Integrated Comb-Driven Silicon Photonics

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Abstract: We realize the combination of integrated microcomb and silicon photonics, employing the advanced AlGaAsOI optical nonlinear platform and novel SiPh chips. Data link with 2-Tbps aggregate rate and highly reconfigurable radio frequency filter are demonstrated.

1. Introduction

Integrated photonics is bringing promising reformation to fields ranging from information technology [1], biology [2] to physics [3]. Silicon photonics (SiPh) [4] and integrated microcomb [5] are two transformative technologies of integrated photonics in the last decades. Silicon photonics, transmitting, processing and detecting light in integrated silicon chip, bring tremendous improvement of scalability, integration and cost-efficiency to micro optical system, contributing to the attractive complementary metal–oxide–semiconductor (CMOS)-compatibility. While the lack of parallel coherent light sources blocks the further promotion of SiPh. Fortunately, integrated microcomb, another crucial integrated photonic technology, is consist of mutually coherent and equidistant optical frequency lines. Utilizing the natural massively parallelism provided by mature optical wavelength-division-multiplexing, integrated microcombs have disruptively refactored conventional optoelectronic information systems, such as high-capacity data link [6], optical computation accelerator [7], parallel laser ranging [8] etc. However, for most of microcomb-driven systems, numerous bulk compounds are still needed to stabilize the microcomb and operate each comb tooth. There is no clear solution for the combination of SiPh and integrated microcombs.

Here, we make a key step in combining these two essential technologies [9]. Employing the dark-pulse mode-locked comb state in an AlGaAsOI platform, a robust, operation-simplified parallel coherent optical source [10] is generated. The novel microcomb is employed to empower SiPh chips for two typical applications. One is the large-capacity data link with two-terabit-per-second aggregate rate. The other is a highly integrated microwave photonic filter with reconfiguration time of ∼ µs. Our work provides a novel paradigm for advanced integrated optical system, and promote the future widespread application based on SiPh and integrated microcombs.

2. AlGaAsOI microcombs generation

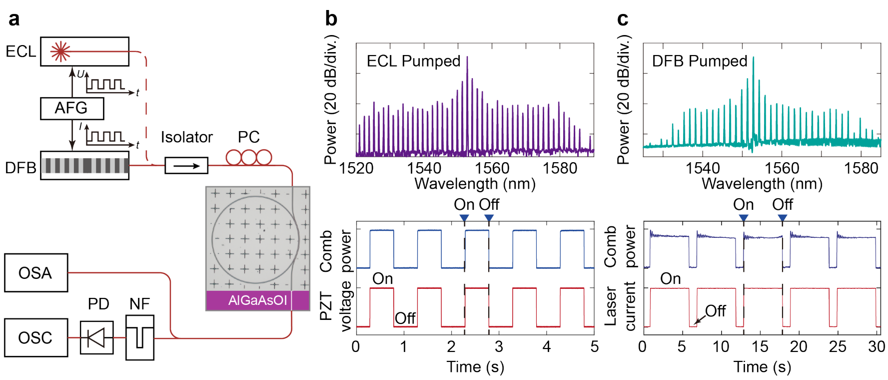

Fig. 1. **(a)** Experimental setup for the turnkey AlGaAs dark-pulse microcomb generation. **(b)** ECL and **(c)** DFB laser chip driven comb spectra and the comb power variations along with the control signal in five consecutive switching tests.

Fig. 1 shows the scheme of the turnkey microcomb generation. An arbitrary function generator (AFG) is used to send a square wave, to control the voltage applied onto the PZT in a commercial external cavity laser (ECL). The output wavelength of the ECL would be swept from shorter wavelength to longer wavelength due to the change of cavity length, controlled by the PZT. Such wavelength sweeping could stimulate the dark-pulse state in the AlGaAsOI microring under enough optical power. Contributing to the high nonlinearity and strong thermo-optic effect in the AlGaAsOI platform, the dark-pulse comb state could be supported and stabilized under mW-level pump power, allowing a stable comb generation using a DFB laser diode. Similarly, the square wave from the AFG is used to control the driven current of the laser diode. As the increase of the diode current, the warm-up process in the laser diode will make the output wavelength sweeping from the shorter wavelength to longer wavelength, estimating the dark-pulse state.

