School of Electrical and Electronic Engineering
FACULTY OF ENGINEERING

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Integrated THz quantum-cascade lasers for atmospheric radiometry

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Overview

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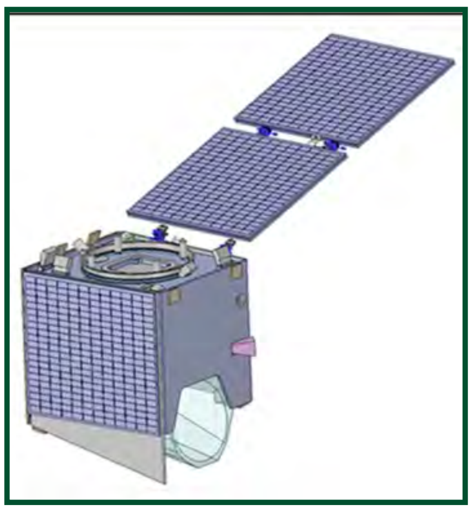
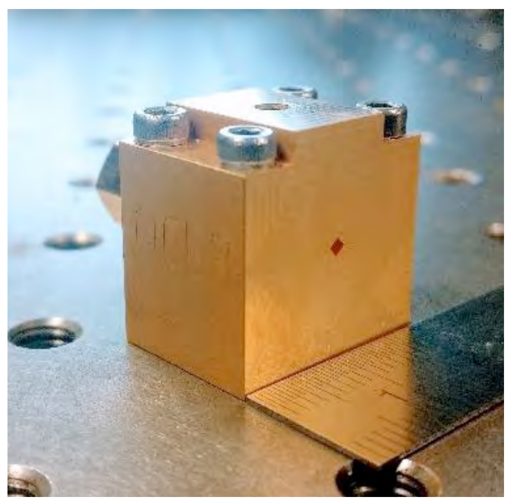
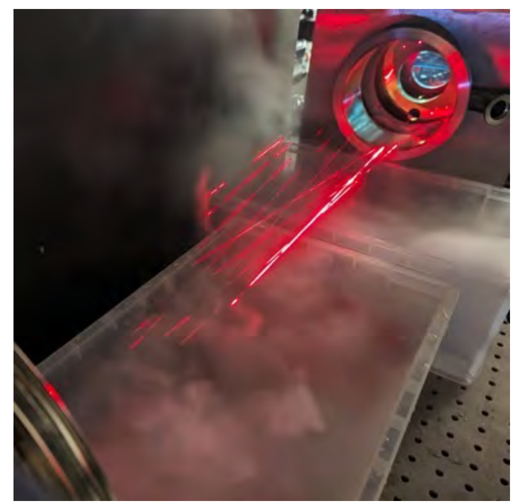
- Terahertz (THz) atmospheric & space research
- Waveguide integrated THz QCLs
- Gas spectroscopy applications







THz gas spectroscopy

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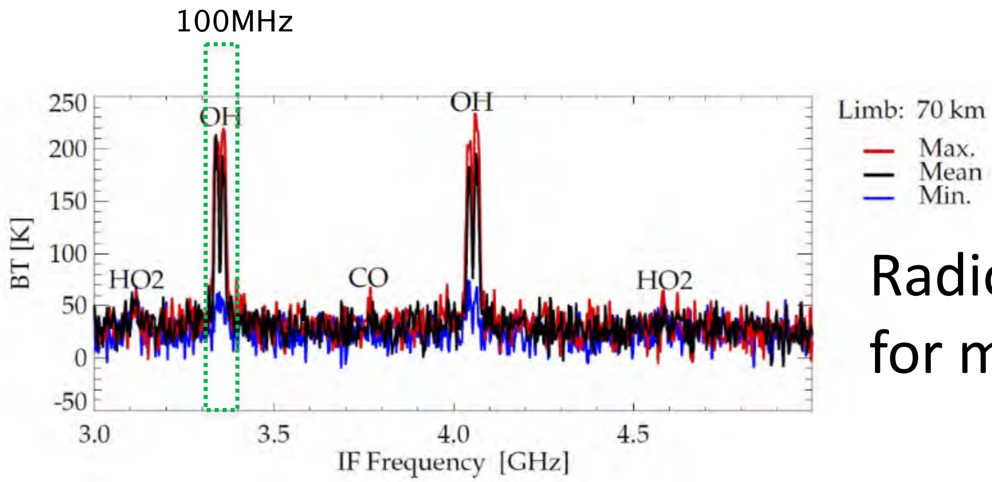
Spectral "fingerprints" of several important atmospheric gases lie in THz band



Radiometric retrieval simulations for mesosphere at ~3.5 THz

QCLs!

