BROADBAND MID-INFRARED QUANTUM CASCADE LASERS FOR SPECTROSCOPIC APPLICATIONS IN EXTERNAL CAVITY

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Abstract

In recent years, the prevalence of lasers in electronic devices has skyrocketed. Everything from a computer mouse to data communications to spectroscopy applications is based on the ability to coherently control the emission of light. Quantum cascade lasers are unique semiconductor devices based on intersubband transitions that allow for lasing from the mid-infrared to the terahertz regime. This property, termed wavelength agility, can be achieved because the laser emission frequency is determined by a sequence of quantum wells and barriers; vastly different emission energies can be accessed by changing the number, thickness, and order of the semiconductor layers. Additionally, the lasers can be designed with a broadband gain structure. When such lasers are operated in a grating tuned external cavity, the single mode laser output can be tuned over several hundred wavenumbers.

These features of the quantum cascade laser, together with their small size (∼mm), make it ideal for spectroscopy in the mid-infrared regime. Between \( \lambda = 3 - 12 \, \mu \text{m} \) there are two atmospherically transparent regions, termed the first and second atmospheric windows, where many small molecules have characteristic absorption features. Some prominent examples are greenhouse gases including CO\(_2\), CO, N\(_2\)O, and CH\(_4\). The ability to tune the emission of a quantum cascade laser makes it possible to simultaneously detect different molecules in compound liquids and gases.
Accessing the full gain bandwidth of the quantum cascade laser makes it a versatile source for spectroscopic applications. Applying anti-reflection and high-reflectivity coatings to the laser facets will modify both its electrical and optical behavior, improving its wavelength agility. Anti-reflection coatings with reflectivities \( \leq 1 \% \) over bandwidths of several hundred wavenumbers are designed and fabricated, as well as dielectric reflective coatings ranging from partial coatings \((R = 65\%)\) to nearly perfect mirrors \((R = 98\%)\).

Quantum cascade lasers also have several features that allow the design of very broad gain bandwidth laser structures. These features are discussed and implemented in a new design for the wavelength range spanning 3 – 4 \( \mu \text{m} \). When combined with the anti- and high-reflection coatings discussed above, such devices in an external cavity featured tuning ranges of over 500 cm\(^{-1}\) in pulsed mode.

Finally, the superluminescent behavior of quantum cascade lasers is studied. When a quantum cascade laser is prevented from reaching its lasing threshold by high cavity mirror losses, the device emits superluminescent light with a high degree of spatial coherence (due to the device’s waveguide geometry), while maintaining low temporal coherence (characteristic of amplified spontaneous emission). Peak powers of 38 \( \mu \text{W} \) at 10 \% duty cycle were achieved, which is three orders of magnitude higher than the blackbody radiation of a globar of comparable size, temperature, and spectral range. The combination of these features make quantum cascade superluminescent diodes very attractive for optical coherence tomography and mid-infrared microscopy.

Such devices, fabricated with anti-reflection coatings on both cavity mirrors, can also serve as amplifiers for frequency combs.
Zusammenfassung


Diese Merkmale der Quantenkaskadenlaser, zusammen mit der geringen Grösse, machen sie zur idealen Lichtquelle für kompakte Spektroskopiesysteme. Zwischen $\lambda = 3 – 12 \, \mu m$ gibt es zwei atmosphärisch transparente Bereiche, in denen viele kleine Moleküle charakteristische Absorptionslinien aufweisen. Einige prominente Beispiele sind Treibhausgase, einschließlich CO$_2$, CO, N$_2$O, and CH$_4$. Die Fähigkeit, die Emissi-

Quantenkaskadenlaser haben einige Eigenschaften, die die Herstellung von Laser mit breitbandigem Verstärkungsbereich ermöglichen. Diese Eigenschaften werden anhand einer Struktur im Wellenlängenbereich von 3 bis 4 $\mu$m besprochen. Laser, die auf dieser Struktur basieren, wurden in einer externen Kavität betrieben und konnten im gepulsten Betrieb über einen Bereich von mehr als 500 cm$^{-1}$ einmodig abgestimmt werden.