Entrainment phenomenon in a mid-infrared QCL with external optical feedback and low frequency modulation

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Summary: This experimental work reports on mid-infrared quantum cascade lasers 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 paramount 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

Quantum cascade lasers (QCLs), firstly experimentally demonstrated in 1994 [1], are optical sources exploiting radiative intersubband transitions within the conduction band of semiconductor heterostructures. The wide range of wavelengths achievable with QCLs, from mid-infrared to terahertz range, leads to a large number of applications including absorption spectroscopy, optical countermeasures and free space communications [2]. 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 laser diode operating with time-delayed optical feedback and periodic forcing show an arrangement of the power dropouts in the laser output [4,5]. 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 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 retrieved with a Fourier transform infrared spectrometer (FTIR). The optical spectrum is perfectly single mode and the DFB peak is at 5.63 microns. The experimental setup is similar to that presented in [6] at 77K. It 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 for real time acquirements and a RF spectrum analyzer to carry out accurate frequency measurements on the optical signal. 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 (Wavelength Electronics QCL2000 LAB) and the DC bias delivered by the source can be sine modulated up to 3 MHz with an external signal from a waveform generator (Rigol DG1022Z).

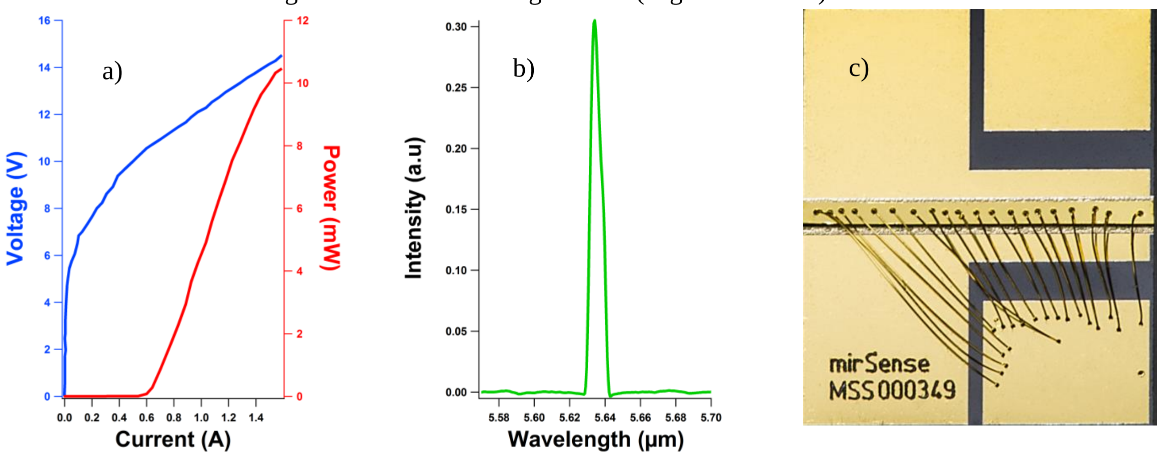

Figure 1: LIV (a) and optical spectrum (b) of the free running DFB QCL with a duty cycle of 3 % at 290K and close-up of the QCL under study (c)

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 2 MHz to 2.7 MHz makes the q value decrease from 5 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. Another parameter of prime importance in the occurrence of these LFF spikes is the amplitude of the sine forcing. Fig 3. shows that the q value is strongly increased when increasing the AC amplitude from 40 mA to 160 mA, the frequency of the sine forcing remaining constant at 2 MHz. This phenomenon occurs for various continuous biases applied to the QCL, the three of them being above the threshold of the solitary laser (331 mA at 77K). Furthermore, it is relevant to notice that changing the DC bias does not really affect the q value, whatever the value of the AC amplitude (Fig 3.).