Band	Centre ν (THz)	Primary target species	Secondary target species
1	4.7	O	O_3
2	3.5	OH	CO, HO_2
3	**2.0**	**O**	**NO, O_3**
4	1.15	NO	O_3
5	0.8	O_2	O_3

THz quantum-cascade lasers

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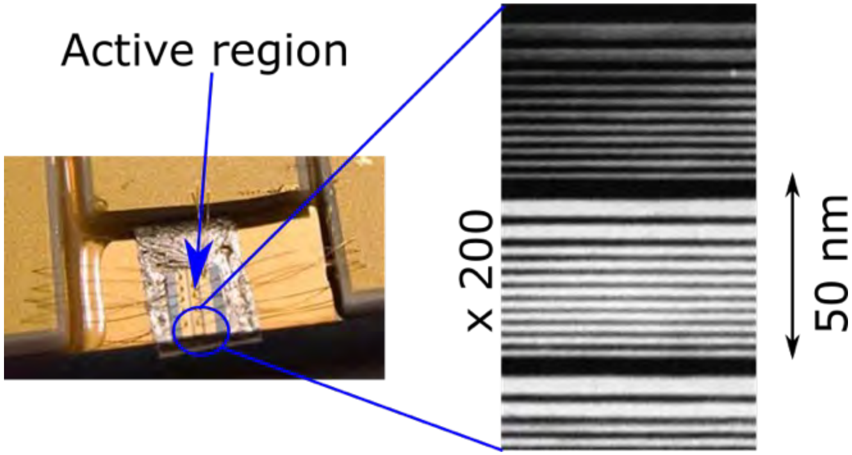
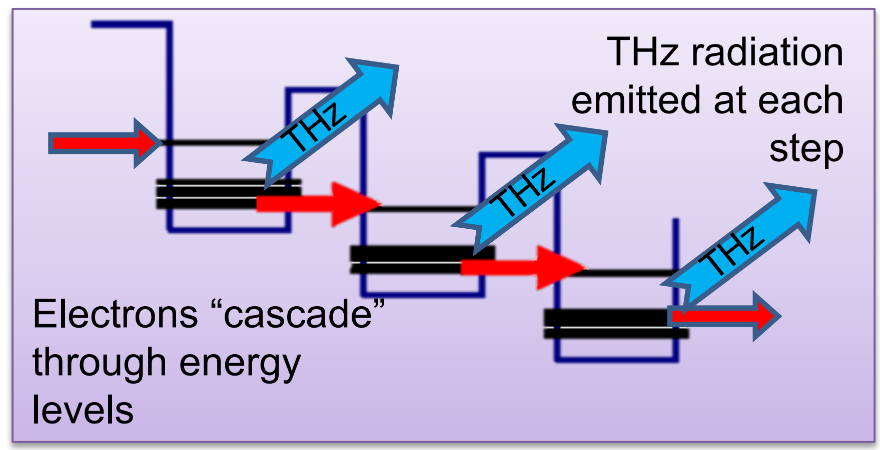
Epitaxially-grown GaAs/AlGaAs heterostructures within plasmonic waveguides





"Electron-recycling" process yields > 1 mW continuous-wave power in ~2-5 THz band

