Dispersion-Engineered Resonator-Based Interleaver Co-Designed with Kerr Comb Source

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Abstract: We demonstrate interleavers with ∼30 dB crosstalk suppression and wide ≥60 nm optical bandwidth, utilizing dispersion-engineered resonators co-designed with normal-GVD Kerr comb sources. This scalable design supports ultra-broadband photonic interconnects.

1. Introduction

High-bandwidth optical links are essential for addressing the growing demand in data transmission, a major bottleneck for performance scaling. Among the various approaches, comb-driven integrated photonic systems offer a promising solution for high bandwidth and low-energy consumption links. Normal group-velocity dispersion (GVD) Kerr comb sources, which convert a single pump laser into many equally spaced wavelengths, are particularly attractive for such systems due to their scalability and high conversion efficiency [1–3].

In this work, we demonstrate interleavers co-designed with a high-power Kerr comb source operating in the normal-GVD regime, incorporating dispersion-engineered resonators to enhance scalability and bandwidth in integrated photonic interconnects. The dispersion-engineered add-drop resonators enable Free Spectral Range (FSR) matching with the comb source, mitigating crosstalk and dispersion effects across a wide optical bandwidth. This allows us to achieve crosstalk suppression of ∼30 dB while maintaining high bandwidth scalability.

2. Interleaver & Kerr Comb Co-Design Methodology

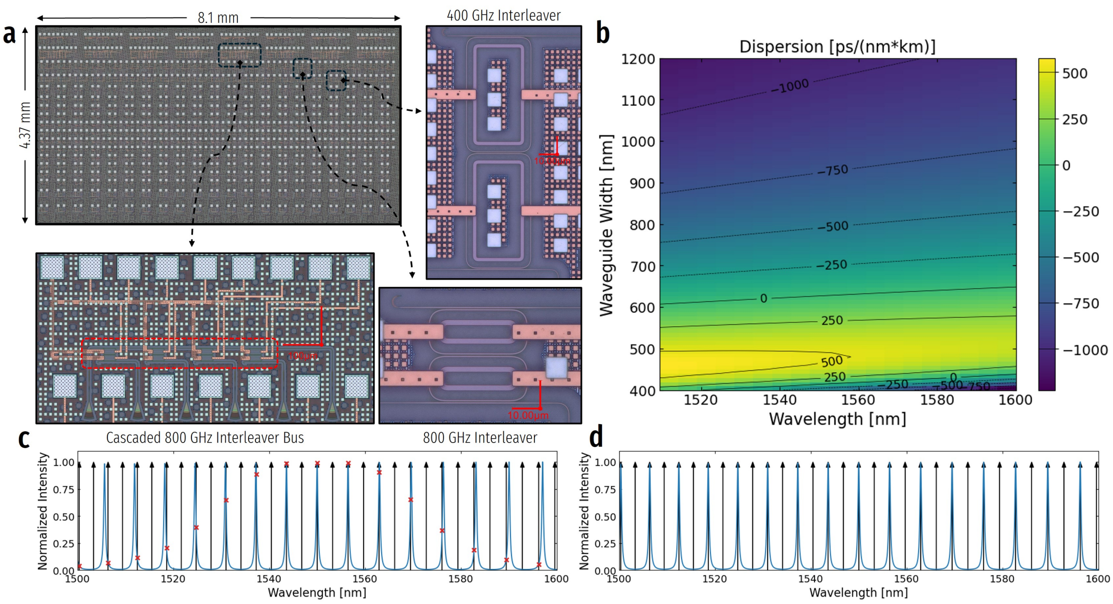

Fig. 1. **(a)** Foundry-fabricated resonator-based interleaver designs. **(b)** Dispersion of different waveguide widths across wavelength. **(c)** Comb lines depicted as black vertical arrows, overlaid with dispersive resonator-based interleaver spectrum. Red 'x' symbols indicate transmission after passing through interleaver. **(d)** Depiction of dispersionless resonator-based interleaver spectrum.

Dispersion is a critical factor to consider when designing interleavers that work efficiently with normal-GVD Kerr comb sources across a broad bandwidth [4]. Waveguide dispersion can cause misalignment between the interleaver passbands and the comb channels, leading to performance degradation, especially when approaching the bounds of the optical bandwidth. Fig. 1c illustrates the effects of FSR mismatch between the comb and a dispersive interleaver, while Fig. 1d shows FSR-matching between the comb and interleaver with zero dispersion. In our approach, we use dispersion-engineering to balance material and geometric dispersion in silicon waveguides, achieving near-zero dispersion at a waveguide width of approximately 630 nm, as shown in Fig. 1b.

