Investigations and Reduction of Frequency Noise in Mid-Infrared Quantum Cascade Lasers

Stéphane Schilt[1], Lionel Tombez[1], Stéphane Blaser[2], Romain Terazzi[2], Camille Tardy[2], Richard Maulini[2], Alfredo Bismuto[2], Tobias Gresch[2], Michel Rochat[2], Antoine Muller[2], Thomas Südmeyer[1]

[1]Laboratoire Temps-Fréquence, Université de Neuchâtel, Neuchâtel, Switzerland
[2]Alpes Lasers SA, 1-3 Pass. Max-Meuron, Neuchâtel, Switzerland

Email: stephane.schilt@unine.ch

Emerging applications in the mid-infrared for optical metrology and high precision spectroscopy require narrow linewidth laser sources. Quantum cascade lasers (QCLs) constitute a versatile laser technology for such applications. Their capability to be frequency-modulated at rates of hundreds of kHz [1] offers a large potential for the realization of narrow-linewidth lasers by active stabilization to an optical reference. However, assessing their noise properties and spectral purity in free-running regime is a necessary preliminary step towards such applications.

In this work, we summarize our latest investigations on the origin of frequency noise in free-running QCLs. First, we demonstrate that internal electrical noise generated within the QCL structure by the electrons flow constitutes the major contribution to the frequency noise. Voltage fluctuations observed across the laser induce variations of the electrical power dissipated in the laser, which in turns produce frequency noise. Therefore, studying this electrical noise is a simple and powerful method to investigate noise processes in QCLs. Then, we performed the most systematic and detailed investigation of noise in QCLs ever reported, by studying a set of 22 QCLs at 7-8 µm, fabricated in different processes, with different structures and parameters, to assess their possible impact on the noise spectrum. Our study shows a large dispersion of the electrical noise among the various considered devices (Fig. 1a), with a visible impact of the laser width, and globally revealed a much lower noise in ridge waveguide lasers than in buried heterostructure devices. Some observations also seem to indicate that the main noise source in some of the studied QCLs arises from the presence of junctions within the devices, acting as Schottky diodes with a noise scaling as the square of the laser differential resistance (Fig. 1b).

Finally, we used the voltage noise information to implement an active noise reduction method in a QCL without using any optical frequency reference [2]. In our proof-of-principle demonstration, a near-infrared laser illuminates the top surface of the QCL to stabilize its internal temperature, demonstrating a 10-fold frequency noise reduction (Fig. 1c) that paves the way for the realization of compact low-noise semiconductor lasers in the mid-infrared.

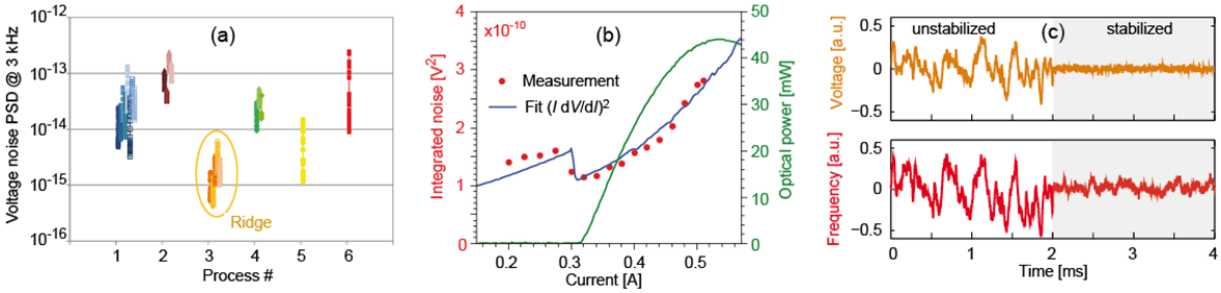

Fig. 1: (a) Voltage noise at 3 kHz measured at various currents for QCLs made from different processes. (b) Noise dependence as a function of the operating current in a QCL, showing a Schottky diode behaviour arising from the presence of junctions within the device. (c) Frequency noise reduction in a QCL achieved by stabilizing the laser voltage without using any optical reference.

[1] L. Tombez, et al., Appl. Phys. Lett. 103, 031111-1 - 031111-5 (2013)
[2] L. Tombez, et al., Opt. Lett. 38, 5079-5082 (2013).