Enhanced chaotic performance with optically injected quantum cascade lasers

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Abstract: Quantum cascade lasers, which are able to emit deterministic chaotic patterns, are found to exhibit improved chaos properties when using optical injection instead of conventional optical feedback. These findings are of paramount importance for developing high-speed secure communications in the mid-infrared domain.

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 [1] because the atmosphere is highly transparent between 3 and 5 µm and between 8.5 and 11 µm. QCLs were experimentally proven to emit a chaotic signal when subject to external optical feedback with high feedback strength [2]. This method paves the way for chaotic key encryption at mid-infrared wavelength enabling secure communications for free-space applications. Chaos encryption requires that the receiver laser synchronizes with a chaotic transmitter laser. The chaos is then subsequently used as a carrier for the encrypted message [3]. However, studies with external optical feedback in QCLs have shown that the chaos was composed of two main frequencies [2]. One is related to the frequency of the external cavity and cannot be used for communication purposes the arising oscillations are predictable. The other frequency is related to the low-frequency fluctuations (LFFs), a deterministic chaotic pattern inducing a broad spectrum of a few dozen of MHz. Consequently, the transmission of an enciphered message is experimentally limited to a few dozen of MHz for the purpose of secure communications. Optical injection from a master laser into a slave laser has also proven its ability to trigger chaos in the slave's output [4]. By experimentally applying this technique to a QCL, we were able to obtain chaos as well with a frequency of a few dozen of MHz when there is no wavelength detuning between the master QCL and the slave QCL. When varying the detuning, the chaos maximum frequency is found to increase with maximum values of the order of 400 MHz. Combining this technique with chaos encryption allows increasing greatly the maximum frequency of the chaotic carrier which could lead to secure communications with a transmission speed ten time faster than what can be achieved with the sole external optical feedback [4].

2. Device description and experimental setup

The room temperature operating QCLs under study are distributed feedback lasers emitting single mode at ~5.7 µm when driven with a continuous bias. Figure 1(a) shows the optical spectra of master and slave laser for a temperature of 250K and 278K, respectively. Adjusting the temperature of both lasers, while keeping them above threshold current, allows achieving a wavelength detuning close to zero.

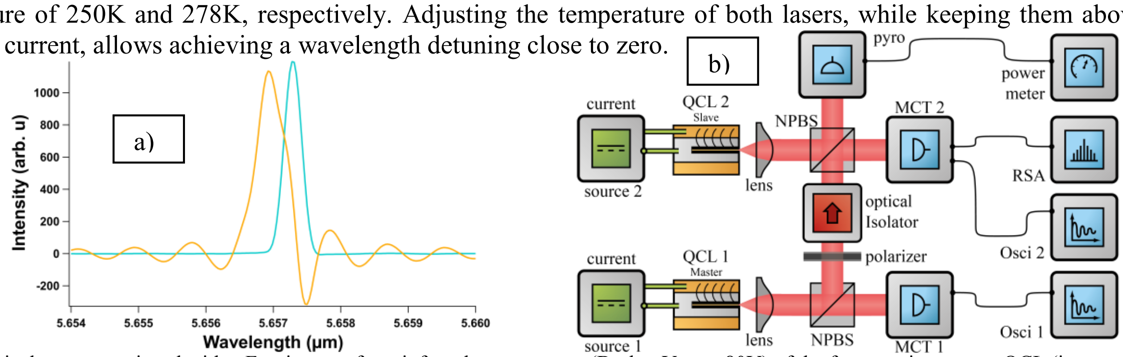

Fig. 1 a) optical spectra retrieved with a Fourier transform infrared spectrometer (Bruker Vertex 80V) of the free-running master QCL (in orange) operating at 250 K and 650 mA and of the free-running slave QCL (in cyan) operating at 278K and 450 mA; b) experimental setup allowing one-way injection with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

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

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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

