Low frequency fluctuations and optical bursts induced by external optical feedback and low frequency modulation in a quantum cascade laser at 9 μm

O Spitz, J Wu, M Carras, C Wong, F Grillot

To cite this version:

O Spitz, J Wu, M Carras, C Wong, F Grillot. Low frequency fluctuations and optical bursts induced by external optical feedback and low frequency modulation in a quantum cascade laser at 9 μm. International Symposium on Physics and Applications of Laser Dynamics, Dec 2018, Hong-Kong, China. hal-02950392

HAL Id: hal-02950392

https://hal.telecom-paris.fr/hal-02950392

Submitted on 27 Sep 2020

Low frequency fluctuations and optical bursts induced by external optical feedback and low frequency modulation in a quantum cascade laser at 9 µm

O. Spitz,[1,2,3,+] **J. Wu,**[3,4] **M. Carras,**[2] **C. W. Wong,**[3] **F. Grillot**[1,3,5]
[1]*LTCI Télécom ParisTech, Université Paris-Saclay, 46 rue Barrault, Paris, 75013, France*
[2]*mirSense, Centre d'intégration NanoInnov, 8 avenue de la Vauve, Palaiseau, France*
[3]*Fang Lu Mesoscopic Optics & Quantum Electronics Laboratory, UCLA, CA 90095, USA*
[4]*College of Electronic & Information engineering, Southwest University, Chongqing, China*
[5]*Center for High Technology Materials, University of New-Mexico, NM 87106, USA*

Summary: This experimental work reports on the first observation of low frequency fluctuations in a quantum cascade laser emitting at 9 µm, in one of the transparency windows of the atmosphere, operating under external optical feedback and external periodic bias forcing. A way of controlling spikes occuring in a deterministic chaotic pattern is experimentally described. These findings are of prime importance for future optical countermeasure systems and secure atmospheric transmission lines as well as for reproducing neuronal systems and the communication between neurons due to sudden bursts.

1. Introduction

Free-space secure communications can be efficiently implemented in the mid-infrared range, especially between 8 and 11 µm where lies a transparency window of the atmosphere. However, the bright background and the lack of sensitive detectors prevent the use of quantum communications over long distances [1]. Secure communications within this optical range can also be performed using chaotic patterns and quantum cascade lasers (QCLs) are well-suited for that purpose. Indeed, these lasers, firstly demonstrated in 1994 [2], are optical sources exploiting radiative intersubband transitions within the conduction band of semiconductor heterostructures. When applying optical feedback with an increasing strength, the QCL dynamics was found to bifurcate to periodic dynamics at the external cavity frequency and later to chaos [3]. Prior work proved that the dynamics of a semiconductor lasers emitting in the near-infrared and operating with time-delayed optical feedback and periodic forcing show an arrangement of the power dropouts in the laser output [4]. These power dropouts result from low frequency fluctuations (LFFs) hence a manifestation of deterministic chaos [3]. In this paper, we unveil the first study of this kind for a QCL emitting in the transparency window arround 10 µm and we propose a way of controlling these irregular dropouts by using an external sine forcing at low frequency.

2. Experimental setup

The QCL under study is a distributed feedback (DFB) laser. The light intensity voltage (LIV) characteristics of the free-running QCL under study are depicted on Fig. 2 a) while Fig. 2 b) shows the optical spectrum. The optical spectrum is perfectly single mode and the DFB peak is at 8.99 µm. The experimental setup is similar to that presented in [5] at 77K, except that liquid helium is used instead of liquid nitrogen in order to decrease the temperature down to 40K. Indeed, the QCL cannot be powered with a continuous wave above 65K. The setup is made of an analysis path with a high bandwidth Mercury-Cadmium-Telluride (MCT) detector which is linked to an oscilloscope at 1 giga sample per second and a RF spectrum analyzer to carry out frequency measurements. The external optical feedback path is set with a gold plated mirror at 27 cm from the front facet of the QCL and a polarizer, which scales the amount of back-reflected light since the QCL wave is TM polarized. The current source in this experiment is a low noise source from Wavelength Electronics and the DC bias delivered by the source can be modulated up to 3 MHz with an external signal from a waveform generator (Rigol DG1022Z).

