Square Wave Emission in a Mid-infrared Quantum Cascade Oscillator Under Rotated Polarization

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Abstract: Quantum cascade lasers, which are known to only emit a transverse-magnetic wave under free-running operation, can output a square wave with transverse-electric emission under polarization-rotated feedback.

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1. Introduction

The technique of feeding back a rotated polarization to a semiconductor laser, known as cross-polarization reinjection, has proved its ability to rotate the polarization of the light emitted by the semiconductor laser [1]. Numerical and experimental works carried out on standard interband laser diodes showed that these lasers do not only display a chaotic behavior, which is usual with conventional optical feedback, but can also emit a square wave in both the TE and the TM modes when the feedback ratio is large enough [1]. The particularity of this square wave is that it is simultaneously present in the TE and TM mode with a phase shift and that the upper part of the square wave can possibly exhibit ultra-fast oscillations beyond the relaxation frequency of the laser diode [2]. We experimentally apply the cross-polarization reinjection technique to a mid-infrared quantum cascade laser (QCL) and unveil a similar behavior except that the square wave does not display oscillations in the investigated bandwidth between 0.1 and 1000 MHz. QCLs are versatile mid-infrared optical sources used in many industrial applications [3] and they are renowned to emit a TM wave because of the symmetry of their gain medium and their material anisotropy. Here we demonstrate the first TE emission in a QCL with cross-polarization reinjection.

2. Device description and experimental setup

The QCL under study is a distributed feedback laser emitting single mode at ~5.7 µm when pumped with a continuous bias of 800 mA at 249 K, as shown on Fig. 1(a). This configuration induces a high internal temperature and this is the reason why the QCL is episide-down mounted on AlN substrate as presented on Fig. 1(b).

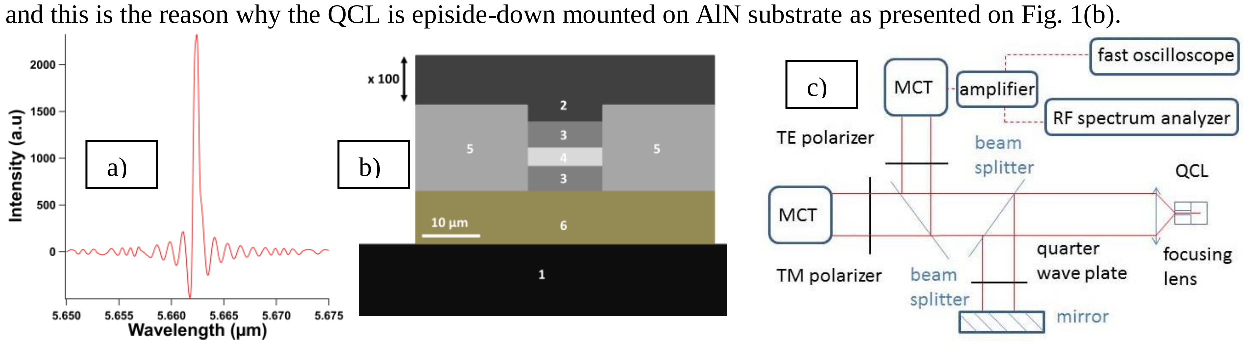

FIG. 1 a) optical spectrum retrieved with a Fourier transform infrared spectrometer (Bruker Vertex 80V) of the free-running QCL operating at 249 K and 340 mA (9 mA above the current threshold); b) schematic of the emission facet of a QCL which is episide-down mounted with mounting base (1), substrate (2), cladding (3), active region (4), dielectric region (5) and gold metallization (6); c) experimental setup which splits the beam to an analysis path above and an external optical feedback path below.

The experimental setup, as presented on Fig. 1(c), is made of an analysis path with a Mercury-Cadmium-Telluride detector with a bandwidth of 50 MHz (KMPV50-0.5-J2) or 1000 MHz (Kolmar KV104-0.1E/10 with KA700 preamplifier) for mid-infrared detection. The detector is linked to a real time spectrum analyzer (RSA) with a maximum real time bandwidth of 110 MHz (Tektronix RSA6114A) and a 40 GS/s oscilloscope (Tektronix TDS6154C) for real time analysis and acquirements. The external optical feedback path is set with a gold plated mirror and a quarter-wave plate (QWP) made for a wavelength of 4.5 µm. If the QWP is placed at 45°, the TM wave emitted by the QCL travels back and forth inside the external cavity and turns to a TE wave before being fed back inside the QCL. The external cavity has a total length of around 35 cm. The non-polarizing beam splitter (NPBS) has a measured absorption of 25% at the laser wavelength. The light that is not absorbed is reflected for 99 % and transmitted for 1%, resulting in a maximum feedback ratio of 35%.

