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Investigation of Novel Tuning Mechanisms in QCLs

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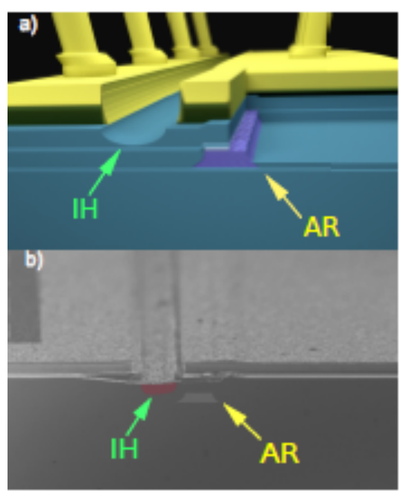
Motivation

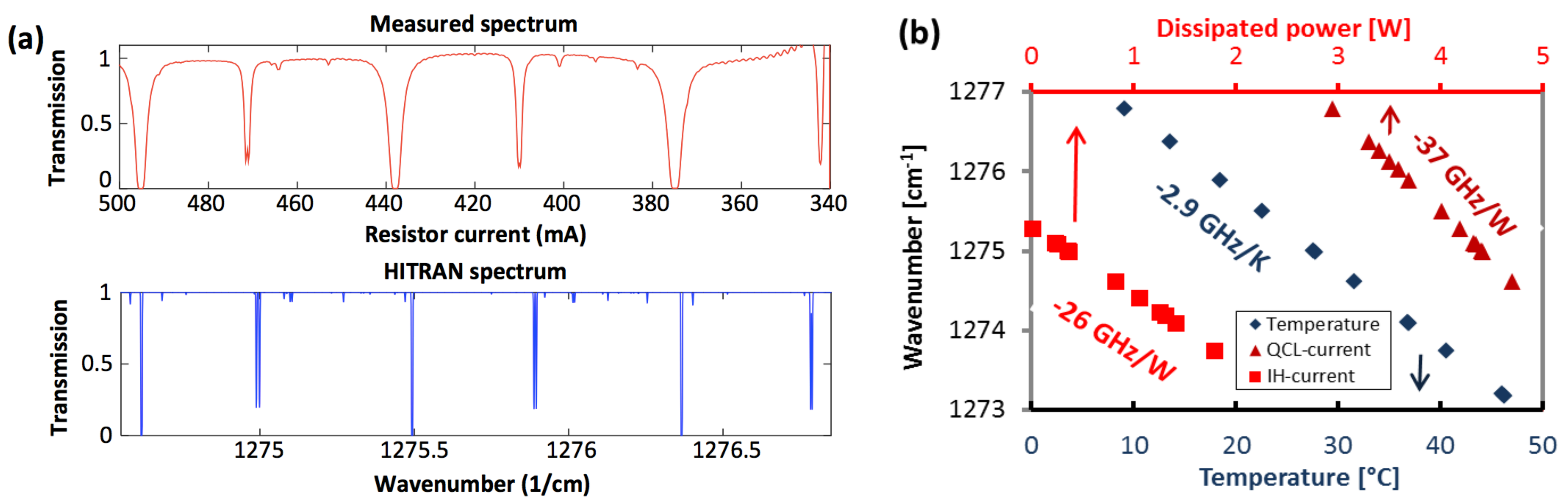
Quantum cascade lasers (QCLs) have proved to constitute an efficient source of mid-infrared coherent radiation with numerous applications in high resolution molecular spectroscopy and trace gas sensing. Sensitive trace gas sensing applications often require a frequency tuning or modulation of the laser through an absorption line of the analyzed gas. This involves a scan of the laser wavelength through the absorption line, or a combination of a fast sine modulation and a slow tuning ramp. For common spectroscopic methods like wavelength modulation spectroscopy (WMS) and photoacoustic spectroscopy (PAS), the laser frequency needs to be modulated and a harmonic demodulation of the output signal is performed after light-gas interaction (optical signal in WMS or acoustic signal in PAS). First or second harmonic demodulation is generally considered.

