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# Performance Enhancement of Quantum-Dash Comb Laser by Combined Use of broadband Noise Source and Self-injection locking

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**Abstract:** We experimentally demonstrate quantum-dash laser performance improvement by injecting optical noise and coherent feedback. The results show the amplification of the side mode lines while preserving the mode-locking and drastically reducing the individual comb linewidth. © 2023 The Author(s).

## 1. Introduction

Quantum-Dash Mode-Locked Lasers (QD-MLL) are considered a revolutionary development in the field of photonics, enabling high-speed data transmission with advanced modulation formats, as well as local oscillators for massively parallel coherent reception [1]. Leveraging the unique properties of these lasers, which are nanostructures with enhanced carrier dynamics, the QD-MLL offers exceptional performance in terms of pulse generation with subpicosecond durations and hundreds of flat and equidistant optical frequency lines spaced by tens of GHz. This innovative laser architecture combines the advantages of mode-locking and quantum dash technology, paving the way for significant breakthroughs in ultrafast optical communication, nonlinear optics, and high-resolution spectroscopy.

In this paper, we experimentally demonstrate performance improvement of a single section QD-MLL via the combined use of a broadband optical noise source and self-injection coherent optical feedback. Under a specific level of noise, the side mode lines of the laser are amplified while maintaining the mode-locking [2], and the individual optical mode linewidth is significantly reduced.

## 2. Operation and experimental results

Fig. 1 shows the experimental setup employed. The frequency comb sources used in our experiments consist of InAs/InP QD-MLL structures with as-cleaved mirror facets. The laser was mounted on a heatsink for a stable temperature control, and kept at  $\sim 25^\circ\text{C}$  with a Peltier cooler. On the first facet of the laser, the emitted light is coupled with a lensed fiber, which has an anti-reflective (AR) coating, achieving a fiber-coupled optical power above 1 mW in free-running operation. The laser was optically injected with broadband optical noise via an optical fiber circulator using a super-luminescent diode, offering a flat noise over the entire spectral bandwidth of the laser. On the second facet of the laser, the output light enters in a free space external cavity consisting of a collimating lens, a polarizer that acts as a variable attenuator to control the feedback strength, and a free-space mirror placed  $\sim 30$  cm away. The feedback strength is known as the ratio of the intensity reflected back into the laser cavity after one round-trip in free-space to the intensity emitted from the laser. The external cavity length is finely adjusted by moving the mirror position in order to target the resonant feedback regime such that the external cavity length is close to an integer multiple of the QD-MLL cavity.

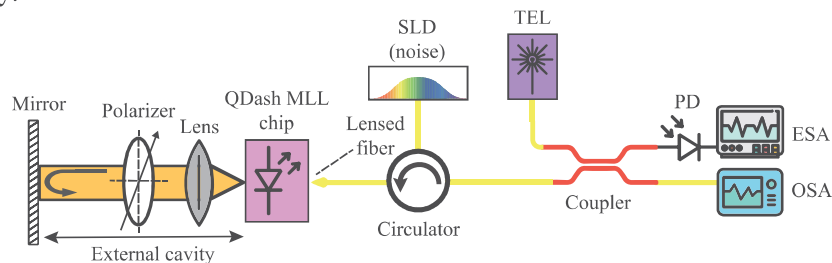


Fig. 1. Experimental setup. QDash MLL: Quantum-Dash Mode-Locked Laser, SLD: Super-Luminescent Diode, TEL: Tunable External Laser, PD: Photodetector, ESA: Electrical Spectrum Analyzer, OSA: Optical Spectrum Analyzer.

The resulting signal under test was mixed with a signal coming from a tunable external cavity laser (TEL) using a 90/10 coupler in order to measure the optical linewidth of the QD-MLL modes by conventional heterodyne technique. This technique uses the RF beat notes between the QD-MLL and the TEL, allowing insight into the

linewidth of each individual mode. The collected light is sent to an optical spectrum analyzer (OSA, Anritsu MS9740B) to observe the amplification of the side mode lines with 0.03 nm resolution and a 20 nm span. The beat signal is analyzed in the RF domain using a fast amplified photodiode (25 GHz bandwidth) coupled with an electrical spectrum analyzer (ESA, R&S FSVR, 30 GHz bandwidth) with 500 kHz resolution and 400 MHz span.