Integrated THz QCLs for satellite applications

Motivation: Satellite applications

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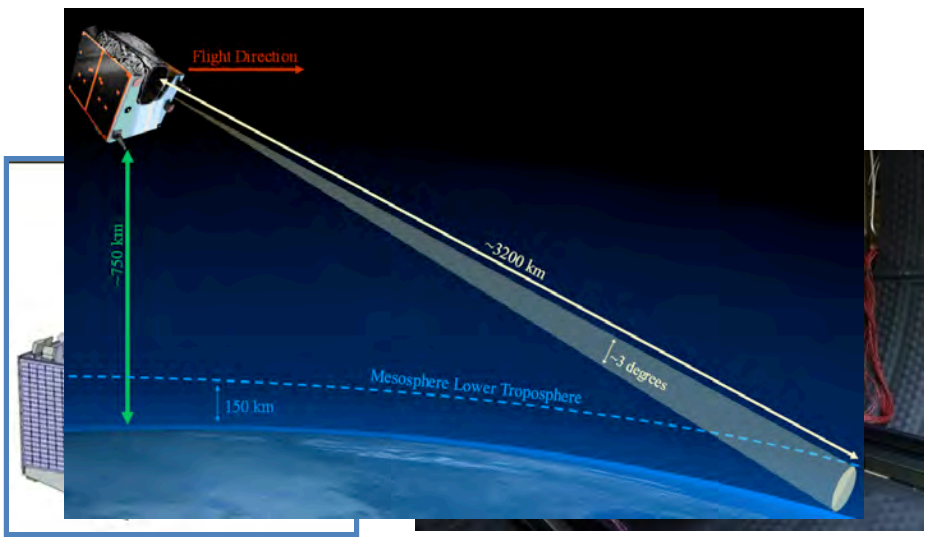
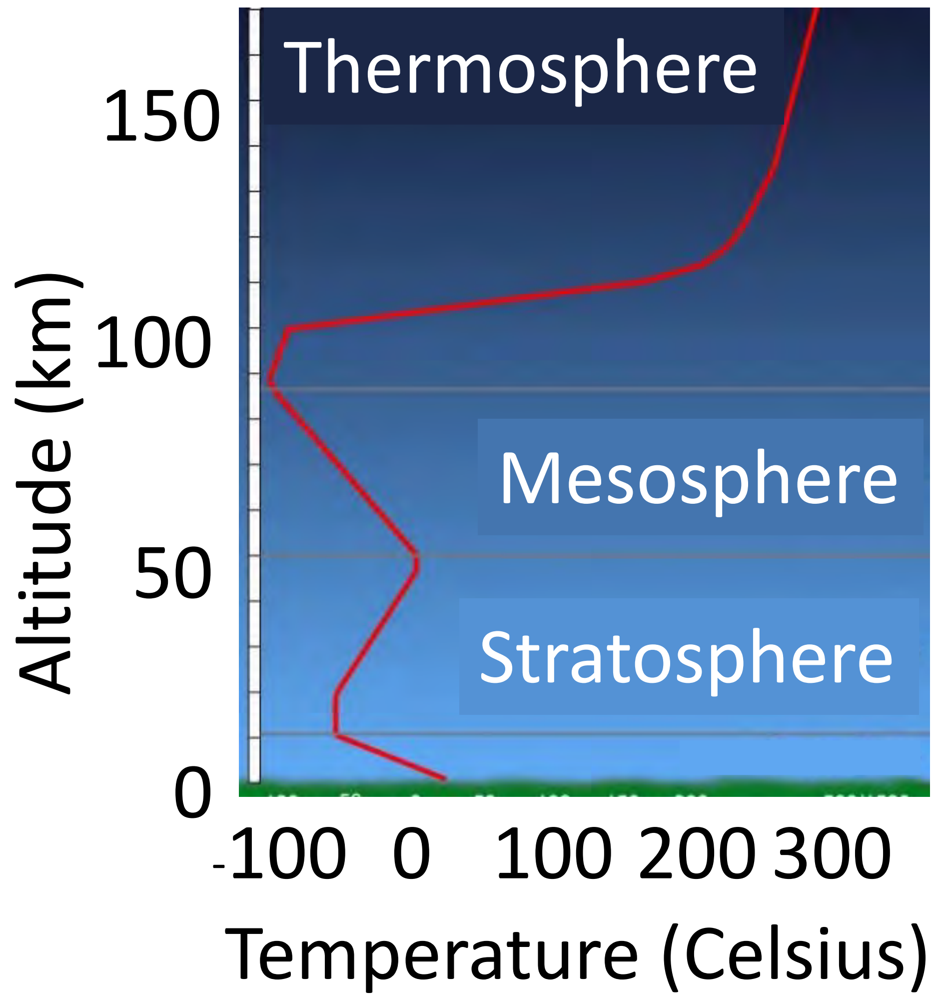
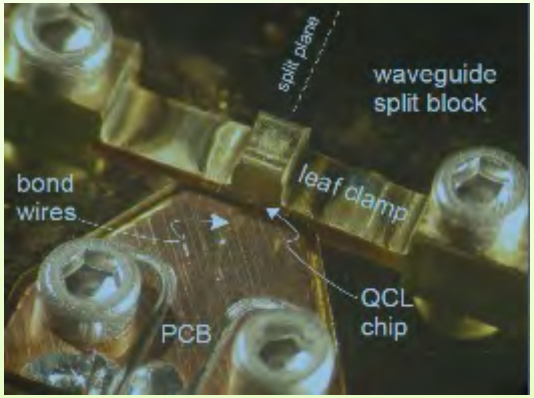
"Linking observations of climate, the upper atmosphere and space weather"



