low power dissipation, and complementary metal-oxide-semiconductor (CMOS)-compatibility, which allows dense monolithic integration with advanced microelectronics. Leveraging optical and electrical properties of crystalline silicon, many high-performance silicon photonic building blocks have already been demonstrated for this application [1-5]. Recent efforts have also yielded high-performance silicon photonic devices fabricated using deposited materials such as Si_3N_4 and polycrystalline silicon [6,7]. Devices fabricated using a deposited material system can potentially enable back-end integration of photonic structures, maximizing the scarce transistor-level real estate for electrical components. Novel Si_3N_4-based nanowires have recently been shown with propagation losses as low as 0.5 dB/cm, enabled by advances in the fabrication techniques of high-quality thick Si_3N_4 films [8]. Such nanowires have significantly lower propagation losses compared to the recently-demonstrated 1.7-dB/cm crystalline silicon nanowires [9], as well as more than an order-of-magnitude lower material nonlinear response, reducing signal-degrading nonlinear effects. Furthermore, the lack of two-photon absorption in Si_3N_4 helps reduce carrier-based crosstalk, resulting in superb multichannel optical data transmission capabilities.

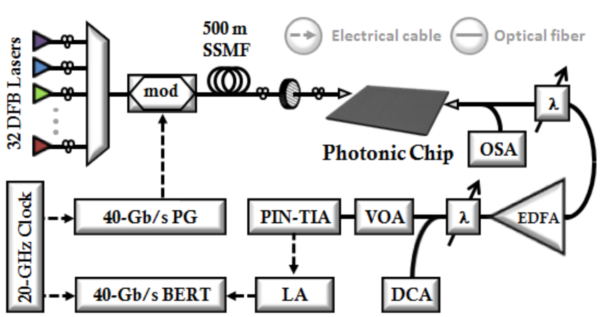

Fig. 1: Experimental setup diagram.

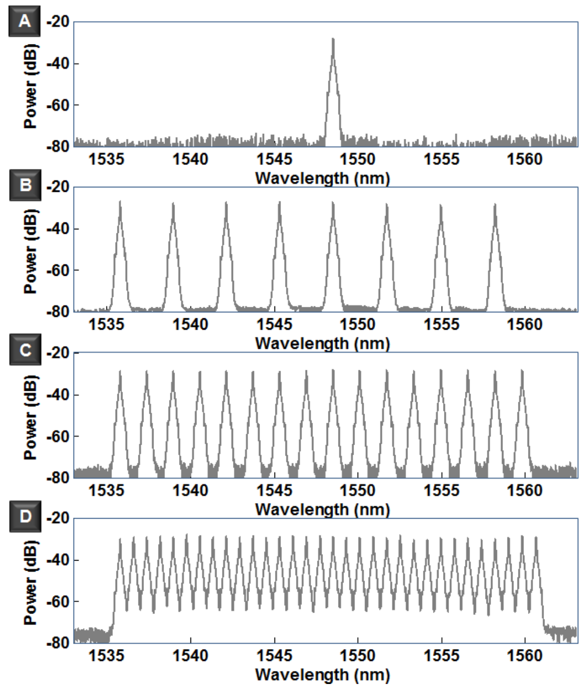

Fig. 2: a-d. OSA traces recorded after propagation through the silicon photonic chip, depicting experimental configurations with 1, 8, 16, and 32 modulated wavelength channels.

In this work, we explore the suitability of the low-loss Si_3N_4 nanowires for transmitting high-speed wavelength-parallel optical data through silicon photonic NoCs. We demonstrate the bandwidth capacity of the nanowire by transmitting 1.28-Tb/s of aggregate optical data (32 channels each modulated at 40-Gb/s) through a 4.3-cm-long device, representing the longest path an optical signal would traverse in the photonic NoC. Open output eye diagrams and error-free transmission, with bit-error rates (BERs) less than 10^{-12}, are observed with up to 32 channels propagating through the nanowire. BER characterization shows a near-constant 0.65-dB power penalty for all channel configurations.

Device and experimental setup

The device discussed here is a Si_3N_4 nanowire with a 750-nm by 1800-nm cross section, fabricated at the Cornell Nanofabrication Facility. Low pressure chemical vapor deposition (LPCVD) is used to grow a thick film of Si_3N_4 on a

4-µm thermally grown silicon dioxide layer. The nitride is grown using a thermal cycling process [8]. The nanowire is defined using electron beam lithography followed by reactive ion etching and is then clad with LPCVD oxide. The nanowire used in this experiment had an insertion loss of 7.1 dB.