We employ a 2nd order add-drop racetrack ring resonator as the core of our interleaver design. This higher-order filter design offers a more defined passband shape, steeper drop-off, and higher extinction ratio, enabling better crosstalk suppression and more robust channel separation [5]. Because the waveguide width of 630 nm supports higher order modes, adiabatic bends must be used within each ring resonator. Therefore, Euler bends are incorporated into the design to ensure minimal crosstalk between modes and to reduce radiation loss [6]. Microscope images of two such 2nd order Euler ring filters are shown in Fig. 1a, fabricated in a dedicated 300 mm wafer run with AIM Photonics.

3. Experiment & Results

Our experimental setup utilizes a silicon nitride chip to generate a 200 GHz spaced normal-GVD Kerr comb, which is fed into a photonic integrated circuit (PIC) containing dispersion-engineered 2nd order Euler ring interleavers. Fig. 2a shows a microscope image of the coupled-ring silicon nitride normal-GVD Kerr comb chip. Using a polarization controller, the comb is optimized for TE polarization, and the output is coupled into the PIC via grating couplers. Thermo-optic phase shifters integrated into the resonators enable fine alignment of the interleaver passbands with the comb lines, which is crucial for optimal performance. Fig. 1a shows microscope images of the Euler ring interleavers; the doped silicon thermo-optic phase shifters are located internal to the dispersion-engineered waveguides. The interleaved output is sent to an Optical Spectrum Analyzer (OSA) to evaluate the crosstalk suppression and channel spacing. A schematic of the experimental setup is shown in Fig. 2b.

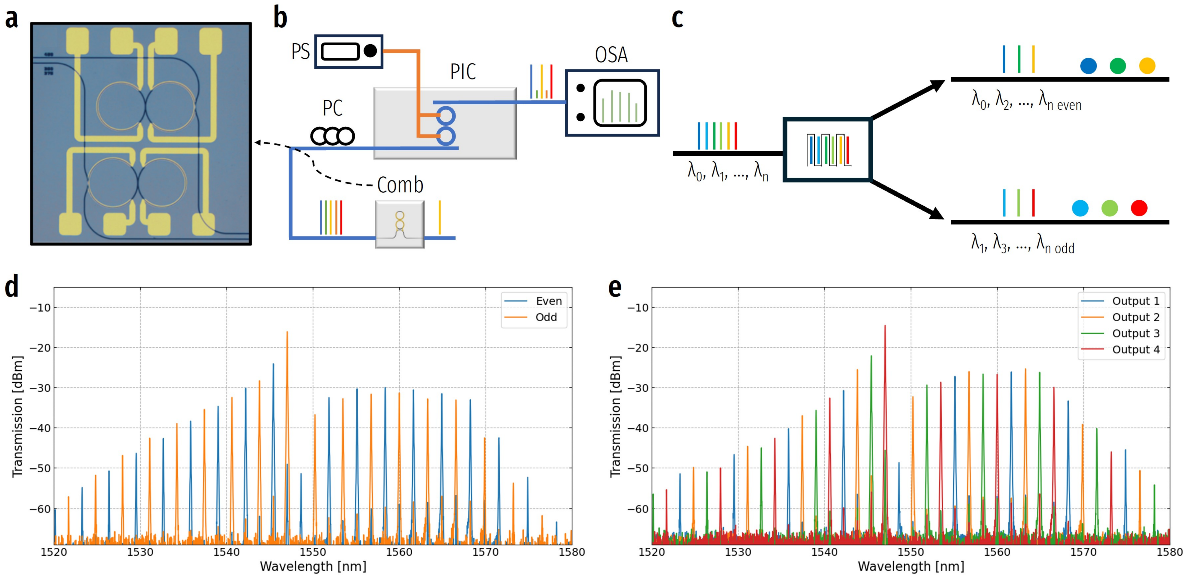

Fig. 2. **(a)** Micrograph of silicon nitride normal-GVD Kerr comb chip with FSR of 200 GHz. **(b)** Experimental setup for demonstration. Comb: Normal-GVD Kerr comb laser source; PC, Polarization Control; PS, DC Power Supply; PIC, Photonic Integrated Circuit containing resonator-based interleaver; OSA, Optical Spectrum Analyzer. **(c)** Schematic description of even/odd interleaving showing doubling of effective channel spacing. **(d)** Experimental results of even/odd interleaving of comb with 400 GHz FSR Euler ring filter. **(e)** Experimental results of multiple-channel interleaving of comb with 800 GHz FSR Euler ring filter.

