INTRODUCTION

The quantum cascade laser technology, based on intersubband transitions in quantum wells, has the potential to make cheap, room temperature, powerful optical sources across the mid infrared and terahertz portion of the optical spectrum.

The key goal of this project is to develop a quantum cascade laser technology platform for both fabrication and use in sensing or telecommunication applications. Progress should be made on three fronts simultaneously: performances, new cutting edge concepts, and physical understanding.

RESEARCH OBJECTIVES

Tuning capabilities of mid-Infrared QC Lasers

In the mid-infrared spectral region, where continuous wave room temperature operation of the QCL devices was achieved in the previous phase of the program, the main goal will be to further broaden the frequency range over which these high performances are achieved. Another important topic is the fabrication of devices with a very large frequency tuning capability, which will enable the spectroscopy of multi-component gases, solids, or liquids.

An exciting new result is the achievement of large broadband tuning of such a device, based on the monolithic stacking of two broadband active regions, with a tuning range of over more than 250 cm\(^{-1}\) for a laser emission centered at about 1000 cm\(^{-1}\). As shown in the figure below, the tuning range in pulsed operation goes from about 8.2 to 10.4 µm. Tuning over 10% of the central wavelength (7.96-8.84 µm) was possible with the laser chip in continuous-wave (CW) operation at room temperature, with a side-mode suppression ratio (SMSR) > 30dB. It is worth noting that the tuning range observed is the largest ever demonstrated at these wavelengths in CW.

THz lasers: higher operating temperatures and longer wavelengths.

Terahertz radiation has acquired an increasing interest in the last decade due to its use in spectroscopy, astrophysics, and imaging techniques namely for biomedical applications. Because of its low interference and non-ionizing characteristics, terahertz imaging is expected to be a powerful technique for safe, in vivo medical imaging, where the use of longer wavelength allows a deeper penetration in the investigated material.
However, the overall level of performance of the THz QCL’s is much lower than in the mid-infrared spectral region. The world record for maximum operating temperature is still 160 K and the maximum wavelength of emission is 180 µm (1.7 THz).

Therefore, the project will concentrate more on fundamental issues in order to ultimately achieve devices emitting over a wide range of frequencies and operating on a thermoelectric cooler. The research is then focussed on finding new solutions for the optical laser cavity and for the gain medium. New exciting results include the demonstration of laser action at 1.2 THz which corresponds to a wavelength of 250 µm. Starting from an initial structure that targeted an emission frequency of 1.8 THz, the laser design was progressively rescaled (and regrown) in order to adapt the lasing wavelength to respectively 1.6, 1.4 and 1.2 THz. The three grown structures showed laser action at the targeted frequencies, settling a new world record in long wavelength lasing from a QCL structure.

On the photonic side, the efforts have been focussed on the realization of waveguides and resonators based on surface plasmons by sandwiching the laser gain material between two metallic layers. The large impedance mismatch between the waveguide core and the vacuum can be exploited to tightly confine the optical mode. A series of THz QCL circular microcavities emitting at 3.5 THz have been realized. Extremely low threshold currents as low as 8 mA were obtained with these devices that showed laser action on a single mode. Such small QCLs may represent a very interesting solution to obtain a compact, low consumption THz source for spectroscopic applications. The double metal concept can be combined with active region patterning in order to obtain photonic confinement in the three directions. A photonic crystal vertical emitting structure based on a triangular photonic lattice has been realized, by etching deep holes in the semiconductor material through metallic apertures. These structures showed laser emission from the top surface at 72 µm wavelength up to a temperature of 120 K, with threshold currents significantly lower than the ridge waveguide QCLs based on the same active material.

**APPLICATION PERSPECTIVES**

The capability to tailor the emission wavelength in order to target specific chemical species make Mid-IR QCL’s the source of choice for infrared spectroscopy.