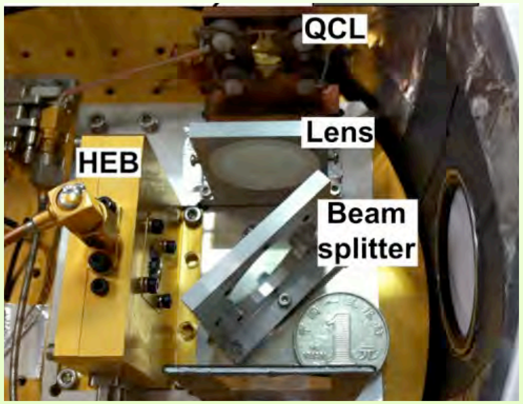


QCL integration approaches



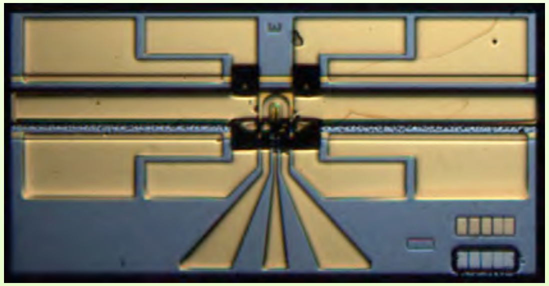
QCL
+ waveguide
+ horn antenna

Justen et al., 26th Int. Symp. Space THz Tech (2015)



QCL
+ HEB mixer

Miao et al., *Opt. Express* **23**, 4453 (2015)



QCL
+ Schottky mixer (monolithic)

Wanke et al., *Nat. Photon.* **4**, 565 (2010)

