Sub-kHz linewidth lasers using integrated Si_3N_4 ring resonators

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1. Introduction

Frequency discriminators are attractive devices for reducing integrated laser linewidths for coherent communication systems and high purity microwave photonic systems. Standard diode lasers have MHz level linewidths, with recent integrated delay line lasers showing a 50 kHz [1]. Typical on chip devices allow for a few cm of delay in a Mach Zehnder (MZI) configuration, but larger delays are needed for integrated devices. Here, we show a fully integrated Si_3N_4 ring resonator used as an optical discriminator with a sensitivity better than a 10 meter delay line interferometer. We utilize the Pound-Drever-Hall (PDH) technique to characterize the resonator bandwidth and improve the linewidth of a state of the art commercial laser by locking to the waveguide coupled resonator.

2. Setup

The PDH setup consist of a single local oscillator driving 2 components, a $LiNbO_3$ optical phase modulator and an electronic mixer. The phase modulator adds sidebands to a commercial 1565 nm RIO ORION laser module, which has a state of the art linewidth of 1 kHz and is only narrowly tunable. To decrease the noise of the laser, the sidebands are sent through an ultra-low loss ring resonator, which has a phase discrimination between the upper and lower sidebands. When this error signal hits a detector and RF mixer port, an asymmetric signal is created which is used for electronic locking after an appropriate loop filter, Fig 1. The discriminator slope is dependent on the resonator FWHM, and determines how much you can suppress frequency noise and narrow the linewidth of the laser. The locking is performed with an integrator and tunable gain stage of op-amps. To measure laser linewidth, we bias a 13 m MZI at quadrature to convert frequency fluctuations to amplitude noise. We then take the PSD on a spectrum analyzer and correct for the $sinc^2$ transfer function.

3. Results

We characterize the bandwidth of the resonator to be 6.7 MHz (30 million Q) and the discriminator slope to be 38 mV/MHz using the 48 MHz sidebands on the optical carrier for calibration. This slope is steeper than the 13 m MZI slope shown in Fig 1, and can afford lower laser linewidths. After closing the feedback loop to the laser, we see a frequency noise reduction of >10 dB at Fourier frequencies 2-10 kHz, with a minimum of 30 Hz^2/Hz currently limited by the amplitude noise in the system. Future work will include reducing the system's low frequency amplitude noise and increasing the loop bandwidth so as to further reduce the laser. This Si_3N_4 resonator is also readily integrated with hybrid Si III/V lasers, promising low noise, narrow linewidth lasers for future metrology and communication applications.

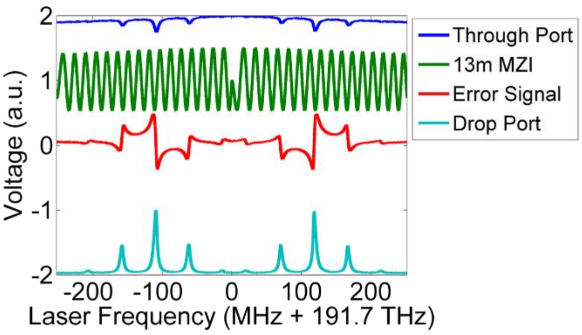

Figure 1. Normalized PDH error signal (red) and resonator modes with phase modulation sidebands (blue, teal) as the laser frequency is swept. The scan rate and slope are calibrated to the 48 MHz sidebands and the 13 m MZM delay line interferometer (green).

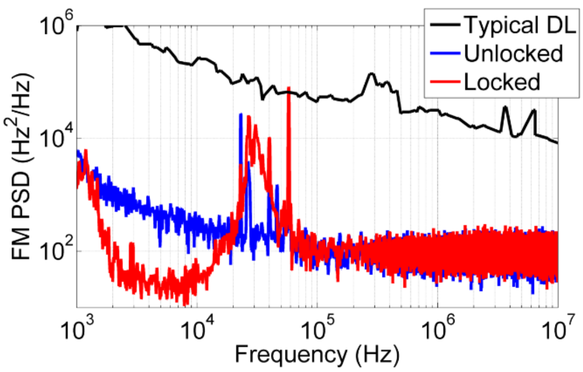

Figure 2. Frequency noise power spectral density for the commercial laser free running (blue) and locked to the Si_3N_4 resonator (red). A typical diode laser with MHz level linewidth (black) is plotted for comparison, from [2].

References

[1] T. Komljenovic et al., IEEE J. Sel. Top. Quantum Electron. **21**, 1 (2015).
[2] M. Poulin et al., in *SPIE LASE*, A. V. Kudryashov et al., eds. (2010).