Kerr Soliton Microcomb Pumped by an Integrated SBS Laser for Ultra-Low Linewidth WDM Sources

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Abstract: An ultra-low linewidth WDM comb is realized using an integrated SiN SBS laser to pump a 128 GHz channel spacing SiN Kerr soliton microring resonator. We measure the frequency noise of each of 25 C-band individual comb lines yielding ultra-low ~10Hz fundamental and ~4.0kHz integral linewidths for high-capacity coherent WDM.

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1. Introduction

Kerr soliton optical frequency combs (OFCs) [1] have the potential to enable massively parallel coherent WDM links with greatly reduced transceiver complexity in contrast to systems using independent lasers for each channel [2]. Compared to other frequency comb generation techniques, such as tabletop and fiber mode-locked lasers, Kerr combs have inherent advantages including soliton stability, extremely wide comb bandwidths, a wide range of possible designed channel spacings and integration compatibility [3]. These benefits are especially attractive in coherent QAM WDM links. Recent demonstrations of Kerr soliton-based coherent WDM links with tunable ECDL pump sources have shown linewidths ~ 10-100 kHz that support 64-QAM modulation [2]. However, scaling to higher baud rates and higher order QAM formats requires low phase noise, ultra-low linewidth WDM carriers. Techniques have been demonstrated to generate ultra-low noise optical frequency combs [4] and the frequency noise of precision stabilized-laser driven Kerr microcombs studied [5]. However, there has been limited work on the pumping of Kerr microcombs with ultra-low linewidth integrated lasers and the linewidth characterization of resulting WDM sources.

Here we report an ultra-low linewidth, 128 GHz channel spacing WDM C-band source, formed by pumping an integrated SiN Kerr soliton optical frequency comb source with an integrated SiN bus-coupled stimulated Brillouin Scattering (SBS) laser. We demonstrate Kerr-soliton microcomb generation of 25 x 128 GHz spaced comb lines with average individual fundamental linewidth of 14.8 Hz and average integral linewidth of 4.913 kHz when pumped with an integrated SBS laser with fundamental linewidth (FLW) ~1 Hz [6]. In order to demonstrate and quantify the coherence transfer of the low FLW SBS source to the C-band WDM carrier tones, we measure the frequency noise (FN) of 25 independent 128 GHz spaced comb lines for wavelengths spanning 1535 nm to 1565 nm. The Kerr microcomb is designed to generate 128 GHz spaced combs lines in order to support a link design with 75 GBaud M-QAM modulation. We measure the fundamental and integral linewidths (ILW) of the pump and each of the individual comb lines and compare the Kerr microcomb fundamental and integral linewidths when pumped with a commercially available external cavity tunable pump laser to the linewidths generated when pumped with the integrated SBS pump laser. We measure a factor of 20X fundamental linewidth reduction when pumped with the integrated SBS laser over the external cavity laser. Given the common SiN integration platform of the SBS laser and the Kerr microcomb, these results show promise for integrated ultra-low linewidth WDM comb sources in a foundry-compatible platform.

2. SBS Laser Pumped Kerr Soliton Comb WDM Frequency Generator

The ultra-low-linewidth WDM frequency comb is generated using a SiN SBS laser that pumps a SiN Kerr Soliton OFC generator as shown in Fig. 1a. Both devices are oxide clad silicon nitride (SiN) core waveguide structures.

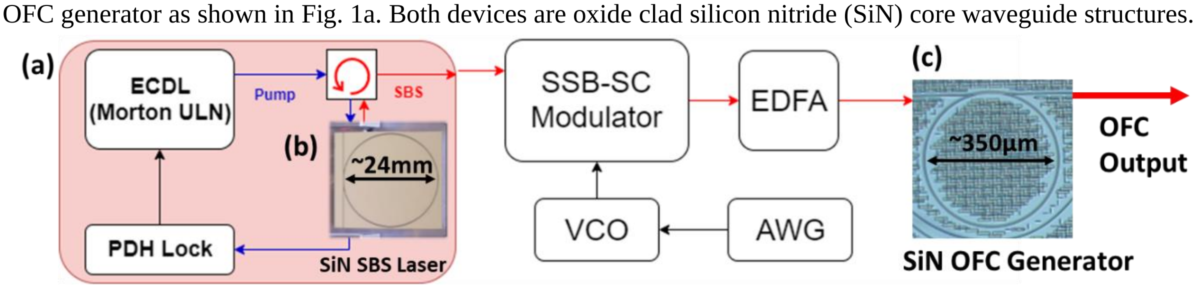

Fig. 1 (a) SBS pumped Kerr Soliton OFC. (b) SBS laser. (c) Kerr soliton microring optical frequency comb generator

The SBS laser is a bus-coupled resonator with a thin SiN waveguide core of cross-section 40 nm x 7000 nm and a loaded Q ~ 30 million (Fig. 1b). Further details of the SBS laser and performance are given in [6]. The OFC generator

(Fig. 1c) is designed with a thick waveguide core with a cross-section of 800 nm x 2600 nm. The OFC resonator with has a loaded Q of ~ 2 million and a 128 GHz (~ 1 nm) free spectral range.

