An Indirect Determination of the Polarization Anisotropy in a Quantum Cascade Laser Under Strong Cross-Polarization Feedback

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Abstract: This work demonstrates that a non TM-polarized wave can be generated by a quantum cascade laser subjected to strong cross-polarization optical feedback. This finding is used to determine the anisotropy between the two existing polarizations

1. Introduction

Quantum cascade lasers (QCLs) are semiconductor lasers emitting in the mid-infrared domain thanks to intersubband transitions [1]. This makes QCLs candidates of choice for applications ranging from laser surgery [2] to spectroscopy and to free-space communications [1]. In intersubband transitions, only the component of the electric field normal to the quantum wells can optically couple to quantum oscillators hence meaning that the light emitted by QCLs is TM polarized because of the selection rule associated to the enveloped functions [3]. Despite that, some experiments have shown that this selection rule is not always verified in quantum well infrared photodetectors (QWIPs) [4] and QCLs [5] wherein the remaining TE component can be as strong as a few percent of the TM component. When applying conventional optical feedback to a QCL, the back-reflected wave is mainly TM polarized and this triggers non-linear dynamics in the TM mode of the laser. Such phenomena are not observed in the TE component of the QCL. In this work, we favor the TE emission of a QCL by applying a cross-polarization feedback technique [6]. The resulting wave is a square pattern with a characteristic time of the order of the µs and a phase-shift between the TE wave and the TM wave. We then propose a new method to measure the polarization anisotropy, that is to say the ratio between the TE optical power and the TM one. When not thoroughly controlled, polarization switching in semiconductor lasers can be detrimental for free-space transmissions, but it is also possible to take advantage of the regular intermittency for optical routing, clock recovery and random number generation [7].

2. Device description and experimental setup

The QCL under study is a distributed feedback laser emitting single mode at ~5.7 µm when biased at 800 mA and 249 K, as shown on Fig. 1(a). The threshold current is 515 mA and the maximum output power is 180 mW, as visualized in Fig. 1(b). The experimental setup presented in Fig. 1(c) is split between an analysis path and a feedback path. The analysis path is composed of a Mercury-Cadmium-Telluride (MCT) detector with a bandwidth of 50 MHz (KMPV50-0.5-J2) 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. It is possible to tune the polarization of the feedback light by rotating the QWP. 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%.

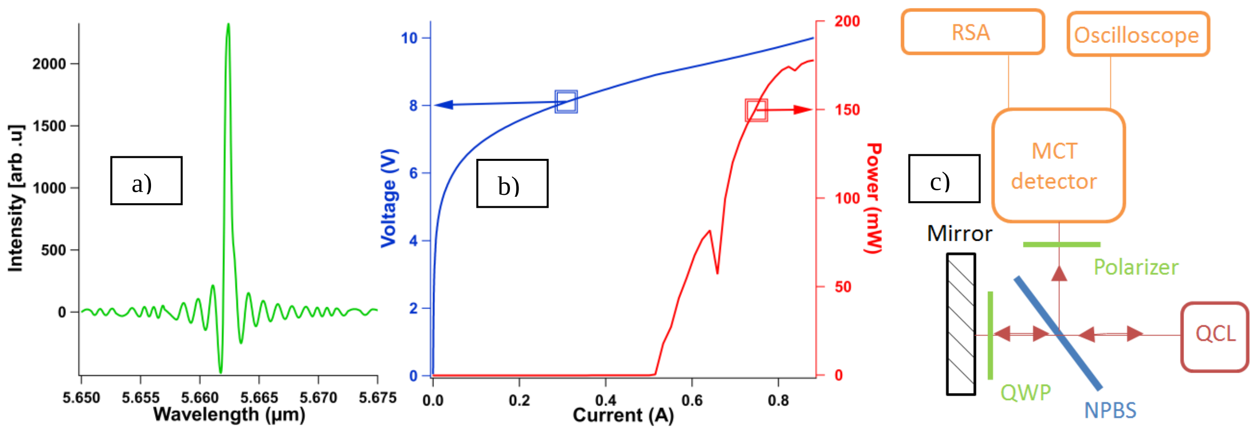

Fig. 1 a) optical spectrum retrieved with a Fourier transform infrared (FTIR) spectrometer (Bruker Vertex 80V) of the free-running QCL operated at 249 K and 800 mA; b) experimental light-intensity-voltage curves at 249 K for the laser under study; c) experimental setup for the cross-polarization feedback configuration, with the external optical feedback path and the analysis path.