The experimental setup (Fig. 1a) used to evaluate data transmission through the nanowire consists of up to 32 distributed-feedback (DFB) lasers set on the ITU DWDM grid (C21-C52, spanning 1560.61-1535.82 nm) whose outputs are combined and amplitude modulated at 40 Gb/s with a non-return to zero 2^{15}-1 pseudo-random bit sequence (PRBS) generated by a pattern generator (PG). The modulated signals are decorrelated using a 0.5-km standard single-mode optical fiber (SSMF) before being launched into the chip through tapered fibers. After propagating through the nanowire, a single channel is isolated using a tunable grating filter (λ), and is then amplified using an erbium-doped fiber amplifier (EDFA). The recovered 40-Gb/s wavelength channel is inspected on a high-speed digital communications analyzer (DCA), and is received using a PIN-TIA photodetector followed by a limiting amplifier (LA). The received data fidelity is quantified using a BER tester (BERT). A variable optical attenuator (VOA) is used to vary the received power, and an optical spectrum analyzer (OSA) is used to inspect the wavelength channels transmitted through the chip.

Experiments and results

We first launch 32 wavelength channels encoded with the 1.28-Tb/s data into the chip (Fig. 2d), with each wavelength channel set to -9 dBm of optical power. We recover four of the 32 wavelength channels spanning the wavelength range (C28 at 1554.94 nm, C36 at 1548.51 nm, C44 at 1542.1 nm, and C52 at 1535.82 nm) for inspection on the DCA and BER characterization. The back-to-back case bypasses the chip with a VOA set with the same insertion loss as the fiber-to-fiber insertion loss through the nanowire. Open output eye diagrams are observed, and BER measurements show a uniform 0.58 dB power penalty (Fig. 3). The power penalty is attributed to polarization and spatial mode dispersion in the nanowire.

In the second experiment, we vary the number of wavelength channels propagating in the nanowire, transmitting 1, 8, 16, and 32 wavelength channels (Fig. 2a-d), and examine output eye diagrams and BERs on a single channel (C36) for each configuration, quantifying the crosstalk-induced degradation of the optical dsignal in the nanowire. Open output eye diagrams and error-free trnamission are observed with an average 0.65 dB power penalty. The lack of degradation as the number of wavelength channels is scaled validates the absense of significant cross-talk in the waveguide.

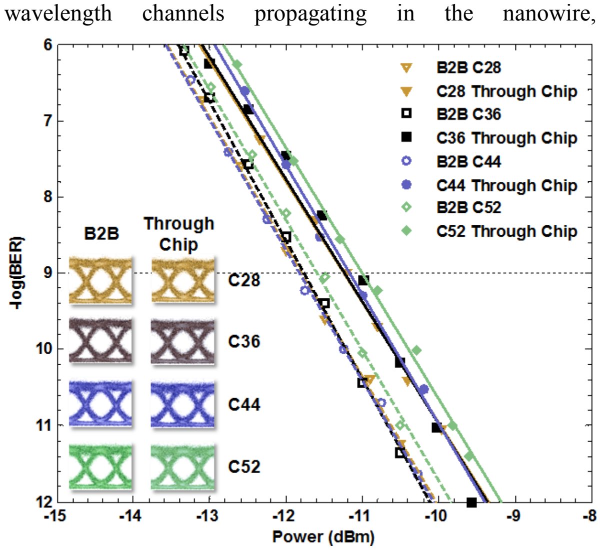

Fig. 3: BER curves for C28, C36, C44, and C52, showing a constant 0.58 ± 0.07 dB power penalty, and an inset of ouput eye diagrams including the back-to-back case.

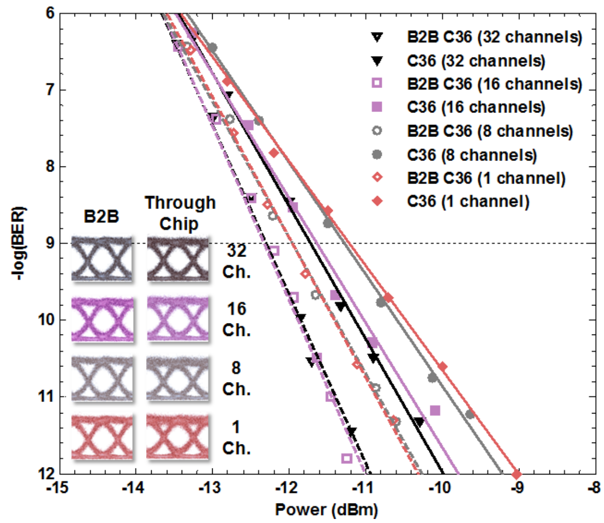

Fig 4: BER curves measured on wavelength channel C36 when 1, 8, 16, and 32 wavelength channels are on, showing a 0.65 ± 0.08 dB power penalty, and an inset of back-to-back and output eye diagrams.

Conclusions

We characterized a novel low-loss nanowire suitable for transmitting high-speed wavelength-parallel optical data throughout silicon photonic NoCs. We transmitted 1.28-Tb/s of wavelength-parallel optical data through the Si_3N_4 nanowire, quantifying performance using measured BER and power penalty performance metrics. We demonstrated 0.65-dB power penalties associated with propagation through this nanowire, establishing the potential of integrating this material system in high-performance photonic NoCs.

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