Microring Modulation-and-Weight Banks

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Abstract: For photonic neural networks, we propose a novel microring bank with carrier-effect and thermal dual-tunability, which can 1) combine modulating and weighting for saved space, 2) improve tuning efficiency, and 3) inherit WDM-enabled scalability.

Photonic neural networks have promised superior bandwidth, efficiency, and latency performance. However, the demonstrated network size falls far short as opposed to its electrical counterparts, primarily due to the large footprint of the integrated components. Multiply and accumulation (MAC) is the essential operation on a photonic chip, and it is realized by a series of integrated devices that independently perform the electrical-to-optical (EO) conversion, optical weighted summation, and optical-to-electrical (OE) conversion. Precisely, in addition to photodetectors handling the OE conversion, an array of Mach-Zehnder interferometers (MZI) or Microring resonators (MRR) modulate input signals onto their corresponding laser lights [1]. Then, subsequently cascaded meshes of MZIs or bank of MRRs apply weighting onto the modulated lights and sum them up [2].

Comparing MZI and MRR, the former has a larger size since longer waveguides are required for sufficient light interaction. Meanwhile, MRR leverages the merit of a resonator to have a similar interaction at reduced physical geometry, and the concurrent wavelength selectivity further allows multiple MRRs to share the same waveguide for further reduced footprint and improved scalability. With that, the modulation (EO conversion) and weighted summation are performed on separate but very similar devices (both are MRR-based), taking more than double the chip area. Besides, the wavelength selectivity necessitates the alignment of the MRRs for modulating and weighting, which can be practically difficult due to fabrication variations.

In this paper, we demonstrated that a single microring resonator can handle functionalities of both the EO conversion and the weighting. The ring waveguide is doped as a PN junction to allow input signal modulation by carrier depletion effect, and a metal heater on top of the ring enables the weighting through the thermal-optical effect. These two sets of tuning mechanisms are naturally aligned as based on the same ring resonator. Additionally, we observed more energy-efficient weighting than the previous separate arrangement, as the tuning

As indicated in Fig. 1a, the slope changes drastically near the center of the resonance frequency, allowing a tiny amount of detuning for sufficient signal weighting outcome. Assuming a Lorentzian-shaped profile, merely 10 percent of detuning from the resonance can achieve the peak slopes. In contrast, rings in conventional weight banks must be detuned more than eight times larger to cover more than 90 percent range of the same amount of weighting. This reduced detuning range translates to reduced energy, contributing to a more efficient way of weighting. Since these revised MRRs still work as standard ring resonators, multiple MRRs with slightly different radii can be put on the same bus waveguide and work without interference, permitting the incorporation of multiple