# Linewidth enhancement factor and optical injection in a hybrid-silicon quantum dot comb laser

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**Abstract:** This work reports on the impact of the linewidth enhancement factor and the optical injection in a hybrid quantum dot comb laser. Results show that both the optical bandwidth and the flatness of the optical frequency comb can be improved.

## 1. Introduction

High performance optical interconnects with large bandwidth play an important role in the next generation of data centers and supercomputers [1], and wavelength-division multiplexing (WDM) becomes promising in using the vast amount of bandwidth offered by optical fibers. Multiple single-wavelength laser is currently applied in achieving WDM. Nevertheless, multi-wavelength laser such as frequency comb laser become more attractive owing to its free spectral range (FSR) that is determined and fixed by the length of laser cavity. On the other hand, Si-based quantum dot (QD) lasers is a promising WDM light source, as they have shown high tolerance to both temperature [2] and external optical feedback [3], as well as low relative intensity noise (RIN)[4]. In the particular case of QD materials, increasing the inhomogeneous gain bandwidth above a certain value does not systematically bring an increase of a frequency comb bandwidth, and in some cases it can even lead only to unlocked regimes (no frequency combs). One explanation might be that for larger gain linewidth the four wave mixing intended as self-injection locking mechanism [6], in providing equally spaced and phase-locked modes becomes less efficient since dispersion for high frequency active modes is bigger. Last but not the least, the inhomogeneous broadening is an incoherent mechanism that one might expect to be detrimental to some extent for a coherence phenomenon as self-mode locking. In this work, we point out ways to improve the comb dynamics of a hybrid-silicon QD comb laser through the linewidth enhancement factor (LEF) and optical injection. It is shown that the frequency comb dynamics is enhanced at larger LEFs whereas the optical injection can further improve both the bandwidth and the flatness of the entire comb spectrum.

## 2. Laser structure & Experimental results

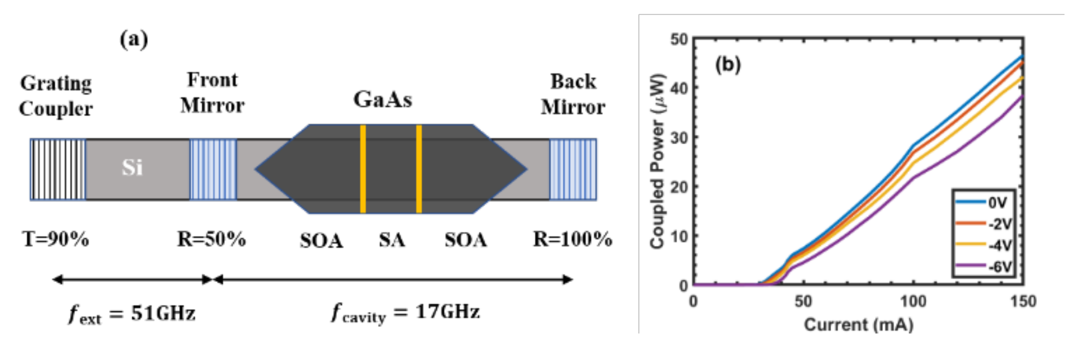


**Figure 1:** (a) Schematic diagram of the hybrid-silicon QD comb laser. (b) Light-current characteristics of the QD comb laser under different voltages on SA.

