

# Self-Pulsation Dynamics of Single Section III-V/Si DFB Laser with Optical Injection

Loubna Benkoula<sup>1</sup>, Youcef Driouche<sup>1</sup>, Amin Souleiman Dabar<sup>1,2</sup>, Joan Manel Ramirez<sup>2</sup>, Kamel Merghem<sup>1,\*</sup>

<sup>1</sup>SAMOVAR, Telecom SudParis, Institut Polytechnique de Paris, 91120, Palaiseau, France

<sup>2</sup>III-V Lab, 91120, Palaiseau, France

\*kamel.merghem@telecom-sudparis.eu

**Abstract:** We demonstrate self-pulsing in a single-section III-V-on-Silicon DFB laser, with a tunable pulsation frequency from 7 GHz to 2.38 GHz. Further investigation into the self-pulsation mechanism under controlled optical injection. © 2024 The Author(s).

## 1. Introduction

Heterogeneous integration of III-V materials on silicon photonics circuits has emerged as an attractive approach to demonstrate compact lasers that address a wide range of applications ranging from all optical telecommunication systems, neuromorphic computing to microwave generation [1]. For radio-over-fiber application, the self-pulsating III-V on silicon DFB laser represents an ideal candidate due to its compactness and possible co-integration with electronics. In this paper, we report the self-pulsating generation of heterogeneously integrated III-V-on-Silicon DFB laser in a single section configuration, exhibiting a tunable pulsation frequency varying from 7 GHz to 2.38 GHz based on the bias current. Furthermore, we have extensively investigated the dynamics of this self-pulsation under external optical injection, demonstrating significant RF linewidth modulation capabilities.

## 2. Device Characterization and Performance

The investigated device is a III-V-on-Silicon DFB laser with backside Bragg gratings [2]. Such a laser combines a low-loss silicon rib waveguide with an III-V PIN waveguide based on AlGaInAs multi-quantum wells. Both waveguides are vertically aligned and separated by a thin bonding oxide (25 nm). The laser has a cavity length of 400  $\mu\text{m}$ , the grating being etched at the backside of the Si guide (in the slab), and presents a  $\lambda/4$ -shifted grating. The studied laser is a single section laser with a threshold current of 35 mA, and a wavelength emission centered at 1528 nm.

The performance of the laser was thoroughly investigated through three distinct methods. Firstly, optical spectra were observed using an optical spectrum analyzer to assess mode evolution.. Secondly, RF beat signals of these modes were measured using a fast photodiode connected to an electrical spectrum analyzer. Lastly, the optical power fluctuations in the time domain were examined using a high-speed oscilloscope. These comprehensive evaluations provide a detailed understanding of the laser's operational characteristics.

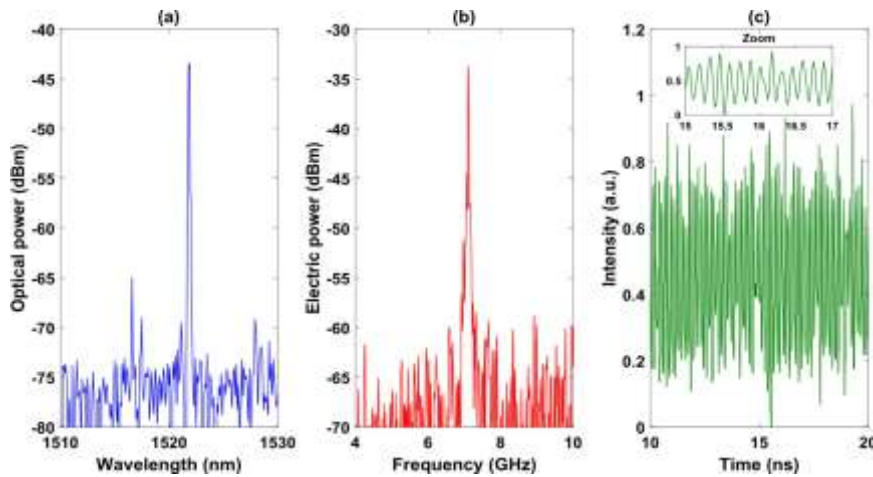


Fig. 1. Laser characteristics with  $I_{\text{bias}} = 84.75$  mA. (a) Optical Spectrum,  $\lambda_c = 1522.51$  nm. (b) RF spectrum of the self-pulsations at 7GHz with  $\Delta\nu_{3\text{dB}} = 15.62$  MHz. (c) Optical power fluctuations in the time domain.