In this demonstration the SBS laser cannot directly achieve the fast frequency sweep required to initiate stable soliton generation, so we employ a single-sideband suppressed-carrier (SSB-SC) modulator with tunable offset frequency as shown in Fig. 1a. Stable soliton generation is required for stable, low noise, stationary frequency combs, and can be made repeatable with a properly calibrated sequence of fast pump laser frequency tuning [7]. The output OFC optical spectrum for a single stable soliton state is shown in (Fig. 2b). Ramping the pump laser from high to low frequency across the soliton microcomb resonance first results in a chaotic comb state due to modulation instability (MI) observed as fluctuations in the converted optical power as seen in the left of Fig. 2c. As the swept optical pump sideband crosses the microcomb resonance, the converted light transitions through several soliton states as indicated by discrete steps in the converted optical power in Fig. 2c. With proper optimization of the pump sideband tuning sequence, a stable and long-lasting soliton is achieved as observed in Fig. 2d.

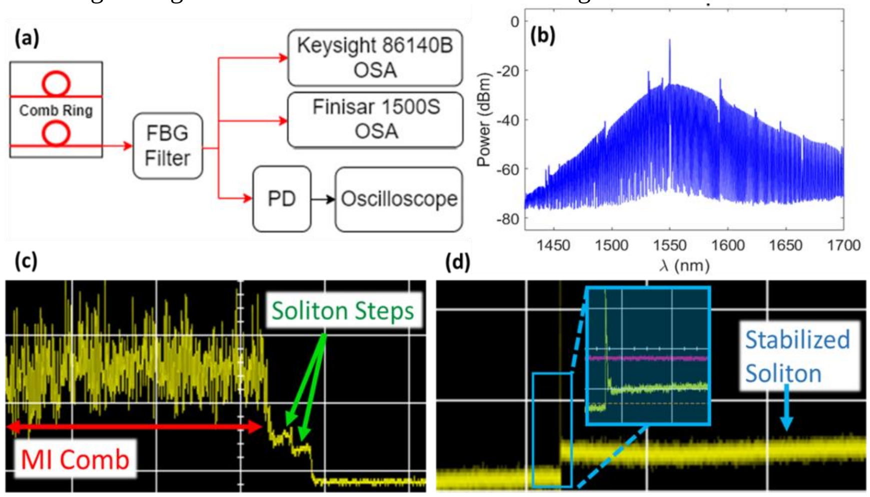

Fig. 2 (a) Test setup for monitoring soliton generation. (b), Optical spectrum of converted light in a single soliton state. (c) Demonstration of comb states as pump frequency is swept through resonance. (d) Formation of a stable single soliton.

3. OFC Comb Line Frequency Noise and Linewidth Measurements

We compared the OFC output comb linewidth under two different pump conditions, first with a commercial tunable laser (Newport Velocity) and then with the integrated SiN ultra-narrow linewidth SBS laser. We measured the fundamental and integral linewidths of 25 comb lines to characterize the transfer of the pump laser noise to individual comb lines (Fig. 3a) using the two different pump sources. These 25 C-band comb lines are shown in Fig. 3b. Optical amplification and filtering were used to isolate single-λ lines (Fig. 3c) with an optical power of ~ 3 dBm and optical signal to noise ratio of ~ 25 dB. A delay line optical frequency discriminator (OFD) system using an unbalanced Mach-Zehnder interferometer [8] was used to measure the frequency noise (See Fig. 3d for an example of one line) of each carrier. Fundamental linewidths were then calculated from the OFD measured white noise floor of each FN spectrum for each laser. Integral linewidths were then calculated for each output line using a phase noise integration method [9] . The results of integral and fundamental linewidth measurements for the velocity tunable laser pumped OFC and SiN integrated SBS laser pumped OFC are shown in the scatterplot in Fig. 3e.

