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Frequency stability of a quantum cascade laser for spectroscopic application

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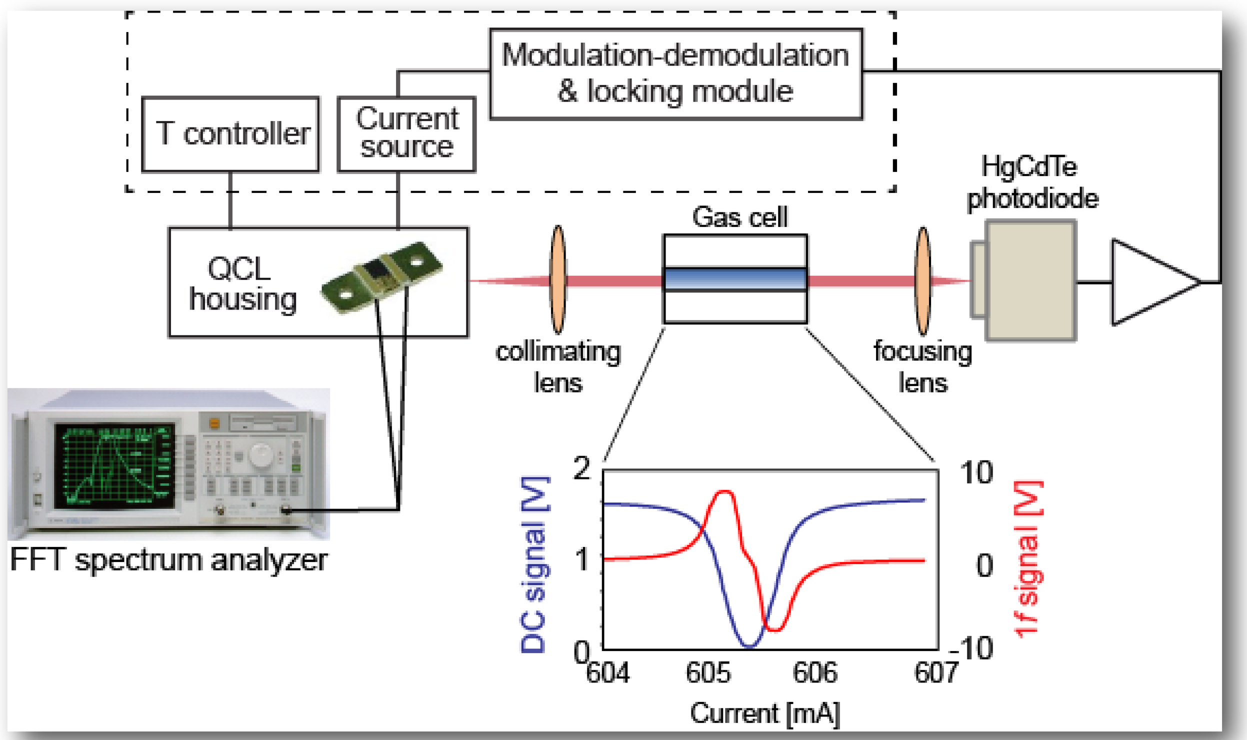
Motivation