Initially, the laser exhibits no pulsations within the bias current range of 35 to 78.3 mA. The pulsation starts at 80.2 mA and continues up to 107.1 mA, after which it ceases. As an example in Fig. 1, for a current of 84.75 mA, the laser operates in monomode at  $\lambda_c = 1522.51$  nm with a pulsation frequency of 7 GHz, and an RF linewidth of  $\Delta v_{-3\text{ dB}} = 15.62$  MHz. By sweeping the current from 84.75 to 107.1 mA, the laser consistently operates in the monomode regime with a shift of  $\lambda_c$  from 1522.51 nm to 1522.95 nm, and the pulsation frequency decreases from 7 to 4.95 GHz. We should mention that starting from 100 mA, a harmonic in RF domain appears at 10.81 GHz with  $\Delta v_{-3\text{ dB}} = 9.11$  MHz. This harmonic persists until the current reaches 105 mA, at which point it is observed at 9.96 GHz. Beyond 105 mA, no pulsation was observed until reaching 215 mA. At this current, the laser continues to operate in the monomode regime at a wavelength of 1526.15 nm, exhibiting a pulsation frequency of 2.38 GHz. As a final note, the laser operates in a bimodal regime only at a bias current of 80.21 mA, with a central wavelength of 1522.3 nm and a secondary mode at 1517.15 nm. In this regime, the laser pulsates at a frequency of 6.9 GHz. This Self-pulsations in DFB lasers may be caused by spatial hole burning, self-Q-switching and beating-type oscillations [1]. Additionally, the frequency of self-pulsations can be shifted by controlling the temperature, as further studied in [3].

### 3. Self-pulsation dynamics under external optical locking

In this section, we investigate the self-pulsation dynamics under optical injection locking using a tunable external cavity laser (ECL) with a narrow optical linewidth of 10 kHz. The ECL is biased at 79.91 mA, which is twice its threshold current, yielding an output power of 8.59 dBm. We define  $\Delta\lambda$  as the spectral peak spacing between the laser under test and the ECL. The laser under test is biased at 84.75 mA, and when the ECL mode is blue-shifted by  $\Delta\lambda = 0.4$  nm compared to  $\lambda_c$ , the RF linewidth becomes significantly broad. Oppositely, when the ECL mode is red-shifted by  $\Delta\lambda = 0.6$  nm, the RF linewidth becomes narrower, reducing to  $\Delta v_{-3\text{ dB}} = 5.85$  MHz. For a red shift of  $\Delta\lambda = 1.3$  nm, as depicted in Fig. 2, the RF linewidth narrows further to  $\Delta v_{-3\text{ dB}} = 3.90$  MHz, which is four times narrower than in the free-running case. Thus, it is possible to narrow or broaden the RF linewidth depending on the positioning of the ECL mode.

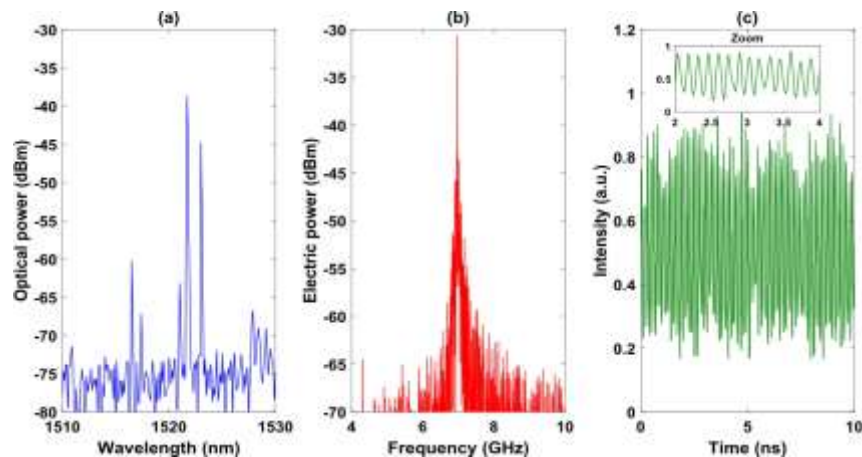


Fig. 2. Self-pulsation dynamics under optical injection locking. (a) Optical Spectrum,  $\lambda_c = 1522.51$  nm,  $\lambda_{\text{ECL}} = 1523.8$  nm. (b) RF spectrum of the self-pulsations at 7 GHz with a narrow linewidth of  $\Delta v_{-3\text{ dB}} = 3.9$  MHz. (c) Optical power fluctuations in the time domain.

### Conclusion

This work demonstrates the self-pulsing behavior of a single-section III-V-on-Silicon DFB laser, with a pulsation frequency range from 7 GHz to 2.38 GHz depending on the bias current, highlighting its potential for use in microwave optical communication. Further study based on optical injection locking allowed us to significantly modulate the RF linewidth, demonstrating the laser's ability to operate in various regimes.

### References

- [1] M. Shahin, K. Ma, A. Abbasi, G. Roelkens, and G. Morthier, "Demonstration of Self-Pulsating InP-on-Si DFB Laser Diodes," in 2017 IEEE Photonics Conference (IPC), 473–474 (2017).
- [2] J. M. Ramirez *et al.*, "Low- $\kappa$ , narrow linewidth III-V-on-SOI distributed feedback lasers with backside sampled Bragg gratings," *Opt. Express* **30**, 36717-36726 (2022).
- [3] K. Ma, M. Shahin, A. Abbasi, G. Roelkens, and G. Morthier, "Demonstration of inP-on-si self-pulsating dfb laser diodes for optical microwave generation," *IEEE Photonics Journal*, **9**, 1–8 (2017).