Kerr Comb-Driven Silicon Photonic Transmitter

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Abstract: We demonstrate the first on-chip silicon photonic transmitter using a Kerr frequency comb source for massive wavelength parallelism. The architecture is scalable to hundreds of wavelength channels, paving the way for multi-Tb/s photonic interconnects.

1. Introduction

The rise of microresonator-based Kerr frequency combs has provided a rapidly maturing platform for compact integrated wavelength division multiplexing (WDM) sources capable of producing hundreds of unique wavelength channels with precise, intrinsic spacing [1,2]. Previous demonstrations of data transmission using Kerr frequency comb sources have been restricted to bulk telecom components for modulating, filtering, and receiving individual wavelength channels [3–5]. Such demonstrations are important for long-haul communications, but are far from feasible for the shorter and shorter reaches demanded by optical interconnects in data center and high performance computing systems due to size, cost, and power constraints.

Here, we propose and demonstrate a novel silicon photonic transmitter architecture for filtering and modulating broadband frequency combs on-chip without the use of off-chip comb filtering or amplification between the comb output and transmitter input. The chip was fabricated at a commercial 300 mm CMOS foundry using a standard silicon photonics process flow, showing potential for future volume manufacturing [6]. The electrically and optically packaged system was evaluated using a Kerr comb source, demonstrating open eye diagrams up to 20 Gb/s per channel yielding a potential aggregate bandwidth of 640 Gb/s with simultaneous channel operation. The demonstrated architecture expands the potential of silicon photonic interconnects to accommodate the extreme wavelength scaling provided by frequency combs, enabling future terabit-scale chip-to-chip links.

2. Proposed Architecture and Experimental Results

When attempting to scale to accommodate the large channel count provided by Kerr combs, traditional single-bus cascaded resonator architectures run into fundamental limits associated with insertion loss, inter-modulation

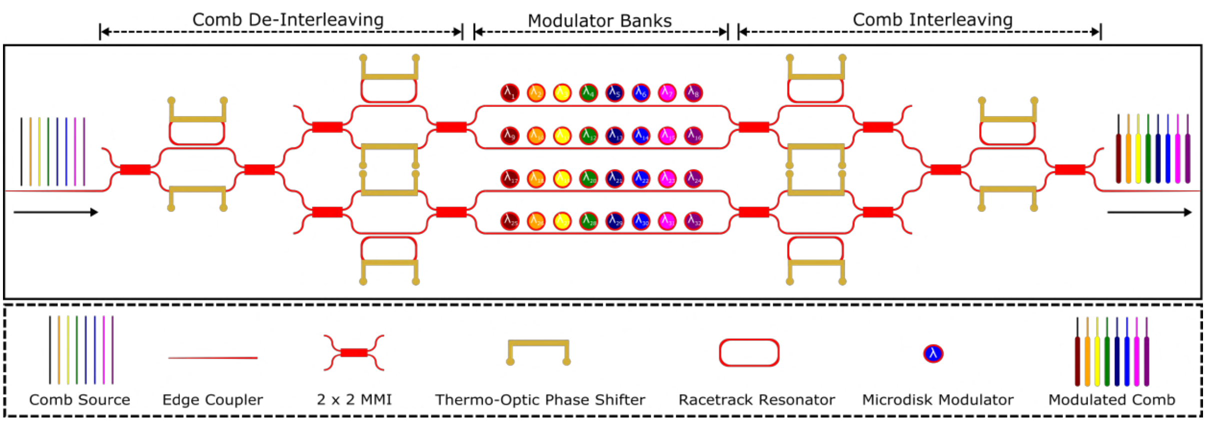

Fig. 1. Schematic of the silicon photonic transmitter architecture for 32 wavelength channels.

crosstalk, and crosstalk induced by unwanted resonances stemming from the limited cavity free spectral range (FSR). In the proposed architecture shown in Fig. 1, these limitations are circumvented through the use of de-interleavers to subdivide the comb into multiple groups before traversing separate cascaded modulator banks, and then interleavers to recombine them onto a single fiber output [7]. By first de-interleaving the comb before traversing the modulator banks, the effective channel spacing on a single bus doubles for each stage of de-interleaving. Furthermore, the number of modulators in a single path is halved for each stage of de-interleaving, greatly reducing the total off-resonance insertion loss. Finally, due to the increased channel spacing and reduced number of modulators on each bus, a Vernier-like scheme can be implemented with the modulator resonances such that the undesired resonances of each modulator can be selectively placed in the 'white space' where they will avoid other comb lines on the bus and thus mitigate FSR-induced limitations.