3. Results and Discussion

When a QCL is subjected to external optical feedback without polarization rotation, it emits a deterministic chaos signal called low frequency fluctuations (LFF) for a high feedback strength [8]. This pattern can only be visualized in the TM component of the QCL. The addition of the QWP in the feedback path gives rise to a square wave modulation, both in the TM mode and the TE mode, with the maximum of the TM square corresponding to the minimum of the TE square and vice-versa. When varying the angle of the QWP, the square pattern is still found in both the TM and the TE modes but the ratio between the two polarizations is changed. Figure 2(a) shows the resulting TM and TE waves when the angle of the QWP is set at 35° and the angle of the polarizer is either 0° (to retrieve the TE component) or 90° (TM component). The duty cycle of the square pattern is 65% for the TM mode and 35% for the TE mode. The characteristic time of the order of the µs confirms that the TE phenomenon is not a back-reflection artifact, since the external cavity roundtrip time is only a few ns. The observed phenomenon could thus be attributed to thermo-optical effects rather than a time-delay destabilization. In order to measure the ratio between the TE mode and the TM mode, we tilt the polarizer so that both signals are displayed in the same time trace, as illustrated in Figure 2(b). By comparing their amplitude, it is possible to derive the following relationship:

$$\frac{A_E}{A_M} = \frac{cos^2(90-\theta)}{C\,cos^2(\theta)}$$

where $\frac{A_E}{A_M}$ is the ratio between the TE mode and the TM mode, θ is the angle of the polarizer and C is the ratio between the amplitude of the two square components, as shown in Fig. 2 (b) with the green and the orange arrow. In the case where $\theta = 10°$, both squares have the same amplitude so $C = 1$ and in the case where $\theta = 20°$, the ratio between the two arrows gives $C = 4.2$. Consequently, $\frac{A_E}{A_M} = 0.03 \pm 0.01$. This method paves the way for anisotropy characterizations in QCLs and the retrieved square pattern can be of paramount importance for optical modulators in the mid-infrared domain where high-speed modulators are currently difficult to achieve.

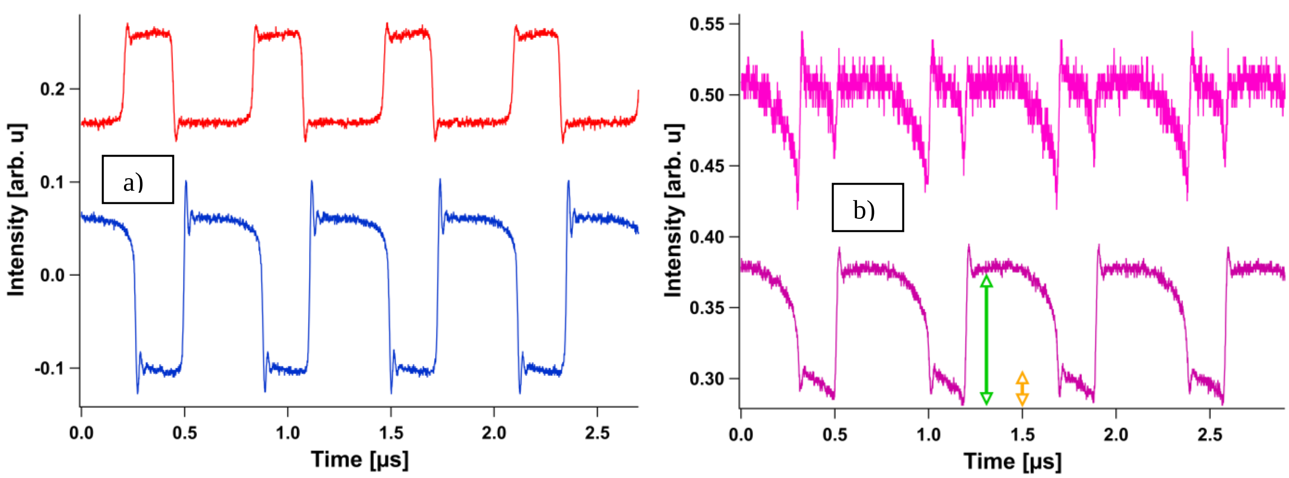

Fig. 2 : (a) Experimental time trace of the laser intensity when the polarizer is set at 0° (red curve) and when the polarizer is set at 90° (blue curve), describing the TE wave and the TM wave, respectively. (b) Experimental time trace of the laser intensity when the polarizer is set at 10° (pink curve) and when the polarizer is set at 20° (purple curve). The TE component and the TM component are both displayed and their amplitudes are underlined with the orange and the green arrows, respectively.

4. References

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