Chip-Scale Frequency Comb Generators for High-Speed Communications and Optical Metrology

ABSTRACT

Frequency combs are key components for a wide variety of applications, ranging from high-precision metrology to high-speed optical communications. In this talk, we give an overview on our recent progress in the area of integrated optical comb generators and of the associated applications. Our experiments cover modulator-based comb sources, injection locking of gain-switched laser diodes, quantum-dash mode-locked lasers, as well as Kerr comb sources based on cavity solitons. We evaluate and compare the performance of these devices as optical sources for massively parallel wavelength division multiplexing at multi-terabit/s data rates, and we report on comb-based approaches for high-precision distance metrology.

SUMMARY

Frequency combs are key components for a wide variety of applications, ranging from high-precision metrology to high-speed optical communications. High-speed optical links rely on coherent transmission using higher-order modulation formats along with advanced wavelength-division multiplexing (WDM) schemes. In this context, frequency combs are perfectly suited as multi-wavelength light sources at the transmitter and as multi-wavelength local oscillators (LO) at the receiver. Unlike carriers derived from a bank of individual laser modules, the tones of a comb are intrinsically equidistant in frequency, thereby enabling transmission of optical data signals at highest spectral efficiency [6]. In addition, stochastic frequency variations of the carriers are strongly correlated, which enables efficient compensation of impairments caused by nonlinearities of the optical fiber in long-distance transmission [7]. To demonstrate the viability of optical frequency combs for high-speed coherent communications, we have performed a set of experiments that exploit different comb generator concepts at the transmitter as well as at the receiver.

In a first set of experiments, we demonstrate frequency comb generation using silicon-organic hybrid (SOH) electro-optic modulators, thereby achieving line rates up to 1.152 Tbit/s transmitted on 9 optical carriers [8]. SOH integration...
combines silicon photonic slot waveguides with organic electro-optic cladding materials to realize highly efficient modulators [9], [10]. These devices enable large modulation depths at moderate drive voltages, thereby generating frequency combs from a single continuous-wave (cw) laser line.

In a second set of experiments, we use injection locking of gain-switched laser diodes to generate frequency combs [11]. When used as a multi-wavelength optical source at the transmitter, these so-called gain-switched combs sources (GSCS) enable line rates of more than 2 Tbit/s on 24 optical carriers. We also demonstrate that GSCS can not only act as a transmitter light source, but also as multi-wavelength local oscillator, thereby exploiting the scalability advantages of optical frequency combs also at the receiver side [12].

In a third set of experiments, we use quantum-dash mode-locked laser diodes (MLLD) as frequency comb sources. These devices exhibit rather large optical linewidths, which either requires dedicated phase-noise reduction schemes [13], self-homodyne detection [14], or digital phase tracking [15] to enable coherent communications with higher-order modulation formats at low symbol rates. However, at high symbol rates of, e.g., 40 Gbd or more, carrier phase noise is less detrimental, and no additional measures are needed. In a WDM experiment with 52 channels, we demonstrate transmission of an aggregate line rate of 8.32 Tbit/s (net data rate of 7.74 Tbit/s) over a transmission distance of 75 km [15]. More recently, we have shown that at sufficiently high symbol rates, MLLD can also be used as multi-wavelength LO, despite their comparatively large optical linewidth [16].

Finally, a fourth set of experiments is dedicated to comb sources that exploit Kerr nonlinearities in integrated silicon-nitride microcavities fabricated by a so-called photonic Damascene process for stress control [17]. In a first experiment, we demonstrated coherent communications using a Kerr frequency comb source, thereby achieving line rates of up to 1.44 Tbit/s on 20 carriers [18]. More recently, we succeeded in increasing the transmission speed to data rates beyond 50 Tbit/s by using highly stable dissipative cavity soliton Kerr combs that provide hundreds of spectral carriers at infrared telecommunication wavelengths [19] – [23]. This corresponds to the highest data rate achieved to date using a chip-scale frequency comb source. In our experiments, we use two interleaved Kerr combs to transmit data on a total of 179 individual optical carriers that span the entire telecommunication C and L bands. Equally important, we demonstrate coherent detection of a WDM data stream by using a Kerr soliton comb as a multi-wavelength LO at the receiver. These results prove the tremendous technological potential of chip-scale microresonator soliton comb sources in high-speed communications. In combination with advanced spatial multiplexing schemes [24] and highly integrated silicon photonic circuits [2], microresonator soliton combs may bring chip-scale petabit/s transceiver systems into reach.

Besides optical communications, optical metrology can also benefit greatly from combining photonic integrated circuits with chip-scale frequency comb generators. This applies, e.g., to high-precision distance metrology [25], where frequency combs allow to maintain high sampling speeds and high precision even when measuring the distance to scattering technical surfaces [26]. The receiver system of such metrology schemes can be efficiently integrated on silicon-on-insulator chips [27]. To realize fully integrated optical metrology systems, these devices can be connected to chip-scale comb-generators comb by photonic wire bonds [28], [29]. While high-speed optical communications is currently the most important driver for co-integration of photonic circuits and chip-scale comb generators, we believe that optical metrology and sensing will also benefit greatly from the tremendous technological advances that the field has experienced in recent years.

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References