The first device measured was designed to target an FSR of 400 GHz to demonstrate even/odd interleaving with the 200 GHz spacing normal-GVD Kerr comb source. A schematic depicting even/odd interleaving creating an effective doubling of the channel spacing is shown in Fig. 2c. The FSR and transmission spectrum of the drop port of the device is shown in Fig. 3a. The measured even/odd interleaved spectrum in Fig. 2d demonstrates excellent crosstalk suppression of ∼30 dB across 60 nm of optical bandwidth. It should be noted that the bandwidth of the measured interleaved comb spectrum is limited by the loss envelope of the grating couplers and noise floor of the OSA. Additionally, we showcase the flexibility of our interleaver design, which can be extended beyond a binary tree configuration typical of Mach-Zehnder Interferometer (MZI)-based designs. Designed with an 800 GHz FSR, as shown in Fig. 3b, our 2nd order Euler ring interleavers demonstrate the capability to interleave every fourth channel while maintaining low crosstalk across the optical bandwidth. This interleaved comb spectrum is displayed in Fig. 2e.

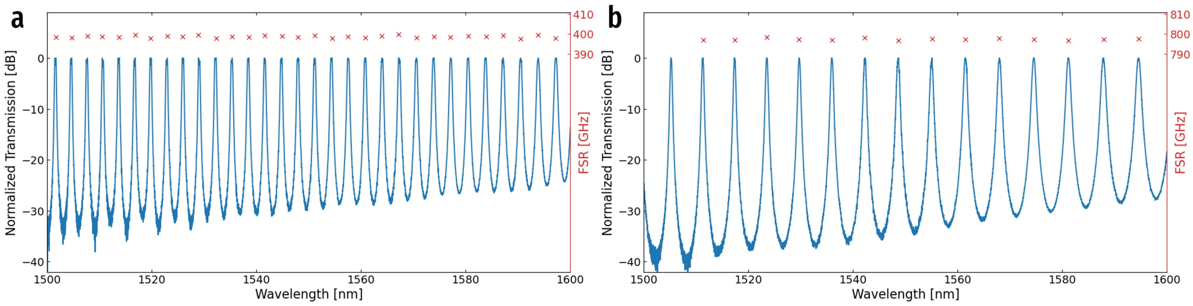

Fig. 3. **(a)** Drop transmission spectrum of 400 GHz FSR 2nd order Euler ring add-drop filter. FSR of resonant device shown in red. **(b)** Drop transmission spectrum of 800 GHz FSR 2nd order Euler ring add-drop filter. FSR of resonant device shown in red.

These results confirm that our dispersion-engineered 2nd order resonator-based interleavers achieve high performance while avoiding the MZI binary tree configuration restriction [7, 8], making them suitable for high-bandwidth, scalable photonic interconnects.

4. Conclusion

We have demonstrated highly scalable silicon photonic interleavers co-designed with a normal-GVD Kerr comb source, achieving crosstalk suppression of ∼30 dB over a wide optical bandwidth. Our dispersion-engineered resonator design enables efficient FSR matching with the normal-GVD Kerr comb, supporting ultra-broadband DWDM photonic interconnects. This work advances the state of the art by offering a solution that avoids the binary tree configuration restriction of traditional MZI-based interleavers and paves the way for next-generation optical communication systems.

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Acknowledgements: This work was supported in part by the U.S. Defense Advanced Research Projects Agency under PIPES Grant HR00111920014, in part by the U.S. Advanced Research Projects Agency–Energy under ENLITENED Grant DE-AR000843, and in part by the Center for Ubiquitous Connectivity (CUbiC), sponsored by the Semiconductor Research Corporation (SRC) and DARPA under the JUMP 2.0 program. The wafer/chip fabrication and custom device processing were provided by AIM Photonics/SUNY Poly Photonics engineering team and fabricator in Albany, New York.