High frequency dynamics in quantum cascade lasers : a roadmap to free-space communications in the mid-infrared

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Abstract: Quantum cascade lasers, which can emit deterministic chaotic patterns, are found to exhibit improved chaos properties when using optical injection instead of feedback. These findings pave a way for high-speed secure communications in the mid-infrared.

1. Introduction

Quantum cascade lasers (QCLs) are semiconductor lasers emitting in the mid-infrared domain. This optical domain is of prime interest for free-space communications because the atmosphere is highly transparent between 3 and 5 µm and between 8.5 and 11 µm. The first tests were conducted shortly after the experimental proof-of-concept of QCLs, and as soon as 2001, a Peltier-cooled device showed the possibility of a data transmission up to 300 MHz over several hundred meters at 9.3 µm [1]. Recent investigations showed the relevance of a similar transmission but at room temperature and 4.65 µm [2]. The versatility of this method, combined with the QCLs' potential for high speed modulation up to 10 GHz [3], demonstrates that these lasers are poised to be the cornerstone of very high speed free-space data transmissions. At lower frequency rates, QCLs are also very promising for secure communications through chaos synchronization [4]. They have indeed been proven to emit a chaotic output when subject to external optical feedback [5]. However, the maximum frequency of the chaotic output is limited to a few dozens of MHz in this configuration. Non-linear dynamics have also been triggered in other semiconductor lasers with, for instance, optoelectronic feedback or optical injection [6]. We experimentally apply the latter technique to a slave QCL and study the non-linear dynamics of its output. When varying the detuning of the master QCL, the chaos frequency is found to increase with maximum values in the order of 500 MHz. Combining this technique with chaos enciphering allows increasing the maximum frequency of the message hidden inside the chaotic carrier, which means a transmission speed ten time faster than what can be achieved with the sole external optical feedback.

2. Device description and experimental setup

The QCLs under study are distributed feedback lasers emitting single mode at ~5.7 µm. Figure 1(a) shows the optical spectra of master and slave laser at room temperature when they are powered with a continuous wave. Adjusting the pumping current or the operating temperature of these lasers, while keeping them above threshold current, allows achieving a wavelength detuning close to zero.

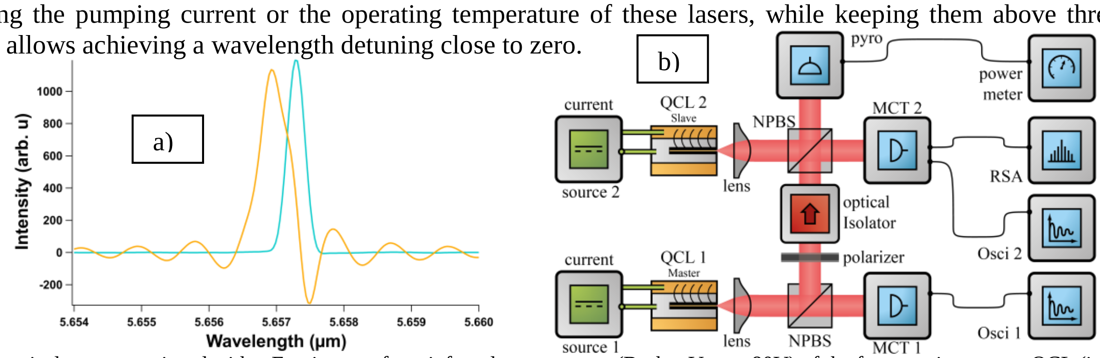

Fig. 1 (a) optical spectra retrieved with a Fourier transform infrared spectrometer (Bruker Vertex 80V) of the free-running master QCL (in orange) operating at 250 K and 650 mA and of the free-running slave QCL (in cyan) operating at 278K and 450 mA; (b) experimental setup allowing one-way injection with the optical isolator. MCT : Mercury-Cadmium-Telluride detector, NPBS : non-polarizing beam splitter, Osci : fast oscilloscope, RSA : real time spectrum analyzer, pyro : pyroelectric detector.

The experimental setup, as presented on Fig. 1(b), allows the analysis of both the slave and the master QCL with MCT detectors with a bandwidth of 1000 MHz (Kolmar KV104-0.1E/10 with KA700 preamplifier). The detector of the slave is linked to a real time spectrum analyzer (RSA) with a maximum real time scanning range of 110 MHz (Tektronix RSA6114A) and both MCTs are connected to a 40 GS/s oscilloscope (Tektronix TDS6154C) for real time analysis and acquirement. An optical isolator avoids back-injection from the slave laser into the master laser. The injection rate is evaluated with a powermeter linked to a pyroelectric detector.

