Frequency Noise of a 4.6-μm DFB Quantum Cascade Laser measured from 130 K to 300 K

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BIOGRAPHY

Dr Stéphane Schilt obtained his master degree in physics from the Swiss Federal Institute of Technology in Lausanne (EPFL) and his PhD in technical sciences in 2002 from the same institution for his work in trace gas sensing by laser spectroscopy. After a 3-year post-doc where he worked on photoacoustic spectroscopy and stabilized lasers, he joined the company IR Microsystems in Lausanne to develop low-cost gas sensors based on NIR lasers. Since 2009, he has been senior scientist at Laboratoire Temps-Fréquence at the University of Neuchâtel, Switzerland, where his research interest is focused on optical frequency combs for time and frequency metrology and QCL frequency-stabilization.

He published more than 25 papers in peer-reviewed journal and has co-authored over 50 contributions in international conferences.

TECHNICAL ABSTRACT

Quantum cascade lasers (QCLs) constitute a versatile source of coherent radiation in the mid-infrared (MIR) spectral region and have found numerous applications in high-precision and high-resolution spectroscopy, trace-gas sensing, but also in the domains of defense and free-space optical communications. In the past decade, remarkable improvements in the general properties of QCLs have been achieved, such as a continuous operation at room-temperature, singlemode continuous emission with the use of a distributed feedback (DFB) grating or a wide continuous tunability with the use of an external cavity (EC). However, the spectral properties of QCLs have been less studied and optimized so far.

In principle, QCLs have the potential to be a light source of ultra-high spectral purity owing to their close-to-zero Henry’s linewidth enhancement factor that results from their different mode of operation as compared to standard diode lasers. However, a narrow linewidth is generally not achieved in practice with QCLs because of undesired effects that compromise their spectral properties, which manifests as a strong 1/f (flicker) noise. A first effect that can prevent a narrow linewidth to be achieved is the presence of technical noise originating from the driving source [1], but even when this contribution is suppressed with the use of a very low-noise current source, a significant linewidth broadening remains, showing that the frequency noise is generated internally to the device [2].

The frequency noise and resulting linewidth of a QCL is an essential characteristic for high-resolution spectroscopy. Some high-precision measurements have shown to be limited by the QCL linewidth [3]. The presently achieved state-of-the-art linewidth for a free-running DFB-QCL is in the sub-MHz range (e.g. ≈600 kHz at 10 ms observation time reported in [4]) and is not improved in EC-QCL [5]. With the advent of optical frequency combs, new domains of research are opening up in high-precision MIR molecular spectroscopy. The measurement of absolute optical frequencies becomes possible, opening new prospects in time and frequency metrology (such as molecular optical frequency standards) or in fundamental science (test of fundamental physics with molecules, e.g. the non-conservation of parity or the stability of the electron-to-proton mass ratio). But such applications require a narrow linewidth laser to fully benefit from the huge precision potential brought by the frequency combs.

With the objective to get better insights on the mechanisms at the origin of frequency noise in QCLs, we studied its evolution over a wide range of temperature in a single device. Previous results reported with different QCLs emitting in a similar spectral range of 4.3-4.6 μm and operated either at room temperature or at cryogenic temperature showed a frequency noise power spectral density (PSD) two orders of magnitude lower at room temperature than at cryogenic
temperature [4, 6-7]. The fact that these results were obtained with different devices made difficult to directly assess the impact of the temperature, as the possible influence of other parameters such as the different dimensions, design and fabrication of these lasers could not be excluded.

Here, we show the evolution of the frequency noise of a 4.55-μm DFB-QCL (from Alpes Lasers, Switzerland) in a wide range of temperature spanning from 128 to 303 K. The frequency noise was measured using different absorption lines of CO (ranging from R15 at 2199.9 cm⁻¹ to R24 at 2227.6 cm⁻¹) in a 1-cm long cell filled with 20 mbar pure CO acting as a frequency discriminator to convert the frequency fluctuations of the laser into measurable intensity fluctuations. Some examples of frequency noise spectra obtained at different temperatures are displayed in Fig. 1a. They show the presence of two different regimes separated by a transition near 200 K: the frequency noise is almost unaltered at $T > 200$ K, while it strongly increases at lower temperature. The QCL linewidth calculated from the frequency noise spectra using the formalism described in [8] is reported in Fig. 2b as a function of temperature. The abrupt transition at 200 K is clearly visible in this figure: the linewidth broadens exponentially below 200 K, while it remains around 1 MHz in the range 200-300 K. At 128 K, the linewidth is larger by one order of magnitude compared to the value achieved at room temperature.

The origin of the frequency noise in the QCL will be discussed. It will be shown to result from internal electrical noise in the QCL structure. Indeed, measurements of the electrical noise of the laser (voltage noise across the laser) showed to follow the same trend with respect to temperature as the frequency noise and linewidth.

![Graph](image_url)

**Fig. 1.** (a) Frequency noise spectra of the 4.55-μm DFB-QCL measured at different temperatures. (b) Linewidth computed from the frequency noise spectra (at 5 ms observation time) as a function of temperature.

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References


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