Tuning of QCL wavelength

Traditionally, the wavelength of a QCL is tuned by changing either the laser temperature or its injection current. Temperature tuning provides a broad tuning range, however it is fairly slow with a time constant in order of seconds as the whole laser submount and chip need to be temperature-controlled.

Recently, a novel wavelength tuning mechanism was demonstrated in QCLs, by incorporating a heating element into the QCL structure, next to the active region. This element is in essence a resistive integrated heater (IH) that is placed in close proximity to the active region in a DFB QCL.

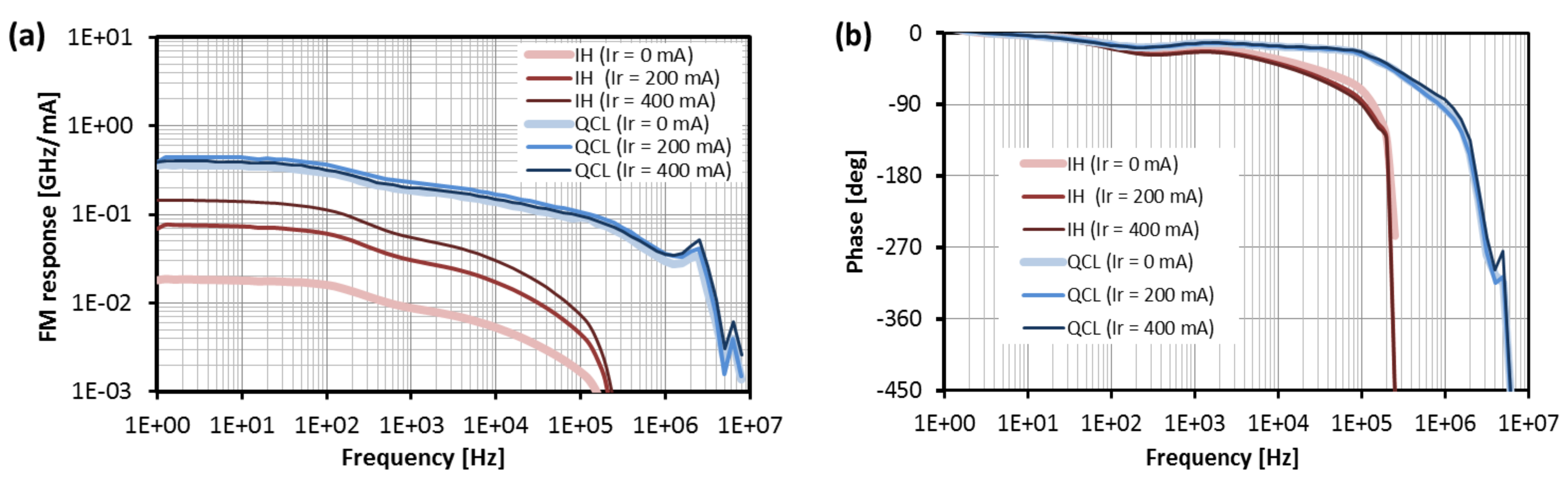




(a) Tuning of the QCL obtained as a function of the electrical power dissipated in the IH and corresponding N_2O absorption spectrum (top: experimental spectrum; bottom: reference spectrum from HITRAN database). (b) Static tuning coefficients of the QCL measured for temperature, QCL-current and IH-current tuning, respectively.

Characterization of QCL modulation through the Integrated Heater

To measure the frequency modulation response, a small sine modulation was applied to the QCL current or to the resistive heater while the laser frequency was tuned to the side of an N_2O absorption line, in the linear range of the absorption profile. The gas cell was used as a frequency discriminator, by converting the laser frequency modulation into intensity modulation that was detected using a photodetector. The detector output signal was demodulated with a lock-in amplifier (in amplitude and phase). The measurements of the transfer function were conducted at different QCL injection and IH currents.