Keystone integration design

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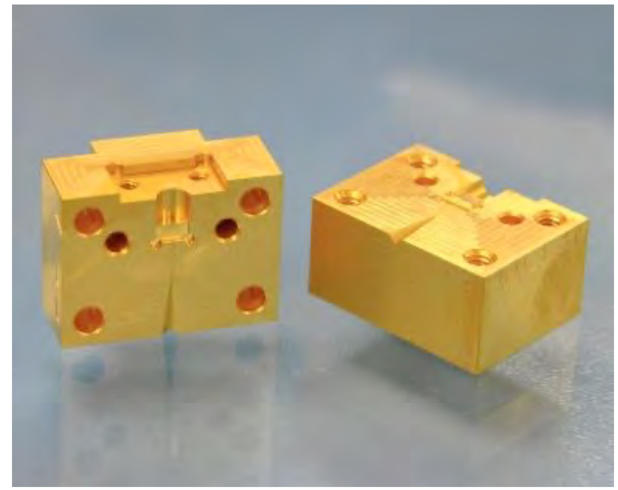
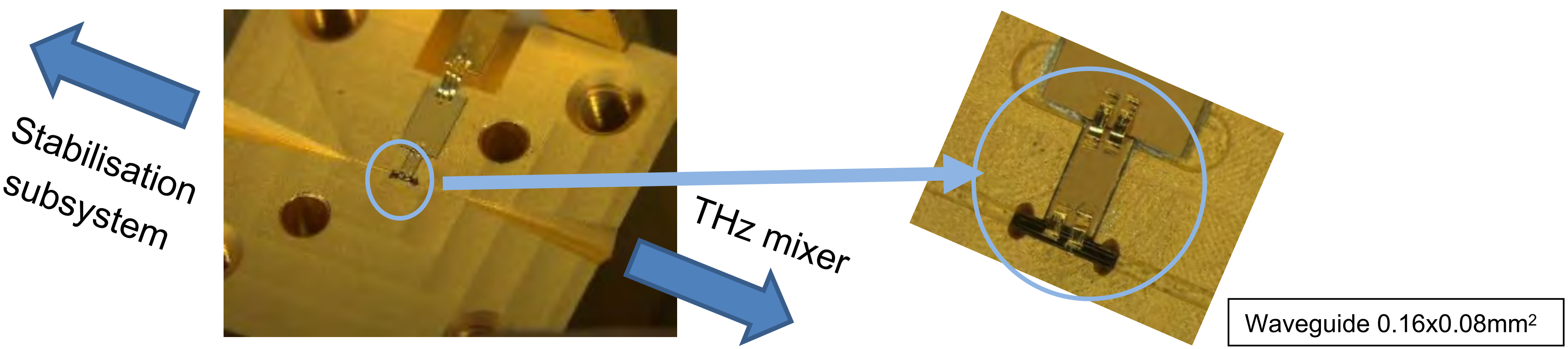
2.0-4.9 THz QCLs integrated within precision micromachined waveguides





QCL frequency-selection design

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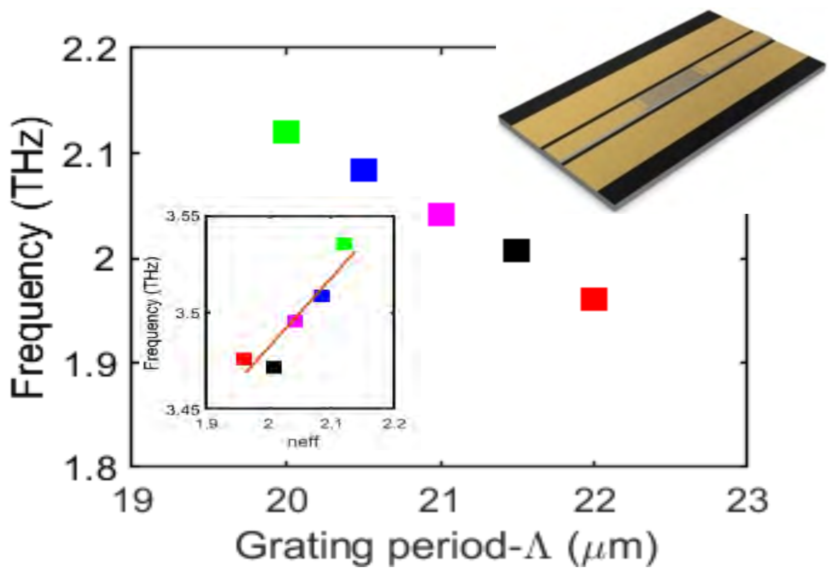

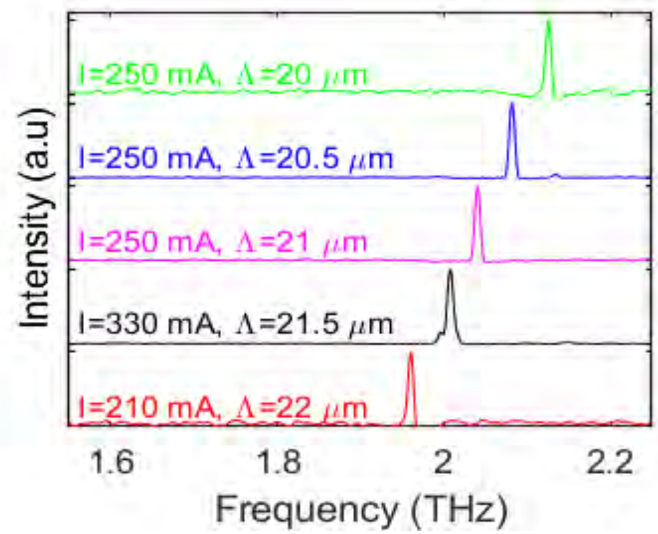

Phase matching condition: $k_i - nk_g = -k_i$

$k_i = 2\pi n_{\text{eff}}/\lambda$ wave vector of the incident beam

$k_g = 2\pi/\Lambda$ grating wave vector

Using 1st order, the phase matching condition can be simplified to: $n\lambda = 2n_{\text{eff}}\Lambda$