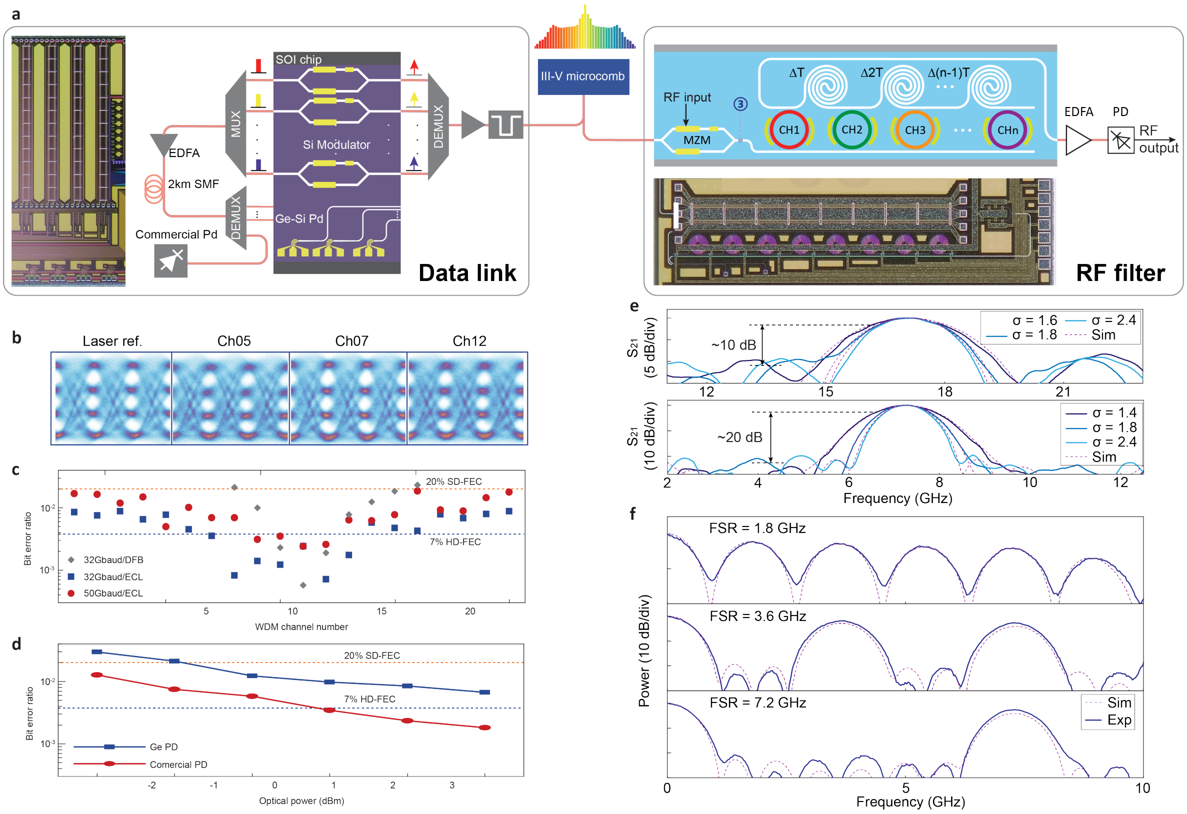

Fig. 2. **(a)** The architecture of parallel optical data link (left plane) and reconfigurable microwave photonic filter (right plane). **(b)** Eye diagrams of the chosen channel after modulation. **(c)** BER for each comb line. **(d)** BER versus receiving power comparison between an on-chip Ge–Si PD and a commercial PD. **(e)** RF filtering responses of the MPF with various passband BWs, based on the integrated delay line(top) and single mode fiber(bottom). **(f)** the MPF with various FSRs, by modifying the comb line spacing.

3. Parallel optical data link

Firstly, the novel microcomb is employed to empower a parallel optical data link. The schematic for the microcomb-driven data link is shown in Fig. 2a. The generated microcomb is amplified and wavelength-selectively routed into the SiPh modulator. The SiPh modulators have a 3 mm depletion region with 33 GHz OE-bandwidth and 0.3 V·cm modulation efficiency. To verify the data capability of carrying multi-Tbit/s, a simplified odd/even test scheme is used here, where the comb lines are filtered out and split into odd/even test bands by a wavelength selective switch (WSS) and afterwards launched into the silicon MZMs. The differential 100 Gbps PAM-4 signal is generated by a commercial pulse pattern generator. The modulated comb lines are amplified and transmitted through a 2 km single mode fiber. At the receive side, every comb line is filtered out by a bandpass filter and detected by a photodiode. Eye diagrams (shown in Fig. 2b) of each channel are produced by a sampling oscilloscope with multi-tap TDECQ equalizer. As shown in Fig. 2c and d, considering a 20% SD-FEC threshold, a 2 km error-free data transmission with an aggregate rate of 2 Tbit/s is demonstrated.

4. Reconfigurable microwave photonic filter

In addition, a reconfigurable microwave photonic filter is realized by injecting the microcomb into the silicon-on-isolator radio-frequency signal processor. Fig. 2a shows the schematic of the microwave photonic filter. The microcomb is employed as multi taps for a FIR (finite impulse response) filter. The radio signal is modulated onto each comb line. The amplitude of each comb line is tuned via the microring weight banks and incremental time delay is lunched as comb lines propagating through the delay line, which calls a tapped delay line (TDL) [11]. The incremental time delay could also be lunched by fiber dispersion using a long single mode fiber. By changing the weight and time delay arranged on each line, RF responses with different free spectrum ranges and different bandwidths are obtained as shown in Fig. 2e and f.

5. Conclusion

In conclusion, we demonstrate the first system-level combination of integrated microcombs and silicon photonics, where a data link with two-terabit-per-second aggregate rate, and a highly integrated microwave photonic filter with reconfiguration time of $\sim$ μs are demonstrated. It is expected to be directly applied to data centers, 5/6G signal processing, automatic driving, optical computing and other fields, and provides a new paradigm and roadmap for the next generation of fully-integrated optoelectronic information systems.

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