Study of hybrid silicon quantum dot frequency comb laser dynamic for 5G and datacom applications

Bozhang Dong[1], Jianan Duan[1], Heming Huang[1], Geza Kurczveil[2], Di Liang[2], and Frédéric Grillot[1,3]
[1]*LTCI, Télécom Paris, Institut Polytechnique de Paris, 19 Place Marguerite Perey, 91120 Palaiseau, France*
[2]*Hewlett Packard Labs, 1501 Page Mill Rd, Palo Alto, CA 94304, USA*
[3]*Center for High Technology Materials, University of New-Mexico, Albuquerque, New-Mexico, 87106, USA*
e-mail: bozhang.dong@telecom-paris.fr

ABSTRACT

This work reports on the high performance of a 1.3 μm hybrid quantum dot frequency comb laser. The material parameters such as gain, differential gain, and linewidth enhancement factor are studied and linked to the comb dynamics. In particular, results show that a larger linewidth enhancement factor is more beneficial for comb operation; moreover, we demonstrate that, by employing optical injection, both the 3-dB bandwidth and the flatness of the whole optical frequency comb is improved. Such novel findings give promising guidelines for the development of high-speed dense wavelength division multiplexing photonic integrated circuits in upcoming 5G telecommunications and datacom applications.

Keywords: frequency comb, quantum dot, silicon photonics, optical injection, linewidth enhancement factor.

1 INTRODUCTION

Broadband optical light sources play a key role in the rapid development of wavelength-division multiplexing (WDM) technologies, which are solutions of high transmission capacity to meet the huge demand in the upcoming 5G telecommunication industry, next generation of data centers and LiDAR system applied to self-driving cars [1]. In contrast to the multiple single-wavelength lasers configuration, the multi-wavelength light source such as the optical frequency combs (OFCs) is therefore a competitive candidate for performing WDM functions, owning to the possibility to achieve a large number channels with equidistant free spectral range (FSR), which is able to support the huge demand in transmission capacity [2]; on the other hand, its reduced device footprint is also advantageous for photonic integrated circuits (PICs) applications. Quantum dot (QD) lasers have been found to be efficient solution to OFCs owning to straightforward comb generation, large gain bandwidth, narrow spectral linewidth, low relative intensity noise (RIN) and high temperature stability [3], [4]; hybrid semiconductor comb lasers fabricated on silicon substrate are developed as well to meet the requirement of low-cost and energy-efficient integrated photonic component for PICs. In this paper, we report on the improved performance of 1.3 μm hybrid QD comb lasers. To do so, we analyze the linewidth enhancement factor (α_H-factor) driven the coupling between gain and refractive index as well as the response of the comb laser to optical injection. The α_H-factor is known as a vital parameter influencing semiconductor laser performance. Then presented results show that the higher the reverse voltage applied on the saturable absorber (SA), the larger the α_H-factor, hence the stronger the frequency comb dynamics. With the view of improving the OFCs performance, we also demonstrate that optical injection (OI) is more beneficial to further enlarge the bandwidth and optimize the whole comb flatness.

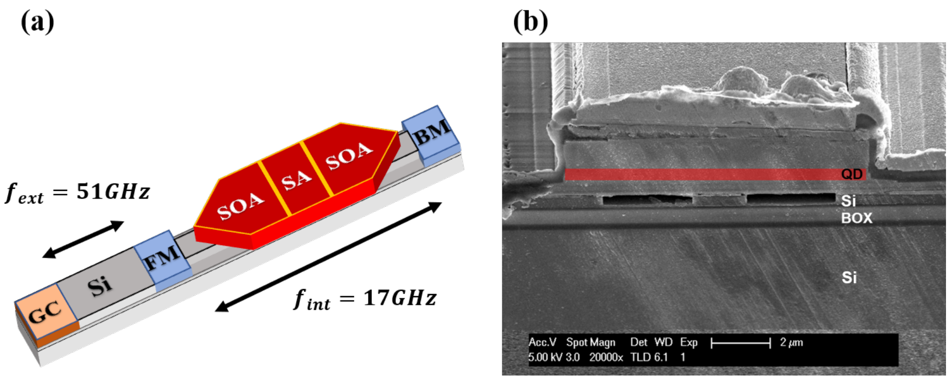

Figure 1. (a) Schematic diagram of the hybrid-silicon QD comb laser under study. SOA, semiconductor optical amplifier; SA, saturable absorber; FM, front mirror; BM, back mirror; GC, grating coupler. (b) SEM image of the cross section of the device. QD, quantum dot active region.