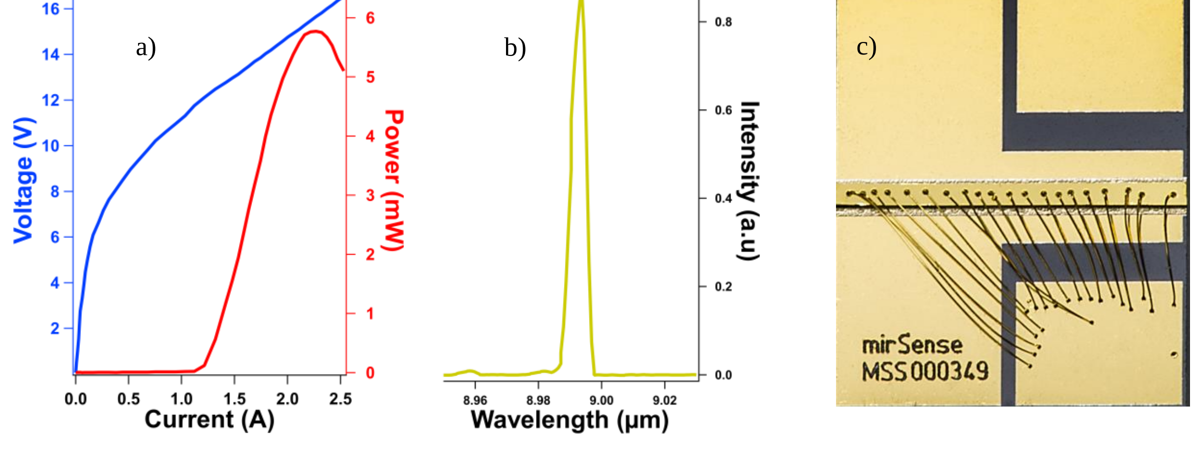

Figure 1: LIV (a) and optical spectrum (b) of the free running DFB QCL with a duty cycle of 12 % at 290K and close-up of the QCL under study (c)

3. Results and discussion

The behavior of the QCL under external optical feedback and sine forcing is studied through the analysis of the q : p parameter [4] where q represents the number of dropouts occurring in the time-series every p periods of the forcing. In our case, the number of dropouts is at least one per period, as can been seen on Fig 2. Therefore, p is fixed to 1. Increasing the modulation frequency from 1 MHz to 1.5 MHz makes the q value decrease from 4 to 2, emphasizing the key influence of the forcing frequency on the entrainment of the spikes which always appear for a fixed phase of the periodic forcing. Thus, the time interval between successive dropoffs remains constant and this strongly differs with what is observed when studying LFFs in a semiconductor laser pumped with a continuous or quasi-continuous bias [3]. The RF spectra analysis furthermore shows that the frequencies retrieved in the experimental waveforms are integral multiples of the forcing frequency. Indeed, the RF spectra printed in Fig 2. only exhibit three peaks below 5 MHz when the external optical feedback is masked and exhibit several peaks up to a few dozen of MHz when both external forcing and optical feedback are applied.

