Frequency locking of an extended-cavity quantum cascade laser to a frequency comb for precision mid infrared spectroscopy

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Extended-cavity quantum cascade lasers (EC-QCLs) enable mode-hop-free frequency sweeps in the mid-infrared region over ranges in excess of 100 cm^{-1} , at speeds up to 1 THz/s and with a 100-mW optical power level. This makes them ideally suited for broadband absorption spectroscopy and for the simultaneous detection of multiple gases. On the other hand, their use for precision spectroscopy has been hampered so far by a large amount of frequency noise, resulting in an optical linewidth of about 30 MHz over 50 ms [1]. This is one of the reasons why neither their frequency nor their phase have been so far locked to a frequency comb. Their use in combination with frequency combs has been performed in an open loop regime only [2], which has the merit of preserving the inherently fast modulation speed of these lasers, yet not to afford high spectral resolution and accuracy.

Here we report for the first time frequency locking of an EC-QCL to a frequency comb. The lock relies on an external frequency correction given by an acousto-optical frequency shifter (AOFS) in a feedback configuration, according to the experimental setup depicted in Fig. 1(a). An EC-QCL from Daylight Solutions with tunability in the $7.5\text{-}8.2\text{ }\mu\text{m}$ range and emitting up to 100 mW is frequency shifted by an AOFS. It is arranged in a double pass configuration to maximize the frequency modulation depth while compensating for beam-steering effects due to the large laser-frequency jittering. The beat-note between the laser and a 100-MHz Tm: fiber frequency comb is obtained by heterodyning at around $1.57\text{ }\mu\text{m}$ the supercontinuum light generated by the comb itself with the sum-frequency between EC-QCL and main $1.95\text{-}\mu\text{m}$ comb output [3] generated in a ZGP crystal. The beat-note is stabilized with a double servo loop acting on the piezo-electric laser frequency actuator till 60 Hz and on the AOFS at higher frequencies.

Fig. 1 (a) Experimental setup. PBS: polarisation beam splitter; SC: supercontinuum fiber; OF: optical filter; AOFS: acousto-optical frequency shifter; BC: beam combiner; FC: fiber coupler; PD: photodetector; LO: local oscillator; VCO: voltage controlled oscillator; HV: high-voltage RF amplifier. (b) Power spectral density of the error-signal under free-running and locked conditions. Inset: averaged spectrum of the beat-note signal in locked conditions.

The power spectral density of the error signal used to stabilize the EC-QCL displayed in Fig. 1(b) shows significant laser noise suppression till 10 kHz . It was impossible in our current configuration to achieve a larger control bandwidth due to the μs -level delay introduced in the loop by the AOFS. The loop was anyway sufficient to reduce by more than a factor of 10 the EC-QCL linewidth, as attested by the 2.5-MHz -large beat-note signal shown in the inset. Application of this stable comb-referenced source to spectroscopy is under way.

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References

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