Widely Tunable and Narrow Linewidth Laser Source based on Normal-Dispersion Frequency Combs and Optical Injection Locking

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Abstract: By injection-locking tones of a normal-dispersion, photonic molecule enabled microcomb, a tunable laser source is demonstrated with $>$ 55 nm of tunable range, $<$ 8 kHz integrated linewidth, $>$ 5 dBm of power, and $>$ 60 dB SMSR. © 2021 The Author(s)

1. Main Text

Single frequency sources which have low noise and are highly tunable are useful in many fields such as spectroscopy, interferometry, communications, and metrology. There are a variety of approaches to produce such lasers, including distributed feedback (DFB) lasers [1], distributed Bragg reflector (DBR) lasers [2], fiber lasers [3], and external cavity diode lasers (ECDL) [4], but research continues to improve and explore the field.

As seen in figure 1, using a method based on [5], we begin with a low noise fiber laser with a 115 GHz tunable bandwidth, then injection lock a DFB slave laser to reach a higher power. We then use this to pump a normal dispersion photonic microring molecule [6] with 100 GHz free spectral range (FSR), and finally use a set of amplifiers, filters, and a Fabry-Perot slave laser for comb tooth selection, cleanup and post-injection locking of a selected comb tone to produce a single mode output. All together, this serves to nonlinearly extend the tunable range of the initial seed laser, at the cost of some additional noise, as studied below.

Importantly, the normal dispersion photonic ring molecule takes advantage of its flat spectral top, thermal tuning on both the primary and auxiliary cavity such that soliton generation at an arbitrary center frequency is possible, and offers excellent efficiency (37 %) as compared to anomalous dispersion solitons. Moreover, the approach is scalable to wider tunability and higher power, can be laser cooled for further noise reduction [7], and offers several other advantages. For instance, there is no use of an erbium doped fiber amplifier (EDFA), and unlike ECDLs and other self injection locking schemes [8, 9], this approach is feedback-free onto the seed laser, which allows for the generation of multiple mutually coherent tones at different frequencies simultaneously as enabled by the frequency comb [10], and for schemes which require a distributed master laser.

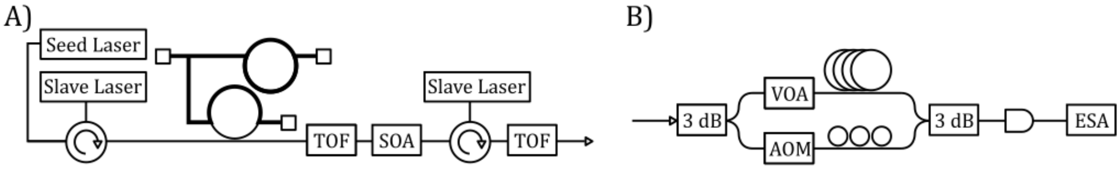

Fig. 1: A) The principle of operation, using pre-injection locking DFB laser, comb generation in a photonic molecule, a set of tunable optical filters (TOF), a semiconductor optical amplfier (SOA), and a post-injection locking Fabry-Perot laser B) Phase noise measurement using a variable optical attenuator (VOA), acousto-optic modulator (AOM), and an electric spectrum analyser (ESA)

In the top of figure 2, we show the final output tones in the range of 1530 nm to 1585 nm, and show that $>$ 5 dBm of output power and $>$ 60 dB of side mode suppression ratio (SMSR) is achieved across the tunable bandwidth, covering the full C-Band and beyond. Here, the shortest wavelength tone corresponds to the $m = -30$ mode, and the longest corresponds to the $m = +36$ mode of the microcomb. Importantly, the seed laser is tunable over a 115 GHz bandwidth, and both resonators in the photonic molecule are heat-tunable over more than a full FSR and a half, such that arbitrary wavelength tuning of the modal crossing and thus comb central frequency is achieved.

In the bottom of figure 2, we show the RIN power spectral density for the seed laser before pre-injection locking,

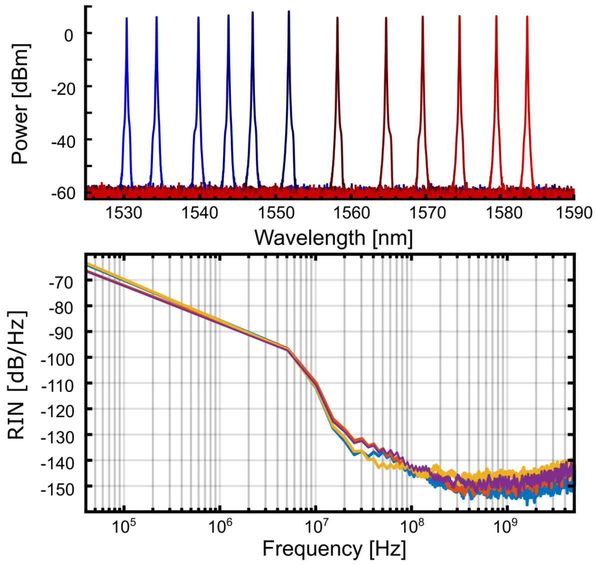

Figure 2) Top) Final output of tones produced across the C-Band and beyond Bottom) RIN of the seed laser (blue), m = 0 tone (orange) and the m = -30 (purple) and m = +36 (yellow) tones.

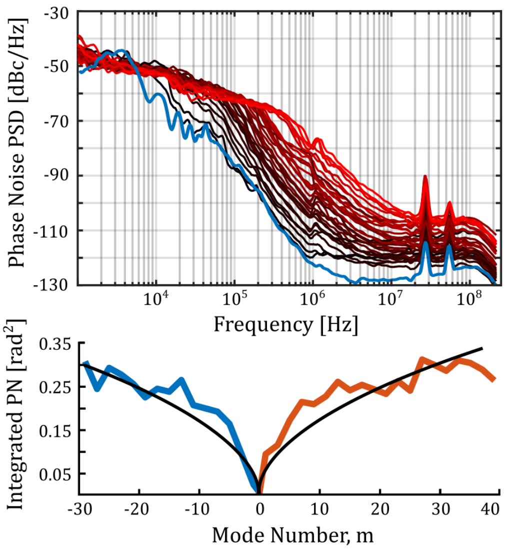

Figure 3) Top) Phase noise of the seed laser and every other produced tone spanning from m = -30 to +36. Bottom) Integrated phase noise (PN), including quadratic fit.

as well as the m = 0, m = -30, and m = +36 final output tones. There is a relatively modest increase in RIN for frequencies above 100 MHz when the absolute value of m is large.

In the top of figure 3, we show the unlocked seed laser phase noise in blue, and every other comb mode after final injection locking and filtration in shades of red, up to the m= -30 and m = +36 modes. In the bottom, we show the integrated phase noise from 8 kHz (corresponding to the 25 km delay line in measurement), up to 125 MHz (the bandwidth of the photoreceiver used). Given that the integrated phase noise stays below $\frac{1}{\pi}$ for all tones, an integrated linewidth of less than 8 kHz is confirmed over the full tunable range [11]. We also measure the fundamental linewidth (i.e. excluding flicker frequency noise) using the fit method [12], and find values of 80 Hz at the central tone up to approximately 710 Hz at the m = +36 tone.

Such a device is well suited for a variety of applications, and offers several advantages, such as its high efficiency, small footprint, and feedback-free operation.

2. Acknowledgments

Knut och Alice Wallenbergs Stiftelse, Vetenskapsrådet (VR-2015-00535 & 2020-00453), and ERC (GA 771410).

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