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Near-field tailoring of mid infrared quantum cascade lasers with conventional optical feedback

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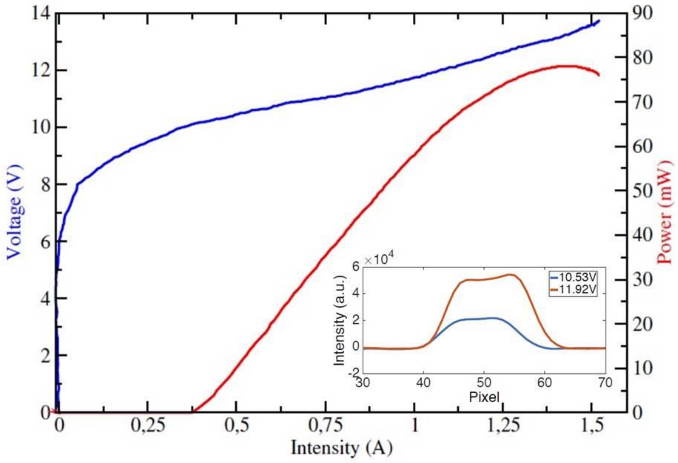
***Abstract**. Quantum cascade lasers have become the most suitable laser sources from the mid-infrared to the THz range. This work examines the effects of external feedback in mid infrared quantum cascade laser structures and shows that different conditions of the incident angle of the feedback wave enable to efficiently tailor its near-field beam profile.*

Quantum cascade lasers (QCL) are semiconductor lasers based on ultrafast intersubband transitions with picosecond timescale that have become the most suitable laser sources from the mid-infrared to the THz range, due to their compactness, efficiency and high room temperature performances [1]. In particular, high-power QCLs are powerful sources for optical countermeasures, including night vision blinding and missile out steering. However, some drawbacks arise with high power lasers that usually lead to a strong degradation of the beam quality. An increase of the active area leads to an increase of the emitted power and peak powers above 200 W were reported with a 400-µm wide laser [2]. Nevertheless, wide QCLs are subjected to heat challenges and multi modal emission affecting the beam quality. For QCLs emitting at 5 µm and with active area wider than 12 µm, several modes coexist inside the cavity and the lasers exhibit strong beam steering [3]. The latter can be well suppressed owing to a nonlinear control based on a conventional optical feedback (COF) [4] [5]. As compared to existing technologies, that are complex and costly, using COF is a more flexible solution to obtain high-quality mid-infrared sources. In this paper, we examine the effects of COF in mid infrared QCL structures and unveil that the incident angle of the feedback wave enables to efficiently tailor their near-field beam profile.

The Fabry-Perot QCLs under study are 3 mm long and 14 µm wide. They are made of 30 periods of GaInAs/AlInAs grown between two InP cladding sheets and they emit around 4.6 µm [6]. The characteristics of one of the QCLs under study when powered with a 3% duty cycle (meaning 600 ns long pulses repeated at 50 kHz) are presented on figure 1. The light-current voltage characteristics are measured at room temperature. The threshold current is 400 mA, the external efficiency is 0.5% and the threshold voltage is about 8 V. The inset stresses that voltage has a strong influence on the shape of the optical near field and leads to beam steering effect. Figure 2 shows cavity modes TM0 and TM1 of the same QCL, simulated with finite-element method software based on Maxwell's equations. These two modes are responsible for beam steering and induce beam deformation.



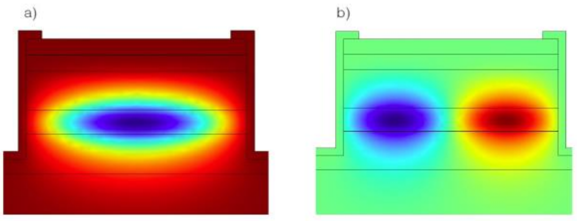


Figure 1(left): Light-current voltage parameters of a broad area QCL. Inset shows the discrepancies between two bias voltages
Figure 2 (right): Simulation of the two transverse modes that can be found inside the QCL cavity

The optical feedback setup is composed with a beam splitter allowing part of the QCL beam to be reflected on the mirror and to be reinjected inside the laser cavity. On the other hand, it allows retrieving the optical near field on an infrared camera made of 124 × 124 pixels. The reflected power is about 5% of the QCL emitted power. The position of the reinjected beam is one of the key parameters and this feature is monitored thanks to a rotating mirror allowing a ±2' control over the reinjected beam position angle. In order to focus the laser beam on both the feedback mirror and the detector, the laser facet is at the same distance from these two items. In our case, the cavity length is set to 22 cm.

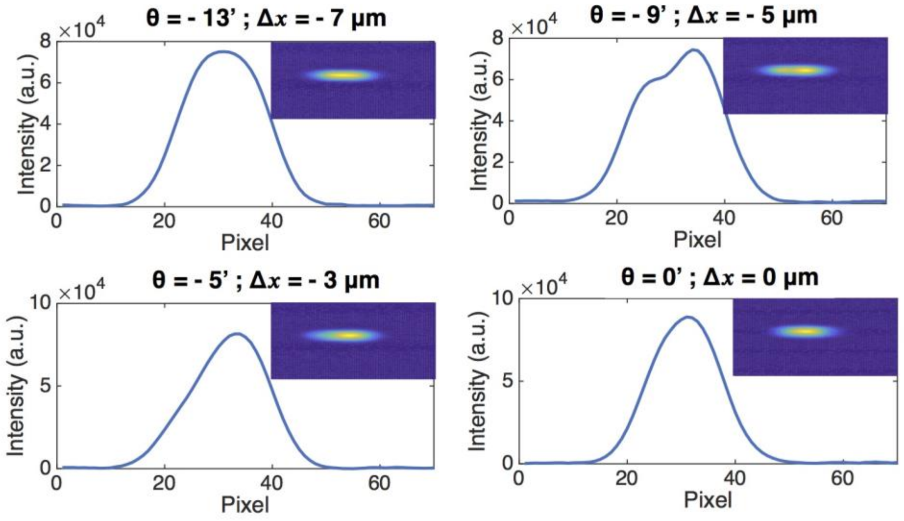


Figure 3: Optical near field of a QCL subjected to optical feedback for different position of the reflected beam. Inset shows the image retrieved with the 124 × 124 pixels infrared camera.

Near field of one of our QCLs when COF is applied can be retrieved in figure 3. The blue curve stands for the summed intensity of each pixels column while the infrared camera image can be found in inset. When θ = 0', the reflected beam is centered on the QCL cavity and the optical near field becomes narrower than in the case where no optical feedback is applied. This happens for θ = -13', since the COF is at the edge of the cavity, knowing that the QCL is 14 µm wide. No peak selection is achieved in that particular case. By rotating the feedback mirror, one can select the higher order mode TM1 as seen for θ = -9' and θ = -5'. Apart from selecting modes, external optical feedback is also able to shape near field profile, as we saw from the inset of figure 1, the beam can be distorted for high bias voltages. In that case, the purpose is to foster fundamental TM0 mode in order to produce a Gaussian shape beam.

This work shows a way to select modes inside a broad area QCL cavity through COF. This method could be tested with wider QCLs to determine whether beam steering can also be reduced in order to get powerful sources with high beam quality. Further work will also investigate Talbot-based cavity for high power operation and from which selection of supermodes will be considered to retrieve a coherent beam from multiple incoherent sources.

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