Integrated, Compact, and Tunable Band-Interleaving of a Kerr Comb Source

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Abstract: We demonstrate band-interleaving of a Kerr comb via a wide-FSR dual-ring RAMZI filter. A sharp filter roll-off of 63.6 dB/nm is measured with a total functional bandwidth >36 nm with broadband crosstalk suppression ≥14 dB.

1. Introduction

As high-performance computing systems and data centers demand ever-increasing data throughput, silicon photonics (SiPh) has emerged as a solution to alleviate the physical layer bandwidth bottleneck, taking advantage of SiPh's CMOS-compatibility and potential for high scalability and energy efficiency [1]. The synergy between SiPh and dense wavelength-division multiplexing (DWDM) technology enables link architectures achieving ultra-high bandwidth densities and ultra-low energy-per-bit. Recent advances in microresonator-based Kerr frequency combs further enhance such DWDM applications [2] by providing many optical carriers with a single integrated source, which can then be individually modulated and dropped via SiPh microresonators cascaded along bus waveguides. The total bandwidth of the carriers on a single bus is limited by the free spectral range (FSR) of microresonators, since high crosstalk can be introduced if resonances of unwanted modes overlap with the adjacent carriers [1]. Although smaller microresonators with a larger FSR may help increasing the bandwidth capacity of the single bus architecture, the microresonator-based modulator size is practically limited by both the foundry process limitations and the requirement for placing RF modulation and thermal tuning structures inside the modulator. In addition, the device insertion loss (IL), as well as design and fabrication complexities, is inversely proportional to radius, potentially reducing device performance and yield in the pursuit of larger FSR. Band-interleaving is a promising solution to overcome the FSR limit, thus increasing the link bandwidth capacity [1]. In this work, we demonstrate a compact and tunable band interleaver based on a dual-ring ring-assisted MZI (RAMZI) that has a sharp roll-off of 63.6 dB/nm. The total functional bandwidth spans over 36 nm, allowing for 22 comb lines with 200 GHz channel spacing in the C-band. We also demonstrate thermal tuning of the cut-off wavelength and band interleaving of the Kerr frequency comb, showing a promising path to increase link bandwidth density.

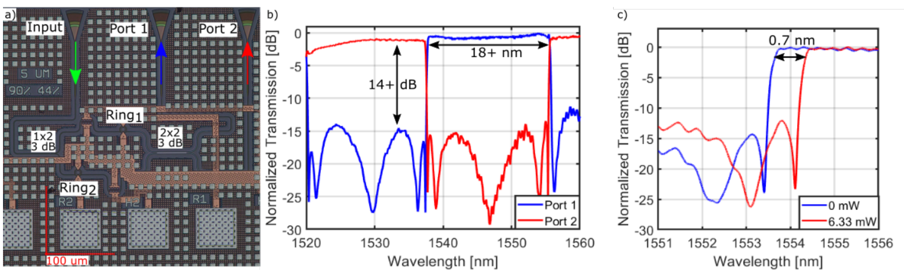

Fig. 1. a) Microscopic annotated image of band-interleaver device. b) Normalized transmission spectra of two ports of the RAMZI band interleaver. The pass band distortion is primarily due to the transmission envelope of the grating couplers. c) Thermal tuning of the cut-off wavelength.

As opposed to even-odd interleaving, in which every other line is routed alternately to a different path, band-interleaving partitions the entire optical bands into large groups of adjacent comb lines prior to traversing the cascaded microresonators. With proper utilization, the total bandwidth can be increased by a factor of 2^{N-1}, where N is the number of interleaver stages [1]. Mach-Zehnder interferometers (MZIs) can perform as band interleavers, however, the edge roll-off must be sharper to mitigate crosstalk near band transition. By cascading ring resonators on a single arm or both arms, RAMZIs can have a much flatter passband and sharper roll-off, making it a good choice for a band interleaver [3, 4]. Such device can also perform as an effective dichroic filter across the full C-band, with roll-off sharp enough to split the spectrum between two adjacent optical carriers allowing for full spectral utilization.