The photonic transmitter chip was fabricated through AIM Photonics' 300 mm multi-project wafer (MPW) service. The full package, including die-bonding, wire-bonding, and fiber-attach, was assembled by Optelligent, LLC. After fiber-attach with index matching fluid and UV curing, the measured edge coupler loss per facet was $\sim$ 2.5 dB. All 96 DC pads around the periphery were wire-bonded to a co-designed PCB to allow for thermo-optic control of the (de-)interleavers and modulator heaters. Ultra-efficient vertical junction microdisk modulators available in the AIM Process Design Kit (PDK) were used due to their superior FSR (25.6 nm), modulation efficiency (88 pm/V), and low peak-to-peak driving voltage compatible with state-of-the-art CMOS electronics (0.9 V_{pp}) [6]. The RF pads to the modulators were not wire-bonded and were instead probed due to the high parasitic inductance of wire bonds. The transmitter chip has power taps after each modulator bus to bypass the final interleaving stages, allowing for intermediate characterization of the system. The Kerr comb generator was designed using a dual-ring design with a tunable avoided mode crossing as described in [8] and was fabricated in a separate process from that used for the transmitter die. The comb operates in the normal group velocity dispersion (GVD) regime, leading to a flatter spectrum, more power per line, and higher pump-to-comb conversion efficiency ($\sim$ 40%) when compared to soliton Kerr combs operating in the anomalous GVD regime.