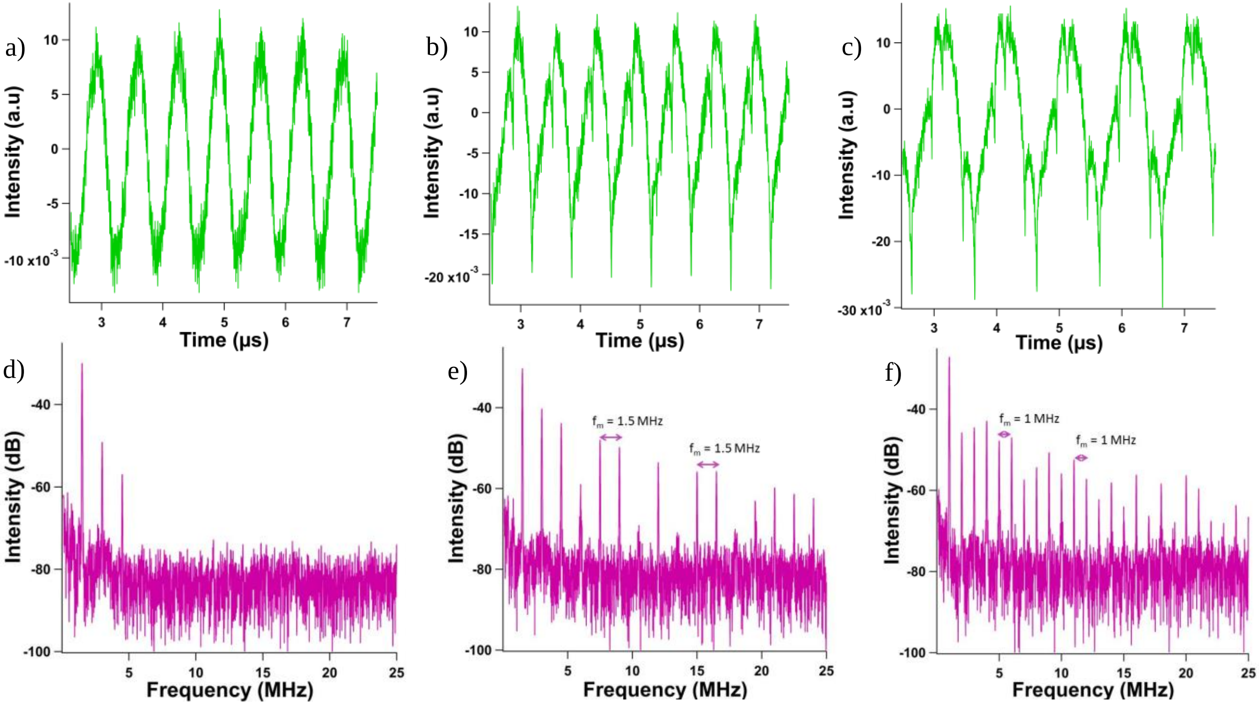

Figure 2: Experimental time traces (top row) and RF spectrum analysis (bottom row) when external optical feedback is applied to the QCL and with a sine periodic forcing of the bias DC current of : 1.5 MHz (b,e), 1 MHz (c,f); diagrams (a) and (d) correspond to the case when no external optical feedback is applied and the modulation frequency is 1.5 MHz. All the traces were retrieved for a DC bias of 975 mA (25 mA above the threshold current) and AC amplitude of 40 mA, which is added to the DC bias.

4. Conclusions

We experimentally observed the first LFF dynamics compatible with a communication in the transparency window at 9 µm. We also unveiled that LFFs in QCLs show an arrangement when applying periodic forcing and external optical feedback. The number of observed spikes per period depends on the frequency of the sine forcing and these spikes always pop up for a given phase of the external modulation. This results in a discrete RF spectrum composed of integral multiples of the forcing frequency. This work is of paramount importance to further understand the deterministic chaotic behaviors in QCLs in order to develop free-space secure communications in the transparency window of the atmosphere and models to mimic the neuronal activity.

5. References

[1] Uchida, A., Optical communications with chaotic lasers: application of nonlinear dynamics and synchronization, Wiley (2012).
[2] Faist, J. et al., *Science, 264* (5158), 553-556 (1994).
[3] Jumpertz, L., Nonlinear Photonics in Mid-infrared Quantum Cascade Laser, Springer (2017).
[4] Sorrentino, T. et al., *Optics Express 23*, 5571-5581 (2015).
[5] Spitz, O. al., *Quantum sensing and Nano Electronics and Photonics XV, vol. 10540, 105401N*, (Proceedings SPIE Photonics West 2018).

Acknowledgements

This work is supported by the French DGA, the French ANR program, the Office of Naval Research and the National Science Foundation.