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Citation for the original published paper (version of record):
Lei, F., Sun, Y., Helgason, Ò. et al (2024). Narrow-linewidth and tunable parametric oscillator. 2024 Conference on Lasers and Electro-Optics, CLEO 2024. http://dx.doi.org/10.1364/cleo_si.2024.sth3i.3

Narrow-linewidth and tunable parametric oscillator

Fuchuan Lei[1,2], Yi Sun[1], Óskar B. Helgason[1], Zhichao Ye[1], Yan Gao[1], Magnus Karlsson[1], Peter A Andrekson[1], and Victor Torres-Company[1]

1. Department of Microtechnology and Nanoscience, Chalmers University of Technology SE-41296 Gothenburg, Sweden
2. School of Physics, Northeast Normal University, Changchun, 130024, China
fuchuanlei@nenu.edu.cn

Abstract: We present a tunable coherent oscillator based on parametric gain. It is realized through self-injection locking one comb line of a Kerr microcomb. Sub-Hertz intrinsic linewidth and 20nm tuning range are achieved.

1. Introduction

Narrow-linewidth yet tunable laser oscillators are essential for many applications, such as precision metrology, sensing and quantum information. Usually, tunable coherent oscillators are based on stimulated emission, as a result, the wavelength tuning range is fundamentally limited by the gain media. Although stimulated Brillouin scattering is widely used for implementing narrow-linewidth lasers [1], the emission wavelength is close to that of the pump. In principle, some other nonlinear optical frequency conversion processes, such as harmonic generation [2], sum/difference frequency generation or four-wave mixing can be employed . However, this is quite challenging in practice because one or two narrow-linewidth pump lasers are required, and the phase matching condition needs to be stringently satisfied over a large frequency range. Based on optically driven nonlinear polarization, optical parametric oscillators (OPOs) have the ability for generating coherent radiation ranging from UV to teraHertz [3], particularly in the wavelength regions which ordinary lasers hardly reach. However, it is not easy to achieve spectrally pure coherent oscillation.

2. Optical parametric oscillator (OPO) with self-injection locking

Here, we introduce a new approach to achieve a narrow-linewidth and tunable oscillator based on self-injection locking (SIL) of a multimode continuous-wave OPO, i.e., a Kerr microcomb [4]. The schematic architecture is shown in Fig. 1. The system is composed of a microcomb and an external optical feedback loop. In this scheme, only one comb line (which can be arbitrary except for the pump) is selected for re-injection, which is realized by inserting a frequency tunable bandpass filter (TBPF) into the feedback loop. Considering that the feedback power ratio is an important parameter in SIL dynamics, an erbium-doped fiber amplifier (EDFA) and a tunable attenuator are included into the feedback loop for precisely controlling of the feedback power ratio. The total length of the feedback fiber loop is about 50 m. With this configuration, we successfully demonstrate substantial spectral narrowing of a CW OPO.

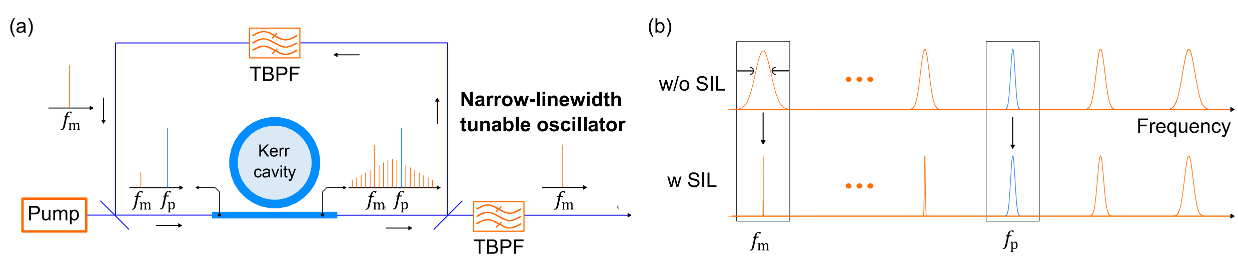

Fig. 1 (a) Architecture of the self-injection-locked narrow-linewidth parametric oscillator. A microcomb (multimode OPO) is generated in a Kerr-nonlinearity microcavity (FSR is about 100 GHz) with a continuous-wave pump. The m-th comb line (counted from the pump, f_m) is selected with a tunable bandpass filter (TBPF) and re-injected into the microcavity. (b) With proper feedback power ratio, the linewidth of the m-th comb line (the coherent oscillator) is significantly reduced, meanwhile, some other comb lines are narrowed accordingly.

3. Sub-Hertz linewidth parametric oscillator

Based the above system, we unveil rich nonlinear dynamics, akin to what has been found in semiconductor lasers with SIL [5]. Our numerical simulations are consistent with the experimental observations [6]. It is shown that there exists a dynamic regime withing which the frequency noise of the comb line can be consistently reduced by three orders lower than the pump (Fig. 2), regardless of the feedback phase. This regime is especially interesting because it implies that our system could be simply operated in atmospheric environment without the need of any servo control.

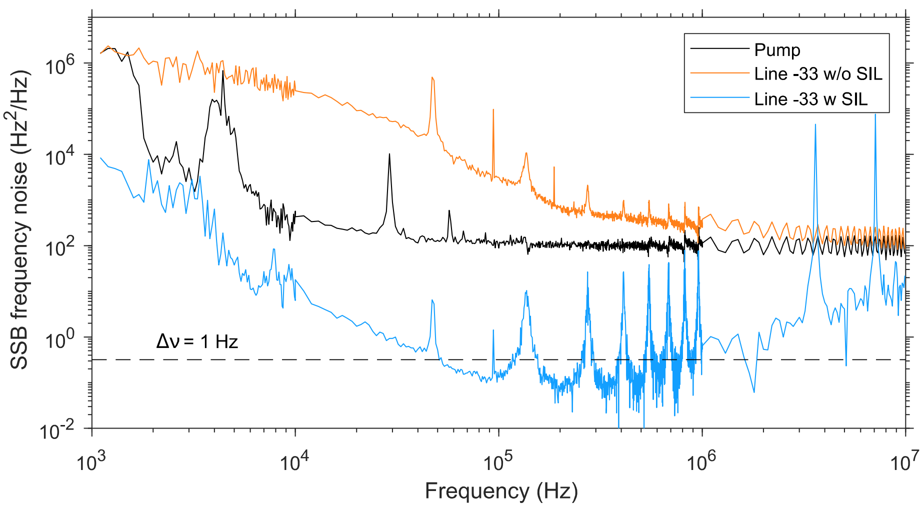

Fig. 2 Measured single sideband (SSB) frequency noise of the pump and the comb line -33 with/without self-injection locking. The level corresponding to a 1-Hz intrinsic linewidth is indicated.

In conclusion, we have demonstrated a coherent oscillator with sub-Hertz intrinsic linewidth, achieved by SIL of a single comb line in a microcomb. By selecting different comb lines, one can obtain a wavelength-selective coherent oscillator. Continuous wavelength tuning should be obtained via simultaneous tuning the pump frequency and the cavity resonance over one FSR of the microresonator. The oscillator being based on parametric gain, has unique advantages for many new applications, especially for the case where the conventional gain materials are difficult to obtain.

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