Fig. 2 depicts the results measured by the OSA with and without noise injection. In free-running (Fig 2(a)), driven by a simple DC current, the laser provides a free spectral range of 22.76 GHz at 200 mA, corresponding to 8 times the threshold current (25 mA), and a nearly-flat envelope of 9.5 nm bandwidth at -10 dB with 50 modes, centered at 1564 nm. In the presence of noise (Fig 2(b)), the side mode lines were amplified giving a 13 nm bandwidth at -10 dB with 71 modes and still partially locked.

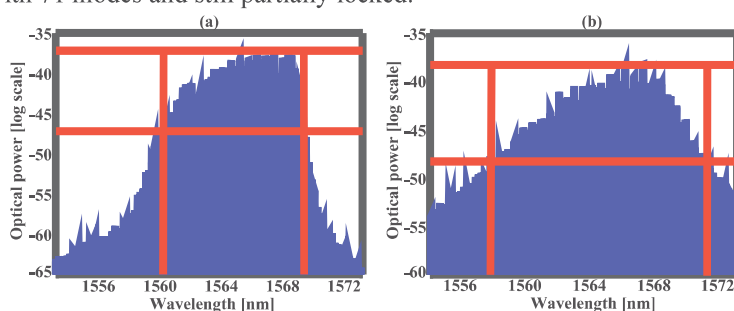


Fig. 2. Optical comb spectrum of the QD-MLL before (a) and after (b) noise injection.

In order to observe and correct the impact of the noise on the individual optical comb linewidth, we investigated the following four cases: free running, with only optical feedback, with only noise injection, and with both feedback and noise injection. The TEL wavelength is positioned in the center of the QD-MLL envelope between two modes, and the beat note is performed with one of the adjacent modes. The results are shown in Fig. 3, normalized and plotted in a linear scale. In the free-running case, Fig. 3(a), the resulted optical linewidth was found to be 29.38 MHz at full width at half maximum (FWHM). By using a coherent optical feedback regime, Fig. 3(b), the optical linewidth is drastically narrowed, indicating reduced optical phase noise of the individual MLL modes, and is found to be 3.33 MHz at FWHM. By injecting the noise without feedback, Fig. 3(c), the optical linewidth is significantly broadened to 57.1 MHz at FWHM, almost doubling compared to the free-running case. For the final case, as a way to correct the broadening due to the noise, we employed the external cavity to induce a coherent feedback regime and observed the effect in Fig. 3(d). The optical linewidth is decreased by five times compared to the only noise case and even less than the free-running case by half.

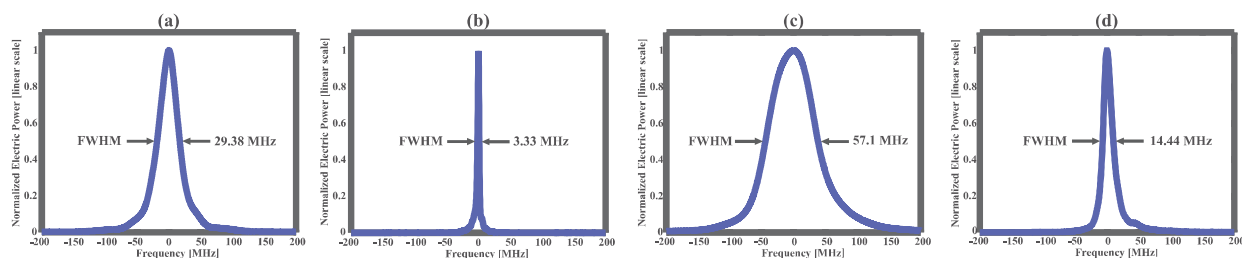


Fig. 3. RF beat note between the QD-MLL and the external laser for the cases: (a) free running, (b) with only feedback, (c) with only noise, and (d) with both feedback and noise.

In summary, we enhanced the performance of QD-MLL via the use of self-injection coherent feedback combined with a broadband optical noise source. The results show the amplification of the side mode lines with a gain of 21 additional modes while reducing the individual mode linewidth to be less than the free-running and noise injection cases.

## References

- [1] T. Verole *et al.*, "Mode locked laser phase noise reduction under optical feedback for coherent DWDM communication," *Journal of Lightwave Technology* **38**, 5708-5715 (2020).
- [2] A.I. Borodkin *et al.*, "Noise-induced enhancement of a quantum-dash laser optical frequency comb," arXiv:2306.10811 2023, <https://arxiv.org/abs/2306.10811>.