Microwave and RF Photonic Applications of Micro-Combs

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Photonic integrated circuits that exploit nonlinear optics for all-optical signal processing have been demonstrated, particularly in silicon, including all-optical logic [1], demultiplexing from 160Gb/s [2] to over 1Tb/s [3], to optical performance monitoring using slow light at speeds of up to 640Gb/s [4-5], all-optical regeneration [6], and many others. The efficiency of all-optical devices depends on the waveguide nonlinear parameter, $\gamma = \omega \, n_2 / c \, A_{eff}$. Although silicon can achieve extremely high values of γ, it suffers from high nonlinear losses due to two-photon absorption (TPA) and the resulting free carriers. Even if the free carriers are eliminated by p-i-n junctions, silicon's poor intrinsic nonlinear figure of merit (FOM = $n_2 / (\beta \, \lambda)$, where β is the TPA) of around 0.3 in the telecom band is far too low to achieve high performance. While TPA can be turned to advantage for all-optical functions [7-9], for the most part silicon's low FOM in the telecom band is a limitation.

In 2008-2010, new CMOS compatible platforms for nonlinear optics were introduced, including Hydex [8-18] and silicon nitride [19]. These platforms exhibit negligible nonlinear absorption in the telecom band, and have revolutionized micro-resonator optical frequency combs. The first integrated CMOS compatible integrated optical parametric oscillators were reported in 2010 [11,19], showing that Kerr frequency comb sources could be realised in chip form by using ring resonators with relatively modest Q-factors. Following this, a stable modelocked laser with pulse repetition rates from 200GHz to 800GHz was reported [12]. The success of this platform arises from its very low linear loss, its moderate nonlinearity ($\gamma \cong$ 233W^{-1}km^{-1}) and negligible nonlinear loss (TPA) [18].

Here, we review radio-frequency (RF) and microwave photonics applications of micro-combs. Optical frequency combs, and microcombs in particular, are ideal sources with which to base microwave and RF transversal filters on [20]. Many RF applications, including radar mapping, measurement, imaging as well as the realization of advanced modulation formats for digital communications, require the generation, analysis and processing of analogue RF signals where both the amplitude and phase of the signals are important. In-phase and quadrature-phase components of a signal can be obtained via a photonic based Hilbert transform [21]. Figure 1 shows a schematic of our ring resonator, with a Q factor of 1.2 million and FSR of 200GHz [11]. The comb spectrum has a spacing corresponding to the FSR of the microring, and was a "Type II" comb [22] with limited coherence between the comb lines. For the photonic Hilbert transformer demonstrated here, however, this was more than adequate. Figure 1 shows the output of the Hilbert transformer [21], displaying an RF range of over 5

octaves, and a high quality output. We review a wide range of novel RF functions based on microcombs. These devices have significant potential for applications in telecommunications and on-chip WDM optical interconnects for computing and many other applications.
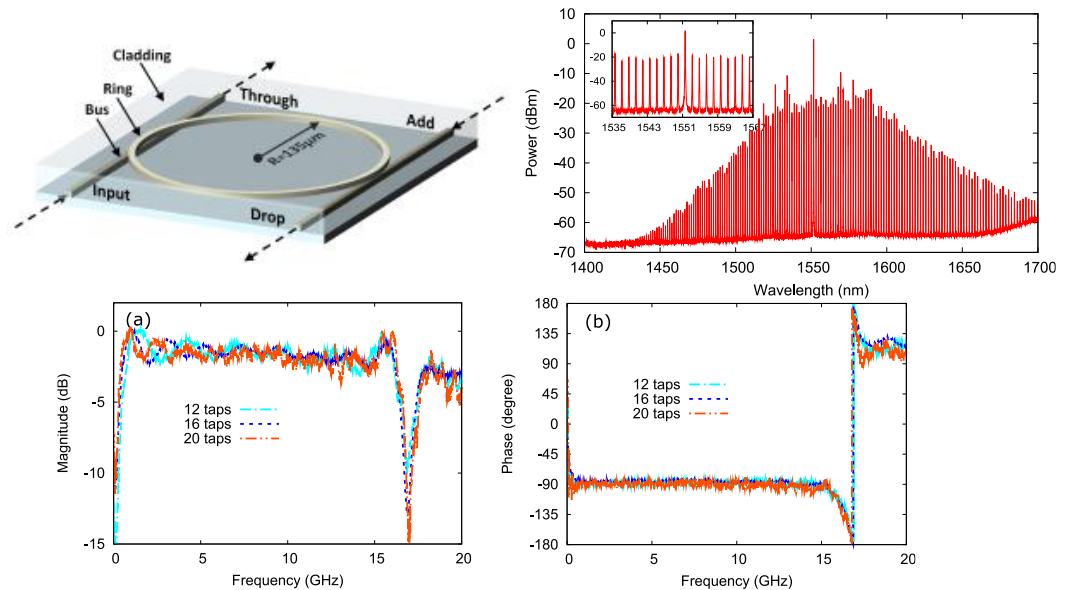

Fig. 1. Integrated ring resonator (top left), output comb spectrum (top right), Hilbert transform output (bottom) for both amplitude and phase.

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