Widely tunable external cavity quantum cascade lasers for high resolution spectroscopy and chemical sensing

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The development of laser spectroscopic techniques strongly relies on increasing the availability of new tunable laser sources. Quantum cascade lasers (QCLs) have proved to be robust light spectroscopic sources for mid-infrared (mid-IR) spectroscopic applications.[1] QCLs have recently made significant advances as effective mid-infrared spectroscopic sources for trace gas detection. Continuous wave, room-temperature QCL devices have been demonstrated and are now available for applications that require compact, high power (>50 mW), liquid-nitrogen free, mid-infrared spectroscopic sources.[2] This feature makes them suitable for applications which require compact, sensitive, thermoelectrically cooled spectroscopic sources. The wavelength tunability of DFB-QCL relies on thermal tuning of the refractive index by temperature or an injection current variation, which limits the frequency coverage to ~ 10 ÷ 20 cm^{-1}. Therefore DFB-QCLs are typically designed for operation at a single target frequency with a practical tuning range of few wavenumbers (cm^{-1}) and are usually used in trace gas detection and quantification of small molecules with narrow, resolved ro-vibrational lines. Such applications can also be addressed by using an external cavity configuration QCLs (EC-QCLs) with mode-hop free tuning.[3] The EC-QCL sources have an important advantage over DFB-QCLs, which is broadband wavelength tunability. The gain characteristics of QCL can provide sufficient amplification to achieve laser action over a much broader spectral range. Several specific QCL designs have addressed the issue of further broadening of the QCL gain curve that include: 1) a bound-to-continuum QCL design first proposed by Faist[4] and further developed for EC-QCL applications by Maulini et. al.[5] and 2) a heterogeneous QC structure first demonstrated by Gmachl et al.[6] A luminescence spectrum of 350 cm^{-1} and a pulsed EC-QCL tuning of 265 cm^{-1} were recently achieved by combining both concepts a heterogeneous quantum cascade active region structure based on two bound-to-continuum designs emitting at 8.4 and 9.6 μm.[7]

This presentation will describe recent progress in the development of room temperature, continuous wave, widely tunable mid-infrared EC-QCL spectroscopic sources that employ broadband QC gain chips at 5.3 μm [Ref. 5] and 8.5 μm [Ref. 2] and a piezo-activated cavity mode tracking system for mode hop free wavelength tuning. This technology is particularly suitable for high resolution spectroscopic applications of broadband molecular absorbers and multi species trace-gas detection. A single mode tuning range of 155 cm^{-1} and 135 cm^{-1} was achieved for 5.3 μm and 8.5 μm EC-QCL respectively. Several examples of QCL applications that are currently being investigated by our group will be reported. These include high resolution spectral measurements of small molecules such as Nitric Oxide (NO) at reduced pressures and the detection of broadband absorbing species with unresolved rotational structure (such as acetone, Freon 125, and ethanol) using quartz enhanced photoacoustic spectroscopy (QEPAS).[8]

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