Figure 2(a) and 3(a) compare the experimental time traces of the slave laser retrieved with the sole external optical feedback and with optical injection, respectively. Both figures focus on the highest chaotic frequency that can be achieved. For Fig. 2(a), the maximum retrieved frequency is 50 MHz (shown in Fig. 2(b)) representing the limit of the transmission rate in free-space communications. Furthermore, this configuration corresponds to a case where external optical feedback leads to high-dimensional chaos. Such chaotic complexity does not occur for a wide range of feedback strengths, but for only specific values. The chaotic bubble is consequently thin and the reproducibility is tough to achieve in the case of a QCL driven with continuous bias. When the optical signal of a master QCL is injected inside a slave QCL, chaos can also be found in the slave's output if the injection rate is high enough and for small detuning ranges. Figure 3(c) shows the RF spectrum of the slave's output when the master QCL and the slave QCL have a zero detuning. Slightly varying the current or temperature of one of the two QCLs can change the detuning between the two QCLs. For a positive detuning of 375 MHz, the optical injection gives rise to a chaotic pattern whose frequencies are centered around 375 MHz visualized in Fig. 3(b). This was the maximum frequency we were able to achieve for the chaotic output of the slave QCL. For a larger detuning, the master QCL shows less influence on the output of the slave QCL which becomes constant. Further investigation will determine the influence of the injection rate, in order to characterize the influence on chaotic frequencies. The long-term purpose is to combine the QCL abilities for high-speed free-space communications [5] with chaos masking in order to achieve secure communications, as already tested in fibers for near-infrared laser diodes [6].

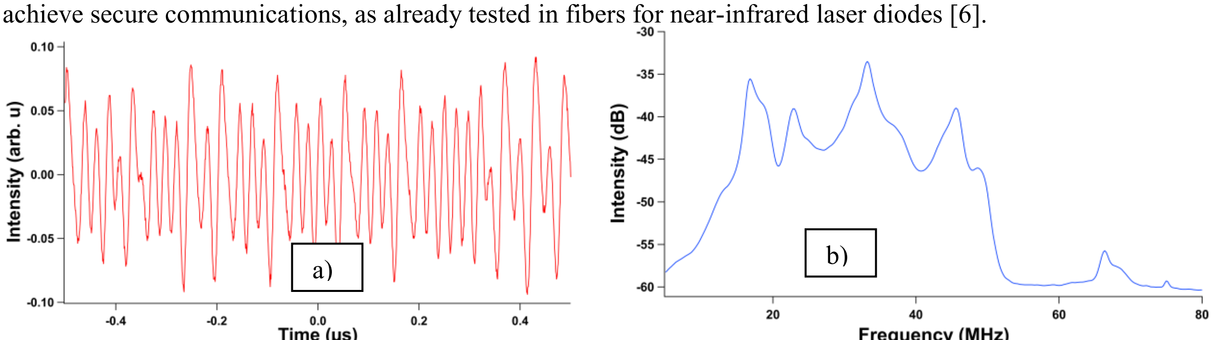

Fig. 2 : Experimental traces of the temporal waveform (a) and the RF spectrum (b) with the sole external optical feedback for a configuration leading to high dimensional chaos. Note the different timescale when comparing Fig. 2 (a) and Fig. 3 (a).

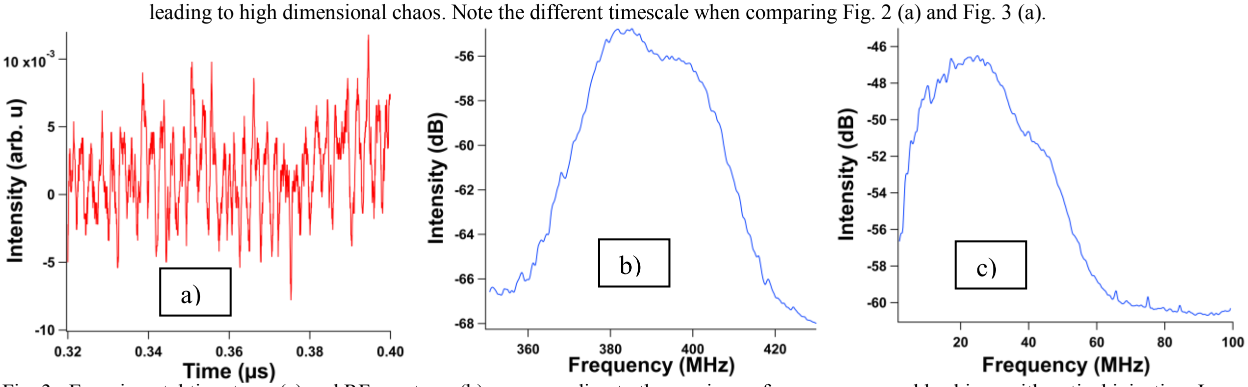

Fig. 3 : Experimental time trace (a) and RF spectrum (b) corresponding to the maximum frequency we could achieve with optical injection. In this configuration, the detuning is 375 MHz. RF spectrum (c) corresponds to the case with zero detuning between master QCL and slave QCL.

4. References

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