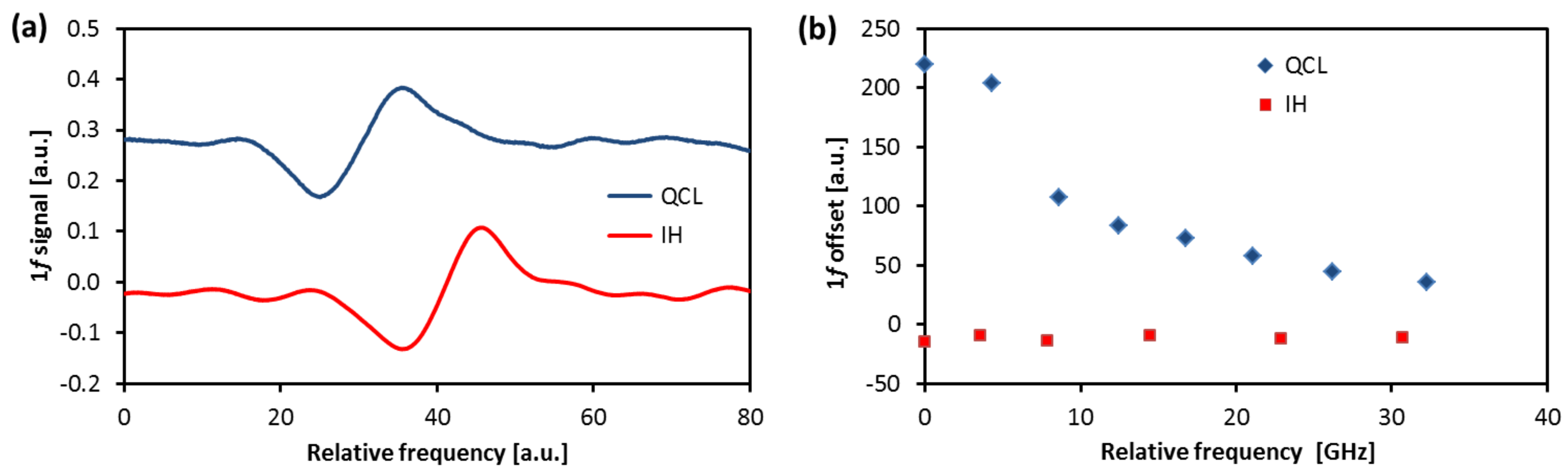


FM transfer function ((a) amplitude and (b) phase) obtained for a modulation of the QCL-current (blue) and IH-current (red), both at different IH currents Ir.

For QCL injection current modulation, the FM response is independent of the IH current. For IH modulation, the amplitude of the transfer function depends on the average IH current due to the quadratic thermal response. It is observed for the IH modulation, a bandwidth of up to 100 kHz can be achieved, which is suitable for use in spectroscopy applications.

Wavelength Modulation Specroscopy

A major benefit of the IH is the significant reduction of the associated optical power variation, thus a reduced RAM is also obtained in comparison to injection current modulation. The obtained derivative signals look similar but a large offset is present for the QCL current modulation. However, a fairly small offset is achieved for the IH modulation for various IH average currents.



(a) Comparison of the first harmonic WMS signal of a N_2O line obtained for QCL injection and IH current modulation, showing the strongly reduced offset obtained for IH current modulation. (b) Amplitude of the offset in the 1*f* signal obtained for QCL and IH modulation as a function of the QCL (IH) current, converted into a corresponding frequency detuning.

Conclusion and outlook

We characterized the tuning and FM transfer function of a QCL with an IH acting as a new frequency actuator. Fast modulation of the QCL frequency up to the 100-kHz range can be achieved by modulating the IH-current, with the important benefit of a reduced associated RAM compared to the usual injection current modulation. We also showed first implementation of WMS using a modulation of the IH-current.