Fig. 3 (d), shows that the frequency noise properties of a pump laser and its generated comb lines are nearly identical in this system at frequency offsets below 5 MHz. While some variance is observed in the fundamental SBS linewidths in Fig. 3(e), we attribute it to fluctuations in the SBS laser fundamental linewidth due to power coupling variations for the SBS laser resonator, instead of dynamics in the OFC. Comparing the FN traces of our SBS laser with and without the SSB modulator in Fig. 3 (b), we find that the modulator adds frequency noise over the entire measured frequency offset range and is found to be the dominant source of added frequency noise. While the slight increase in FN at frequency offsets > 5 MHz is a product of the comb, this noise is frequency dependent and thus does not contribute to fundamental linewidth. Since this noise source is at the high frequency end of our measurement capabilities, it adds noise to the FN spectrum in the 5 MHz offset range, which is where our SBS laser noise typically reaches its white FN floor and fundamental linewidth is measured. This results in the slight increase in measured FLW between the SSB pump and the comb lines. In Table 1 below, we summarize measurement of the 25 comb lines with an average comb linewidth of 14.8 Hz fundamental and 4.913 kHz integral linewidth. This represents a 20x reduction in fundamental linewidth when compared to pumping the same comb generator with our commercially available widely tunable laser and demonstrates fundamental linewidth transfer of the narrow linewidth SBS pump laser.

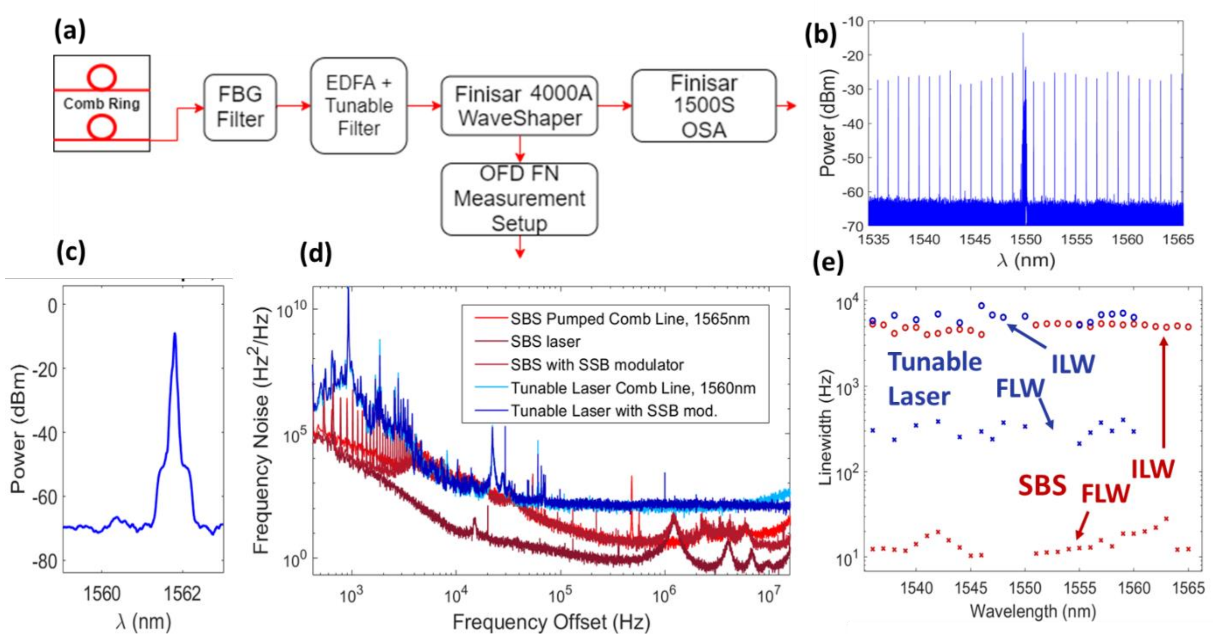

Fig. 3 (a) Measurement setup for individual comb linewidths. (b) Spectrum of the C-band lines selected for FN measurements. (c) A single line filtered using a Finisar waveshaper. (d) OFD frequency noise measurements. (e) Fundamental and integral linewidths.

Table 1. Summary of fundamental and integral linewidths for comparison

	SBS Laser	SBS+SSB Laser	SBS+SSB Comb Lines		Tunable Laser	Tunable Laser Comb Lines	
			Minimum	Average		Minimum	Average
Fundamental LW (Hz)	1.2	7.4	10.4	14.8	244	256.0	310.0
Integral LW (Hz)	1740	5016	4024	4931	4986	5528	6521

4. Conclusion

We have demonstrated a chip-scale SBS laser pumped Kerr microring soliton OFC with a 128 GHz line spacing and have compared the frequency noise and linewidth of the pump to 25 comb lines. Using two different lasers to pump the OFC, we show that the OFC generator effectively transfers the frequency noise characteristics of the pump to each comb line. Pumping the OFC with our integrated SBS laser results in the transfer of the narrow fundamental linewidth of the pump to the comb lines with a 3 Hz Fundamental linewidth penalty. This demonstrates the feasibility of optical coherence transfer of narrow linewidth, low frequency noise pump laser sources to C-band comb lines for high QAM coherent WDM. While the performance of the current architecture is limited by added noise from the single sideband modulator, transfer of a sub-Hz fundamental linewidth SBS pump can be achieved in future realizations by stabilizing the SSB modulation frequency or thermally tuning the OFC ring [10].

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