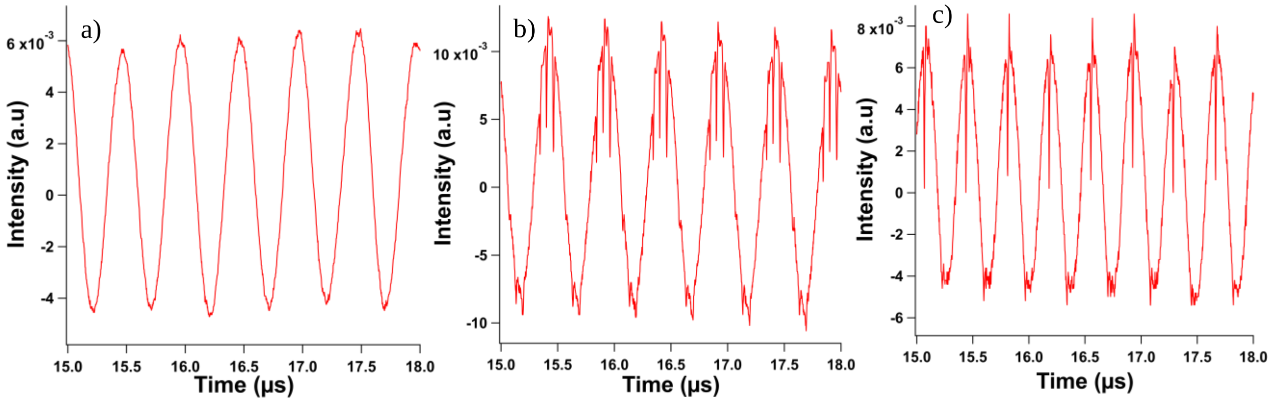

Figure 2: Experimental time traces when external optical feedback is applied to the QCL and with a sine periodic forcing of the bias DC current of : 2 MHz (b), 2.7 MHz (c); trace (a) corresponds to the case when no external optical feedback is applied and the modulation frequency is 2 MHz. All the traces were retrieved for a DC bias of 350 mA and AC amplitude of 120 mA, which is added to the DC bias.

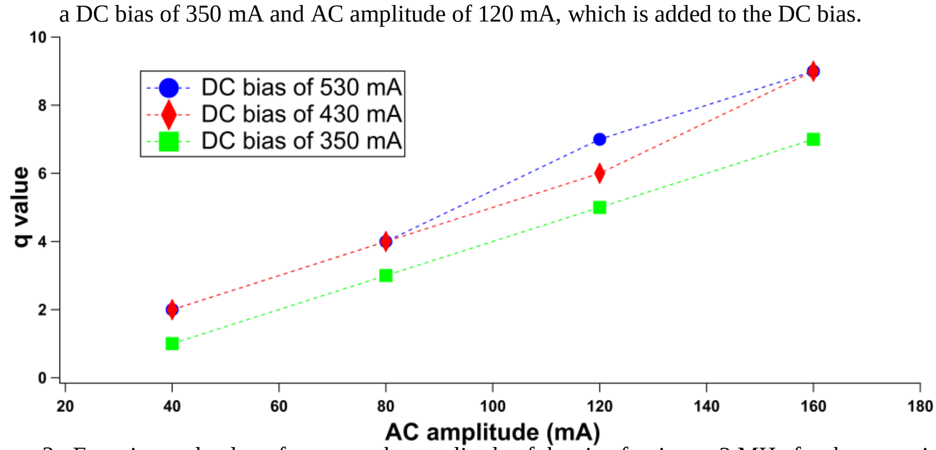

Figure 3: Experimental value of q versus the amplitude of the sine forcing at 2 MHz for three continuous biases above threshold applied to the QCL. Dashed lines are for visual guidance for the reader

4. Conclusions

We observed in the experimental waveforms that the spikes related to the LFFs occur for a given phase shift which depends on the amplitude of the periodic forcing, the value of the DC bias applied to the QCL and the frequency of the forcing. The number of spikes per period also depends on these parameters. This work is of prime importance to further understand the deterministic chaotic behaviors in QCLs in order to develop free-space secure communications and models to mimic the activity of the human brain.

5. References

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