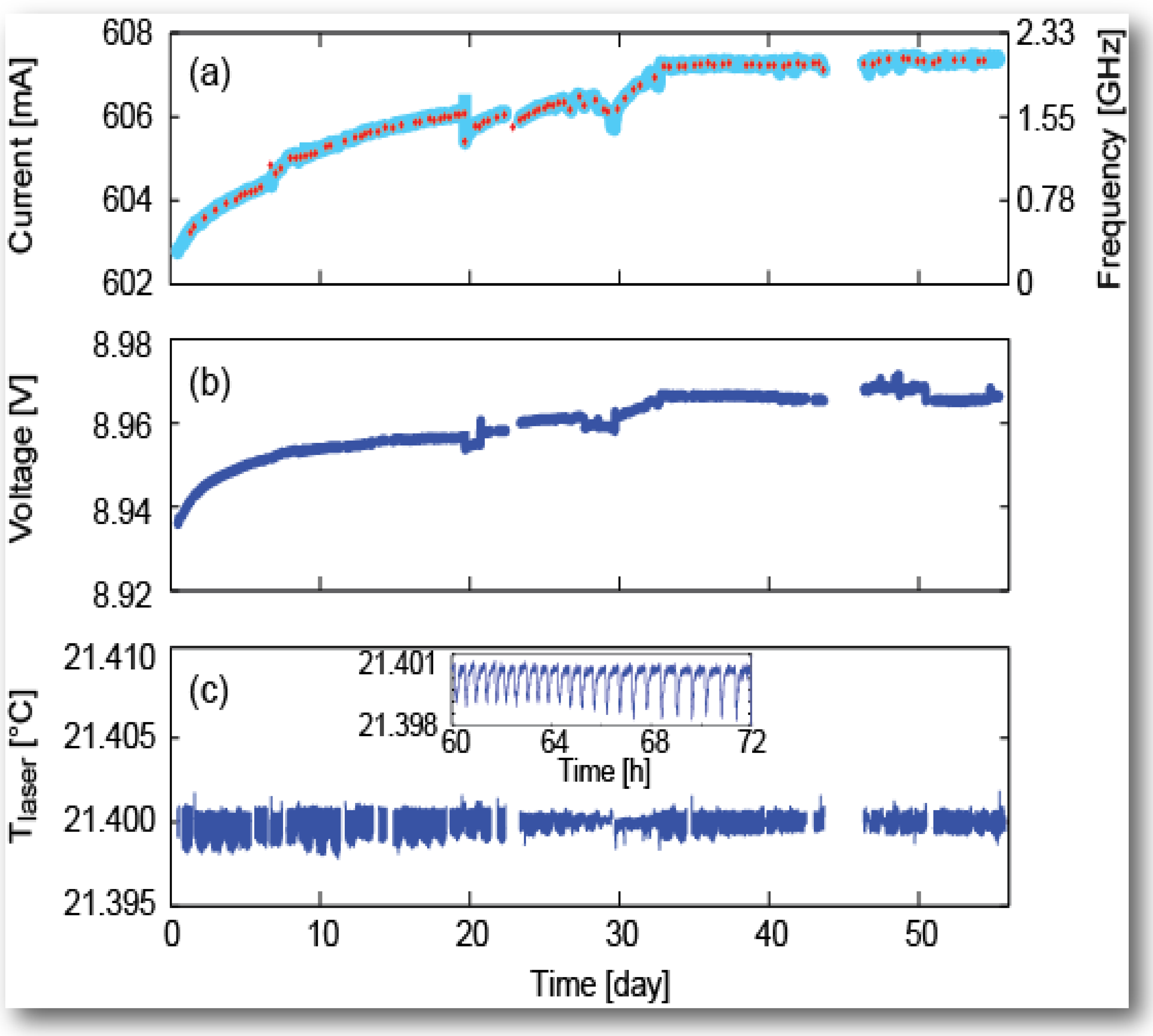
Applications of quantum cascade lasers (QCLs) in sensitive and reliable trace gas sensors require **stable long-term operation**, in particular with respect to their spectral properties. In this work, we present the results of an **experimental study of the frequency stability of a QCL** continuously assessed **over a period of two months**. In addition, we also investigated a possible change in the noise properties of the laser during the same period by regularly measuring its voltage flicker noise. Such study is important for the long-term operation of sensitive laser-based gas sensors as developed in IrSens-2.

Spectroscopy setup for QCL stability and noise measurements

- N_2O absorption line in a sealed low-pressure gas cell used to accurately determine the QCL noise and central wavelength.
- Distributed feedback (DFB) **QCL at λ = 7.96 µm** (T = 21.4 °C and $I \approx$ 600 mA), driven by a home-made low-noise controller .
- Stabilization to the transition centre by wavelength modulation spectroscopy applied by modulating the QCL current.
- The frequency drift of the free-running laser is assessed from the evolution of the DC current required to maintain the laser at the center of the absorption line.
- The current changes are converted into corresponding frequency changes using the laser current-tuning coefficient ($\Delta\nu/\Delta I$ = − 0.39 GHz/mA).
- Regular check by scanning the laser through the resonance.
- Additional noise measurements regularly performed (2-3 times per day)
- **Two months of continuous measurement**

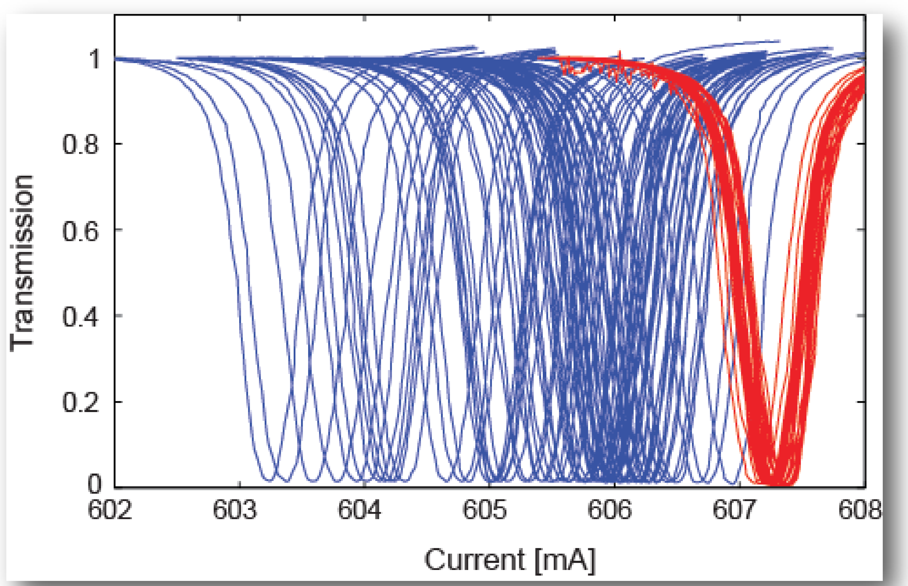


QCL frequency stability over time



Blue line: data from the continuous stabilization to the N_2O transition.

