Tunable External-Cavity Quantum Cascade Laser Sources for Gas Sensing and Spectroscopy

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Abstract: Developments in tunable external-cavity quantum cascade lasers will be presented, along with results on broadly tunable lasers for spectroscopic applications.

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Recent developments in bandstructure engineering and laser design have led to quantum cascade lasers with unprecedented tuning ranges when operated in an external cavity [1]. These wide tuning ranges make these lasers ideal sources for mid-infrared spectroscopy in the molecular fingerprint region [2]. In this paper, the authors report on progress in the development of broadly-tunable external cavity quantum cascade lasers (ECQCLs) for use in gas sensing and spectroscopic applications. In particular, methods to overcome the effects of mode-hops in continuous-wave (cw) tuning will be described. The design, implementation, and testing of a prototype ECQCL will be presented. The prototype ECQCL operates in two modes: a broad scan and a fine scan mode. In the broad scan mode the laser can be tuned across its entire available gain bandwidth. In the fine scan mode, the laser can be tuned to a particular wavelength region and then swept much more rapidly across a smaller frequency range (~1 cm⁻¹). In this second high-resolution mode of operation the ECQCL will operate in cw mode and exhibit continuous, mode hop free tuning over a narrow frequency range.

The buried heterostructure quantum cascade laser used was grown using MOVPE with an active region employing a double-phonon resonance design [3]. The laser is mounted ridge-side up and has a cavity length of 2 mm, a ridge width of 7 µm, and an emission wavelength of 8.6 µm. The front facet of the laser was AR coated to reduce the facet reflection near the laser’s 8.6 µm emission wavelength. The opto-mechanical design of the Littrow configuration external cavity uses both facets of the laser, as shown in Fig. 1. The output from the front facet is sent to the grating and is used to form the external cavity, while the output of the back facet is used as the laser output beam. This has the advantage of increased output power and avoids requiring some method of beam-deflection compensation to correct for changes in the output beam direction due to changes in the grating angle. The lens is a 25 mm diameter broadband AR coated germanium meniscus f/0.5 lens. The grating is a gold coated rectangular-ruled planar reflecting grating with 10 µm pitch. Power-current-voltage (PIV) curves of the laser operating in pulsed mode before applying the AR coating to one facet, after applying the AR coating to the front facet, and in operation in an external cavity are shown in Fig. 2(a).

High-resolution motor steps of the grating angle adjustment can be used to monitor the fine-scan tuning behavior of the ECQCL in both cw and pulsed mode. The cw results, shown in Fig. 2(b), reveal irregular mode hops in integer multiples of 0.74 cm⁻¹ as the laser switches between neighboring Fabry-Perot modes of the QCL chip with the largest gain. The mode-hop spacing of 0.74 cm⁻¹ is close to the expected value of 0.78 cm⁻¹ based on the QCL chip’s index and length. The tuning results for the ECQCL operating in pulsed mode at 50 kHz with a 5% duty cycle are shown in the inset of Fig. 2(b), and reveal less susceptibility to mode-hops between QCL FP modes.

Figure 1. (a) Photograph and (b) schematic showing external-cavity quantum cascade laser design.
Figure 2. (a) Electrical (black) and optical response for QCL when operated in pulsed mode. (b) Tuning operation of ECQCL in cw and pulsed (inset) mode.

For operation in broad-scan mode, the pulsed ECQCL’s maximum grating tuning range of ~80 cm\(^{-1}\) was determined by recording the lasing wavelength on an FTIR spectrometer vs. grating angle, as shown in Fig. 3(a). The pulsed ECQCL was then used for gas spectroscopy in broad-scan mode by tuning the wavelength over ~40 cm\(^{-1}\) and monitoring the transmitted power through a vapor cell containing ~600 torr of methane (CH\(_4\)). The experimental results, shown in Fig. 3(b), show good agreement with the results from a HITRAN 2004 simulation over the same wavelength region. The HITRAN results have been smoothed over a window of 1 cm\(^{-1}\) to represent the convolution of the transmission features with the ~1 cm\(^{-1}\) linewidth of the ECQCL, which has been broadened due to the inherent chirp associated with operation in pulsed mode.

Figure 3. (a) FTIR spectra of ECQCL operating in pulsed mode at various grating positions. (b) Pulsed ECQCL spectroscopy of methane (CH\(_4\)) compared to HITRAN simulation.

In summary, work on the design, implementation, and characterization of external cavity quantum cascade lasers for spectroscopic applications is presented. We address the performance characteristics of the ECQCL for broad scan and fine scan spectroscopic applications, attempting in particular to eliminate the mode-hopping behavior that significantly affects continuous-wave operation.

References