The comb laser under study is schematically illustrated in Fig. 1(a). It consists of a 2.3-mm-long cavity including a 1200-$\mu$m-long semiconductor optical amplifier (SOA), as well as front and back mirrors with power reflectivities of ∼50% and ∼100% formed by multimode interferometer. The reflection from the grating coupler is on the order of 10% and this forms an external cavity of 51 GHz. The 17 GHz laser cavity consists of a 120-$\mu$m-long saturable absorber (SA) that is placed at the center of the cavity. The comb dynamics is observed by changing the reverse voltage applied on the SA whereas mode converters are applied to transfer the optical mode between the active hybrid waveguide and the passive Si waveguide. A grating coupler is then used to couple out the light. More details of the device structure are reported elsewhere [5]. Measurements are operated at room temperature (293 K). Fig. 1(b) displays the light-current characteristics of the QD comb laser under different voltages on SA. The threshold current $I_{th}$ increases from 32 mA at 0 V to 38 mA at -6 V resulting from higher internal loss caused by larger absorption in the SA. The LEF of the QD comb laser is extracted under different voltage bias on SA from the amplified spontaneous emission method [3]. As shown in Fig. 2(a), the LEF equals 4.2 under -6V on SA against 0.8 at 0V. Thus, the increase of the LEF with the reverse voltage on SA leads to an optimal comb operation at -6 V as shown in Fig. 2(b) by the free-running spectrum (blue). Indeed, the average LEF calculated over the entire comb spectrum can be written such as,

$$(\overline{\alpha})^2_{comb} = \frac{1}{\Delta\nu} \int_{comb} d\nu' \alpha^2(\nu') \tag{1}$$

with $\Delta\nu$ the width of the comb spectrum while $\nu$ is the frequency of the radiation emitted by the laser. Therefore, a larger LEF is more beneficial for improving the comb dynamics which was also found in quantum cascade lasers frequency combs [7].

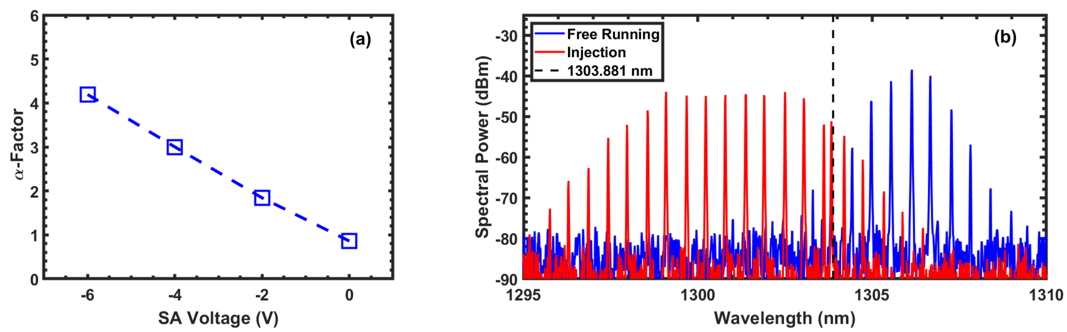


**Figure 2:** (a) LEF under different voltages on SA. (b) Optical spectra at $3\times I_{th}$ as well as -6V on SA at free-running (blue) and that under injection at one intra-mode (red).

Optical injection is a technique that can be used to process optical frequency comb by isolating and amplifying individual comb modes. The effect of optical injection is now studied at 3 $\times I_{th}$ and -6V. Due to the induced-loss from both the coupling stage and the grating coupler, a low injection strength (< -10 dB) is considered in the whole experiment meaning that the LEF is not affected by the injected field. For the free-running operation (Fig. 2(b), blue spectrum), the bandwidth of the comb spectrum is 8 nm with 11 modes above the noise floor. Using intra-modal optical injection (vertical dotted line) and operating the comb laser outside the locking region, both the flatness and the bandwidth are strongly improved (Fig. 2(b), red spectrum) with 8 lines (against one under free-running) within the 3-dB bandwidth. On the top of that the total number of lines above noise floor increases from 11 to 20. Last but not the least, such broadening effect at weak injection convinces us that the injection effect is reasonable to be found more obvious, once we are able to improve the design of device and experimental set-up thus reduce the internal loss.

## 3. Conclusions

To sum, these initial experiments unveil the effects of SA on LEF, as the SA contributes to larger LEF thus provides more non-linear properties to the QD comb laser. Optical injection effect is also taken into consideration in order to demonstrate that stably unlocked regime can improve both the bandwidth and the flatness of the entire comb spectrum.

## References


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