2. Device Design & Results

Fig. 1a shows the band interleaver design, which consists of 3 dB MMI couplers, thermo-optic (TO) tuned RAMZI arms and assist rings. Based on our previous analysis, the optimal power coupling to ring 1 and 2 for sharp roll-off and flat bands are 0.9 and 0.44, respectively [4]. In addition, the rings' effective path length, L_r, should be around twice the MZI arm length difference, ΔL. More precisely, the length relation is $\beta L_r = 2\beta\Delta L \pm \pi$, where β is the propagating mode's phase constant. The FSR of a RAMZI determines the total bandwidth which equals to $2c/n_g L_r$ in frequency, where c is the speed of light and n_g is the group index of the constituent waveguide. To maximize the functional bandwidth, a racetrack style ring is not desired, as the coupling length contributes to resonator path length. In our design, radial rings with wrap-around style bent directional couplers (BDCs) are used. The radius of assist rings is 5 microns, matching the RAMZI FSR of 36 nm. Doped silicon heaters are placed in the center of the rings, which enables TO compensation of fabrication variations as well as adjustment of the cut-off wavelength.

A tunable laser was swept from 1520–1560 nm at a 10 pm resolution to characterize the transmission spectrum of the band interleaver, which is plotted in Fig. 1b. The passband 3 dB bandwidth is 18 nm corresponding to a 36 nm functional bandwidth, and the crosstalk is measured to be better than 14 dB. The roll-off is as sharp as 63.6 dB/nm, measured from 3 dB point to 10 dB point. Such a sharp roll-off greatly reduces the insertion loss and crosstalk near the band transition. Fig. 1c shows thermal tuning of the cut-off wavelength, with an efficiency of 0.11 nm/mW. The thermal efficiency can be further improved by more efficient heater designs and device thermal isolation via undercut technique. To demonstrate the efficacy of the device, we use a dual-ring Kerr comb with 200 GHz channel spacing as the input source and demonstrate band interleaving, shown in Fig. 2. The pass band and stop band each accommodate 11 comb lines.

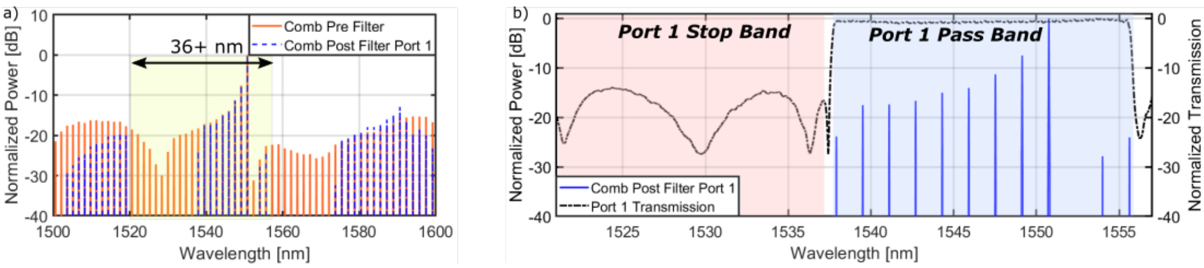

Fig. 2. a) Measured normalized 200 GHz Kerr comb spectrum before and after filtering and b) zoomed in spectrum illustrating effectiveness of sharp roll-off, demonstrating spectral splitting between adjacent lines. The noise floor of the OSA prevents lines in the stop band from being visible.

3. Conclusion

In summary, we presented the band interleaver based on RAMZI and demonstrated the band interleaving of the Kerr frequency comb. Our device demonstrated a sharp roll-off of 63.6 dB/nm with a total functional bandwidth of 36 nm. The bandwidth can be further improved by advanced ring designs with smaller radii, though more exotic bend geometries may be required. It is demonstrated to be a feasible method to further scale SiPh-based DWDM link architectures towards increased bandwidth capacity.

References

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