IEEE-standard waveguides

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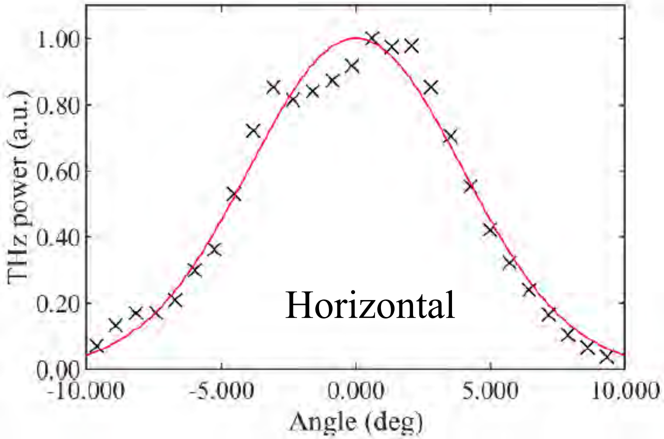
IEEE Std. 1781.1-2012 for metallic rectangular waveguides

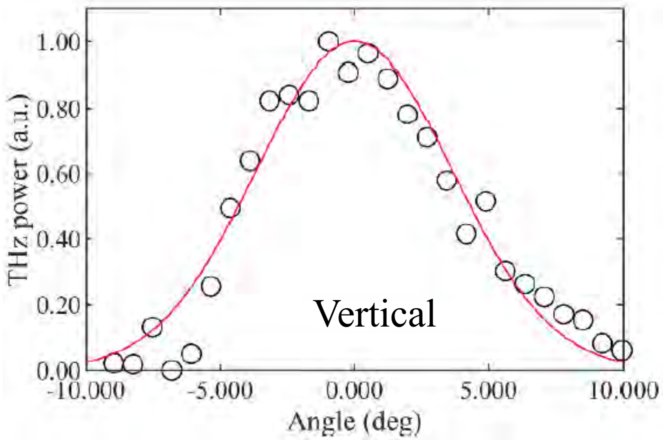
$$f_c = \frac{c}{\sqrt{\varepsilon_r}} \times \frac{1}{2a}$$

WM-130 waveguide (130 × 65) μm^2 is the optimal choice for fundamental 1.4–2.2 THz waveguides.

Ideal divergence: $\theta = \frac{0.88\lambda}{a} \times \frac{180^o}{\pi} = 7°$

Measured: 9° (both axes)





Cryocooler integration

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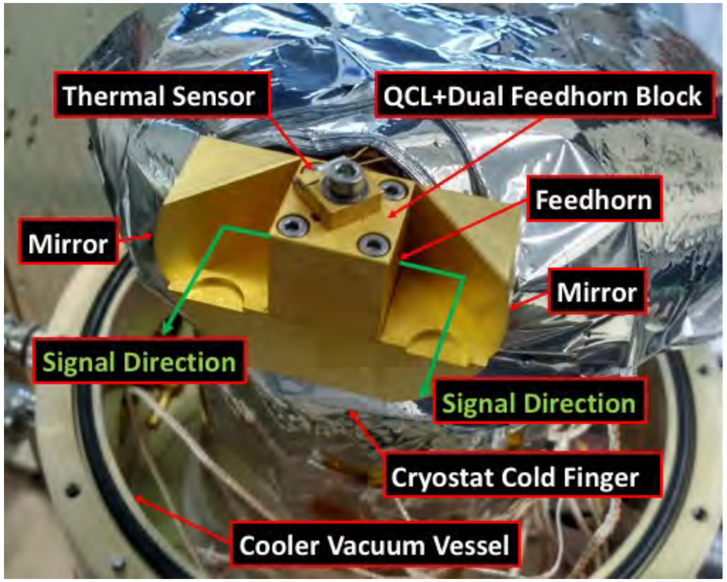