2 ANALYSIS OF DEVICE

2.1 Description of device

The schematic diagram and the SEM image of the hybrid-silicon QD comb laser is shown in Figure 1(a) and (b), respectively. The device under study consists of a 2.3-mm-long internal cavity (repetition rate at 17 GHz), where a 1200-μm-long semiconductor optical amplifier (SOA) and a 120-μm-long SA at the center are bonded. The two facets of the cavity are then combined with a front mirror (FM) and a back mirror (BM) at 50% and 100% power reflectivities, respectively. Outside the FM is followed by a 0.75-mm-long (repetition rate at 51 GHz) external cavity, which is applied to output a 102 GHz FSR on frequency comb behavior; and the light would eventually be coupled out by a 10% coupling efficiency grating coupler (GC). Varying the reverse voltage applied on the SA contributes to generate the comb dynamics, whereas the mode converters are applied to transfer the optical mode between the active hybrid waveguide and the passive Si waveguide. The full laser epitaxial structure and more detailed descriptions about the generation of 102 GHz repetition rate can be found elsewhere [5], [6].

2.2 Results discussions

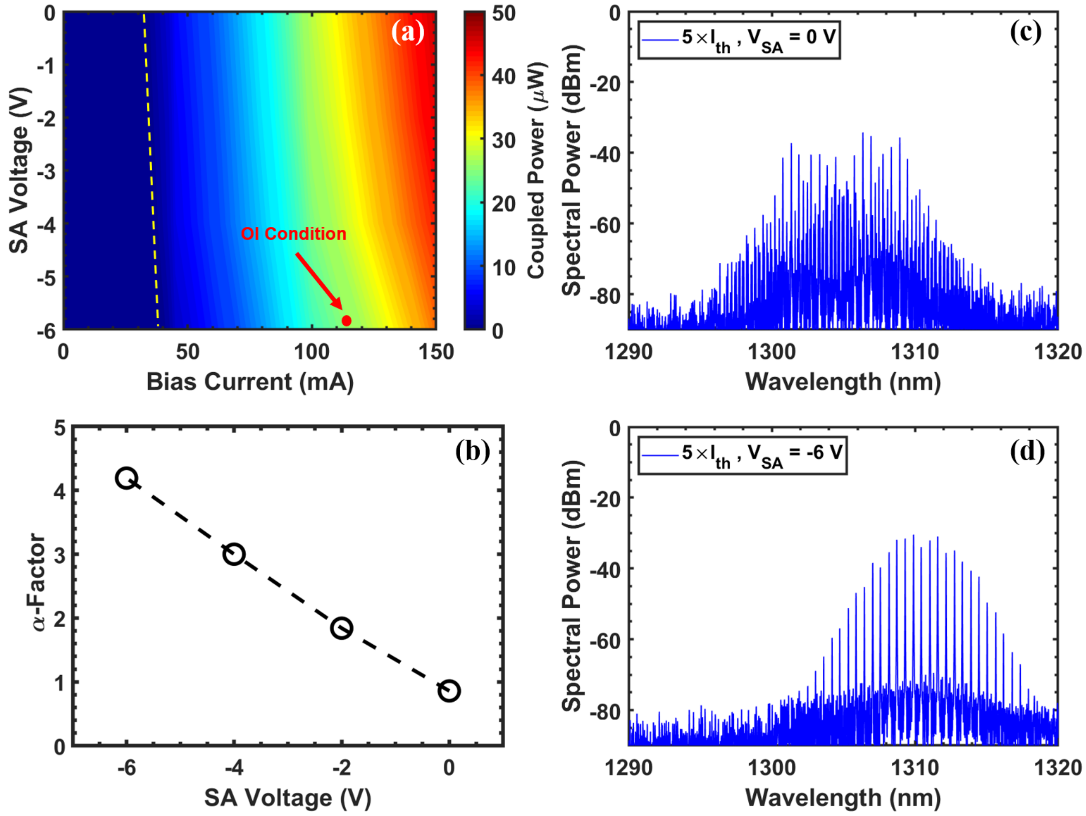

Figure 2. (a) Mapping of the coupled power under different reverse voltages on SA and bias current conditions. The yellow dashed line represents the evolution of the laser threshold with the reverse voltage. The red bullet corresponds to the device operation conditions applied in the optical injection, which is introduced in this paper hereafter. (b) α_H-factor at threshold as a function of reverse voltages on SA. Optical spectrum at 5 I_{th} with reverse voltage on SA at (c) 0 V and (d) -6 V.

Figure 2(a) depicts the mapping of light - current characterization as a function of the reverse voltage on SA of the comb laser under study. Let us note that the device temperature is carefully monitored and kept constant at room temperature (293K) throughout the experiment. The evolution of threshold current I_{th}, which is marked by the yellow dashed line, indicates that a higher reverse voltage on SA decreases the output power and increases the threshold. For instance, I_{th} is found to slightly increase from 32 to 38 mA as the reverse voltage is varied from 0 V to -6 V, which is introduced by the higher internal loss from the increasing absorption in SA.

Not only the threshold and output power, but also the α_H-factor is found to vary from different reverse voltage applied on SA. In this section, the extraction of the LEF is performed from the amplified spontaneous emission (ASE) [7]. With the view of ensuring a better precision of the LEF extraction, we used a CW current source to get smooth optical modes, which would then be captured by a 20 pm high resolution optical spectrum