3. Results and Discussion

In the case of external optical feedback, the chaotic pattern is composed of two main frequencies as can be seen in Fig. 2. The frequency in the order of a few dozens of MHz is related to the low-frequency fluctuations (LFF) while the fast one is related to the frequency of the external cavity [5]. This frequency can be tuned by varying the external cavity length but, because the amplitude of the fast oscillations is greatly exceeded by the LFF, the cavity length cannot be considered as a lever for tuning the frequency of the chaotic carrier. A more relevant option is to replace external optical feedback by optical injection because in this configuration, the chaotic frequencies emitted by the slave QCL are centered on the detuning frequency and that can be increased up to roughly 500 MHz as shown in Fig. 3(a). A precise tuning of the frequency is achieved by varying the pump current of the master QCL, in our case from 485.5 mA to 486.5 mA. Figure 3 (b) shows the chaotic output of slave QCL for a pump current of 485.8 mA in the master QCL and the noise output when the detuning is too large to trigger non-linear dynamics (the pump current is 485.5 mA in this case). Further investigations will determine the influence of the injection rate, in order to characterize the influence on chaotic frequencies. The long-term purpose is to inject the chaotic signal created by the injection process into a third laser in a configuration similar to that showed in Fig. 1(b). The third laser will thus be synchronized or anti-synchronized [7] with the chaotic signal which is used to hide the message and prevent any eavesdroppers to retrieve it. This method has already been implemented to achieve secure communications in fibers for near-infrared lasers [4] and we plan to extend it to free-space communications by taking advantage of the two transparency windows of the mid-infrared domain. In our case, the injection configuration will also allow faster data transmission compared to conventional optical feedback.

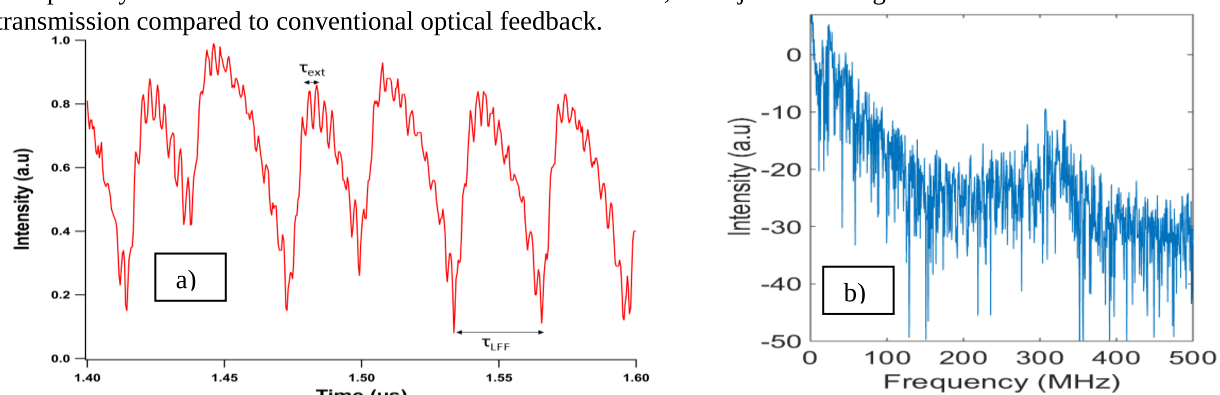

Fig. 2 : (a) experimental traces of the temporal waveform and (b) RF spectrum with the sole external optical feedback. τ_{ext} is related to the frequency of the external cavity and τ_{LFF} is related to that of LFF. Note the different timescale when comparing Fig. 2 (a) and Fig. 3 (b).

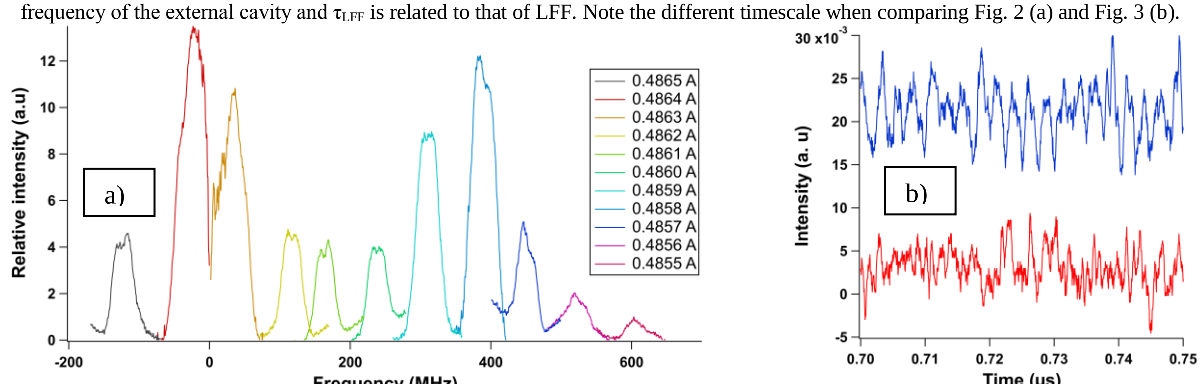

Fig. 3 : (a) experimental time traces of the output of the slave QCL when the pump current of the master QCL is at 485.8 mA (blue) showing chaos and at 485.5 mA (red) showing only noise. (b) RF spectra of the slave QCL when varying the pump current of the master QCL; negative frequencies are only for convenience for the reader and correspond to their positive frequency counterparts.

4. References

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