3. Results and Discussion

Fig. 2(a) and 2(b) show the time trace and RF spectrum analysis when conventional optical feedback is applied into the QCL pumped with a continuous bias. The time trace shows a chaotic pattern called low frequency fluctuations [4], where the RF spectrum is quite broad. This non-linear phenomenon can only be seen in the TM wave since the TE wave does not exist in that case. When rotating the feedback polarization with the aforementioned setup, both the TM and the TE wave display a square wave pattern for high feedback ratios (above 25%). Fig. 3(a) and 3(b) show the characteristics of the TE square wave when recorded with the 50 MHz bandwidth detector. The oscillations on top of the squares are only an artefact of the limited bandwidth and were not spotted with the 1 GHz detector, thus these oscillations are not related to the relaxation oscillations, which have never been spotted in QCLs. However, the low-frequency cutoff of this detector, around 10 MHz, does not allow retrieving the shape of the square wave. We therefore experimentally reported the first TE emission in a QCL with cross-polarization reinjection. The TE emission is characterized by a self-pulsating pattern which could be used to generate random numbers and also to investigate the relaxation frequency of QCLs at several dozens of GHz through wavelength conversion, from mid-infrared wavelength to near-infrared domain.

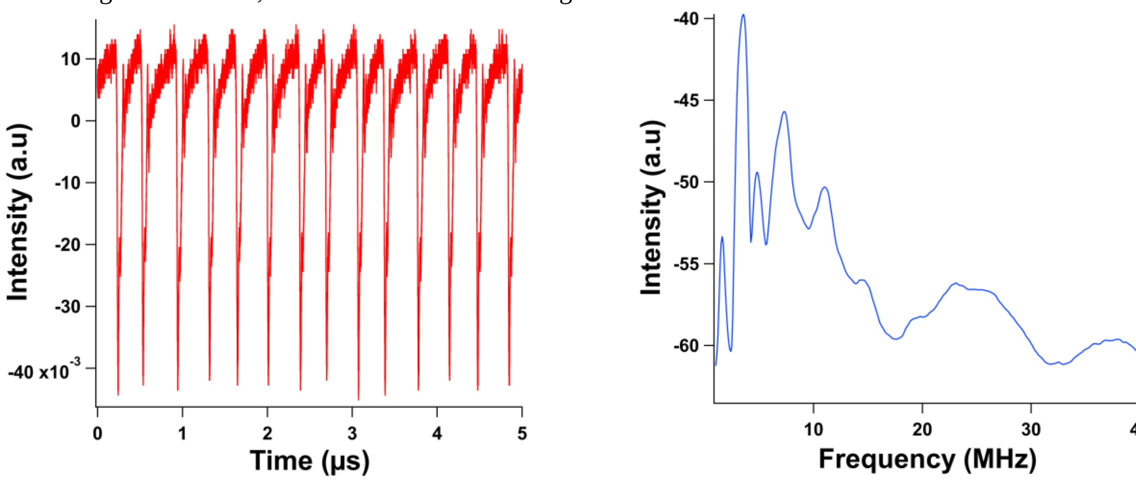

FIG. 2 : Experimental time traces (a) and RF spectrum (b) of the TM wave emitted by the QCL under study when conventional optical feedback is applied. In such case, the QCL does not emit a TE wave

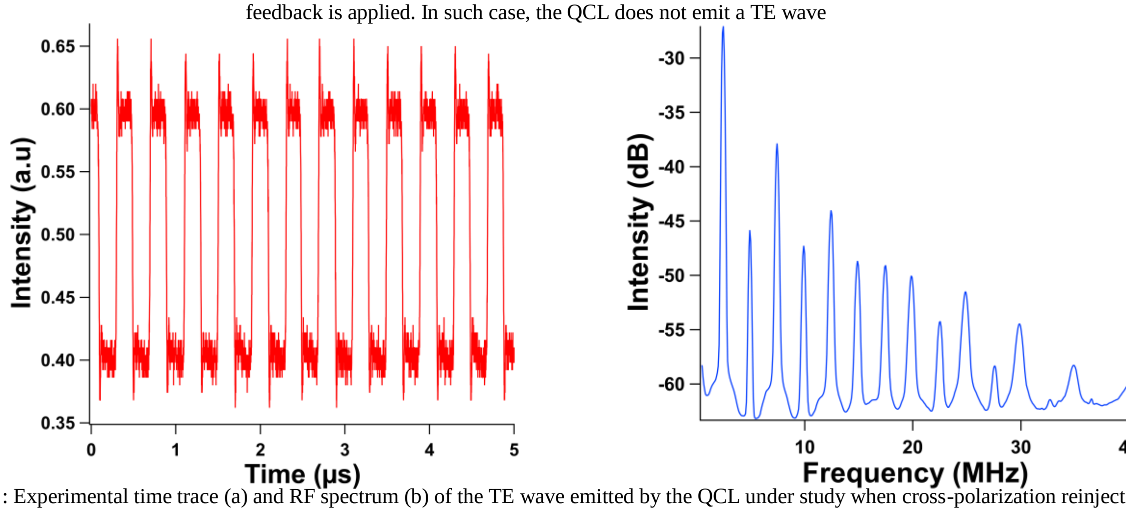

FIG. 3 : Experimental time trace (a) and RF spectrum (b) of the TE wave emitted by the QCL under study when cross-polarization reinjection is applied and the feedback ratio is 35%. The time trace of the TM wave displays the same pattern but with a phase shift of $\pi/2$

4. References

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