# Sub-THz Multi-Wavelength Emission in Quantum Cascade Lasers

A. Wade, G. Fedorov, D. Smirnov (NHMFL), S. Kumar, B.S Williams, Q. Hu (MIT)

## Introduction

The first THz Quantum Cascade Laser (QCL), emitting at 4.4 THz, was first reported in 2002. After only a few years after their invention, THz QCLs are able now to cover the spectral range from 5 THz down to 1.2 THz [1]. Further progress towards the implementation of sub-THz QCLs is a very challenging task because of the small energies of THz photons (1 THz ~ 4 meV). Strong magnetic field applied parallel to the confinement direction of the QCL structure (B⊥2DEG), breaks the energy spectrum into a ladder of discrete Landau levels (LLs) separated by a cyclotron energy, and finally allows to achieve lasing between quasi-zero dimensional LL states [2].

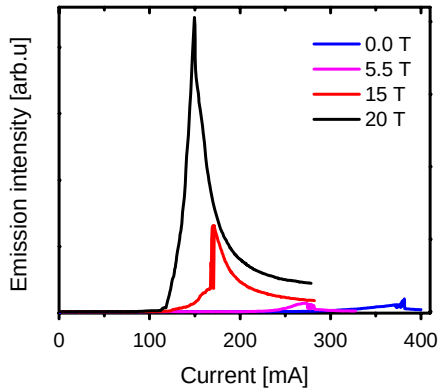


Figure 1. Light-current characteristics at different magnetic fields. At 20T, the QCL emits strong sub-THz radiation.

## Experimental

The samples studied are two GaAs/$Al_{0.15}Ga_{0.85}As$ THz QCLs, similar to that in Ref.[3]. The structures designed to emit at ~3 THz (~12.4 meV) utilize LO-phonon scattering for fast depopulation of the lower state of the laser transition. The QCLs were measured in 31 T DC magnets. Measurements were performed from liquid helium temperatures to 300 K with a current pulser. The pulse width was ~1 μs with a repetition frequency up to 3 kHz. The light was monitored using a fast spreadfield magnetically enhanced InSb hot electron bolometer. Spectra were taken with a Bruker 66 spectrometer.

## Results and Discussion

At zero magnetic field, the QCLs exhibits laser action at ~3 THz. As an external magnetic field is applied, the QCLs behave similarly save for a decrease in the current threshold. Above 15 T and within a range of fields and bias, the laser emission dramatically increases (Fig.1). At these fields the lasers show strong multi-mode emission around 1THz (Fig.2). By applying the appropriate bias and magnetic field, one can achieve laser emission from a single device in a wide range of frequencies: 3.27 to 2.61 and 1.9 to 0.68 THz. To explain observed extremely strong and wide THz emission, we propose a mechanism that includes multiple radiative transitions between different LLs and resonantly enhanced depopulation of the lower state of the laser transition.

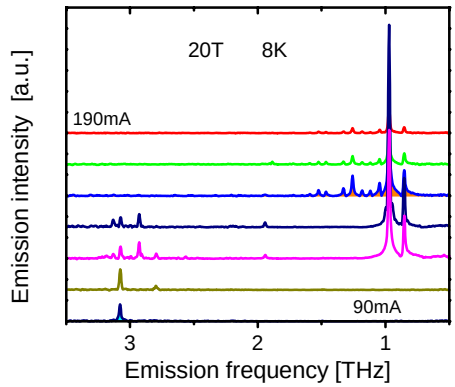


Figure 2. Emission spectra measured at 20T at different currents between 90 mA and 190 mA.

## Conclusions

We observed strong, magnetic field-induced sub-THz radiation from QCLs. These results demonstrate that a magnetic field offers the unprecedented possibility to control the QCL emission frequency.

## Acknowledgements

We gratefully acknowledge support from NHMFL In House Research Program (project 5053).

## References

[1] Williams, B. S. , Nature Photonics, **1**, 517 (2007).
[2] Smirnov, D., *et al*., Phys. Rev. B, **66,** 121305 (2002).
[3] Williams, B. S., *et al*., Applied Physics Letters **83**, 2124 (2003).