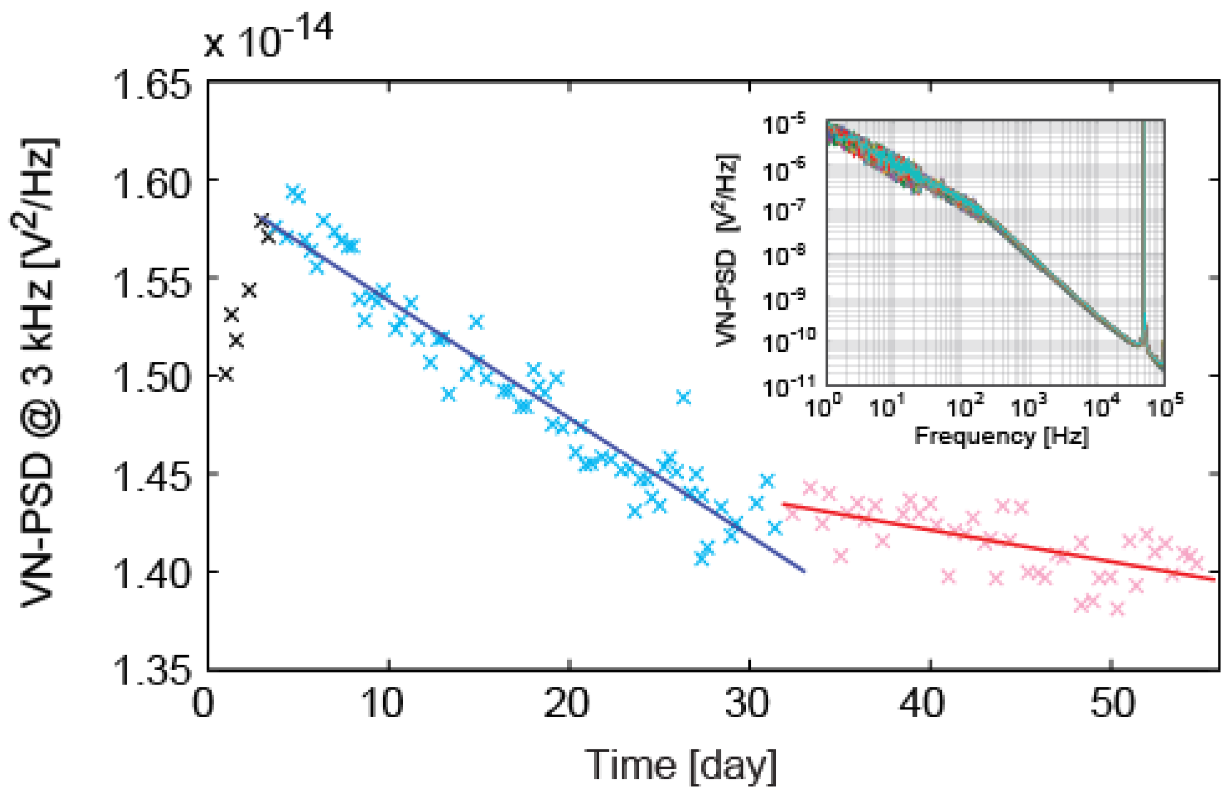
Red points: complementary data obtained from occasional current scans through the transition (see below)



Day 23: restart of the experiment due to a power failure
Day 19: an erroneous set current applied to the laser resulting in a large temperature change
Days 44-46: problem with the monitoring photodiode (laser not stabilized to the N_2O transition)

- **Monotonous drift** of the laser current of about 4.6 mA observed **during a first period** of slightly more than one month (days 0-32), corresponding to a frequency change of ~1.8 GHz.
- Drift comparable to the value of <2 GHz/month reported for NIR DFB laser diodes at 852 nm.
- Then, the change in the QCL current is strongly reduced and the **optical frequency remains within a range of ~100 MHz during more than 20 days**. The QCL voltage also becomes much more stable than in the first part of the experiment.
- No observable variation of the laser current-tuning coefficient $\Delta\nu/\Delta I$ throughout the experiment.
- Possible explanation: improvement of the laser contacts over time resulting from an **annealing effect**, which slightly reduces the voltage drop in the contacts and the associated laser heating.

Noise evolution over time



- The voltage noise across a QCL was shown to be a simple and powerful tool to investigate noise processes, as frequency noise (responsible for the laser linewidth) and voltage noise are highly correlated [1].
- **Regular decrease of the voltage noise over time during the first 30 days**.
- Good correspondence observed between the time where the noise starts to stabilize and the point where the QCL wavelength drift is reduced (at day ~30).
- A similar cause is believed to produce the two effects.

[1] S. Schilt et al., Appl. Phys. B **119**, 189-201 (2015)

Conclusion and outlook

- The observed frequency drift is acceptable for gas sensing applications.
- Interest for similar studies during temperature cycling.