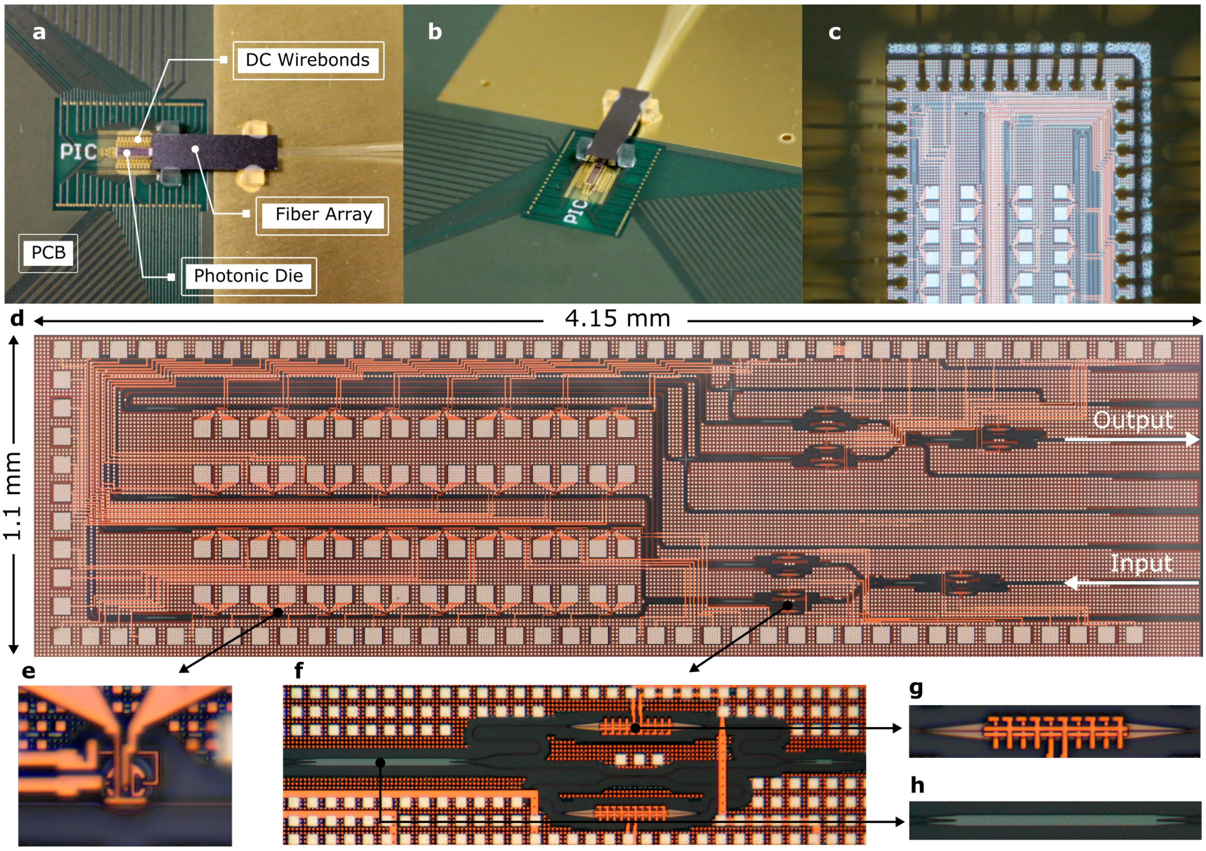

Fig. 2. (a) Top-down view of the optically and electrically packaged system highlighting key constituent components. (b) Perspective view of the system. (c-h) Microscope images of: (c) wire-bonded photonic die, (d) full die prior to wirebonding, (e) microdisk modulator, (f) ring-assisted Mach-Zehnder interleaver, (g) thermo-optic phase shifter, and (h) 3 dB splitter/combiner.

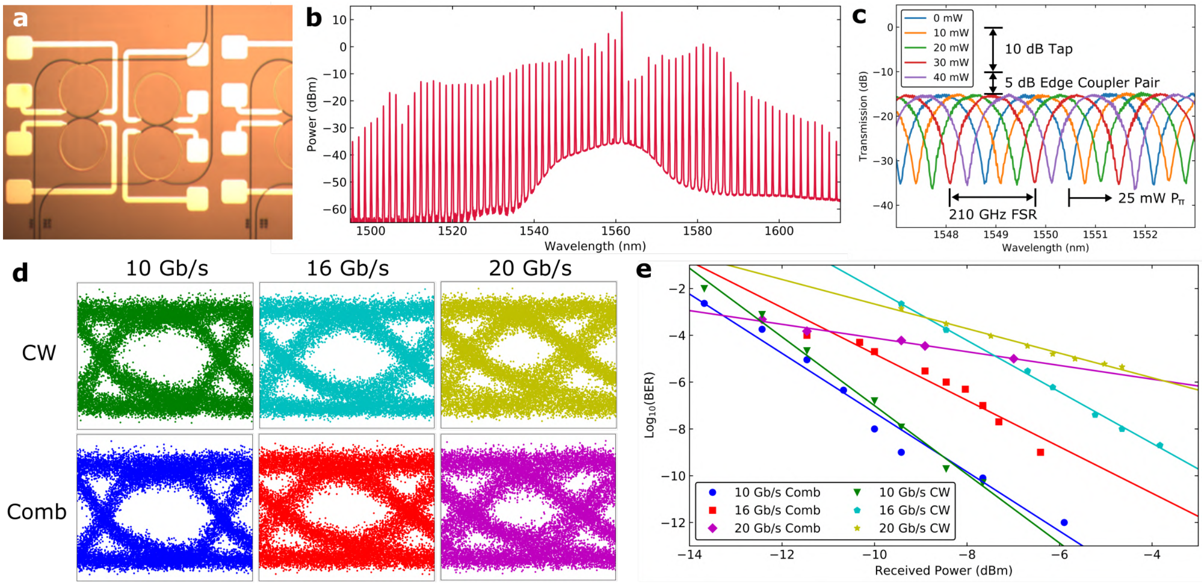

Fig. 3. (a) Microscope image of the dual-ring SiN Kerr comb source. (b) Measured comb spectrum prior to transmitter. (c) First stage de-interleaver spectrum after a 10% power tap. (d) Eye diagrams comparing CW and comb inputs at 1559.85 nm. (e) Corresponding BER curves using PRBS31.

3. Conclusion

We have proposed and demonstrated a silicon photonic transmitter architecture which can scale to accommodate the massive number of WDM channels provided by chip-based frequency comb sources. This demonstration, to the best of the authors' knowledge, is the first to show filtering and modulation of a Kerr frequency comb source entirely on a silicon chip without the use of off-chip filtering or amplification before the transmitter. The silicon photonic transmitter chip uses silicon nitride layers for photonic devices such as inverse-tapered edge couplers and Si-SiN escalators, indicating that monolithic integration of the frequency comb generator on the same die as the active silicon devices is a future possibility with improved foundry nitride processing. This demonstration opens future possibilities for extreme wavelength scaling in next-generation on-board and co-packaged optics.

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