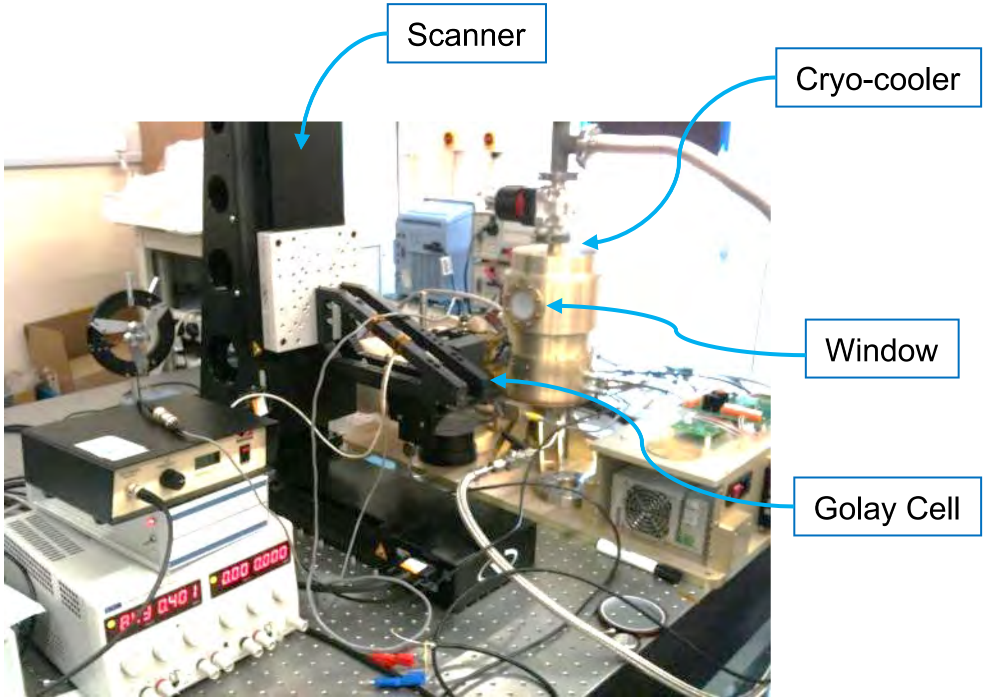

Operation within space-qualified Stirling cryocooler system

Power-locking techniques

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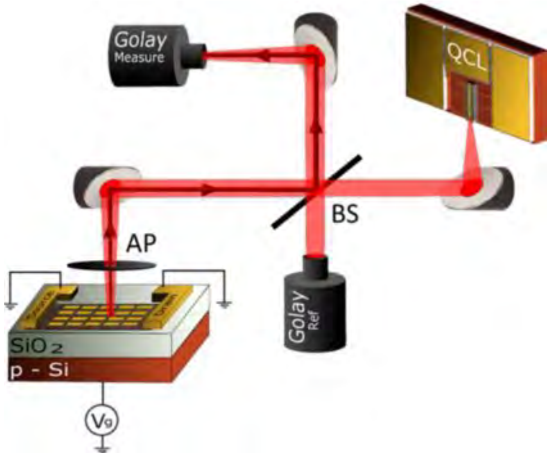
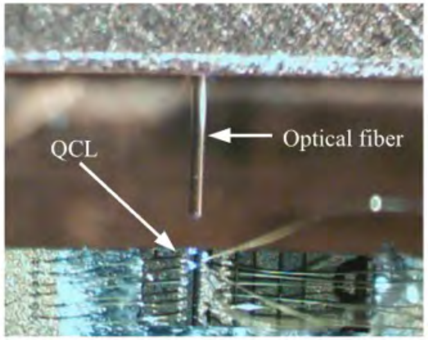
Voice-coil actuators
APL **101**, 101111 (2012)



Graphene/split-ring-resonator array
ACS Photon. **3**, 464 (2016)



Near-IR laser excitation
Opt. Express **27**, 36846 (2019)

Integrated photonic circuit approach

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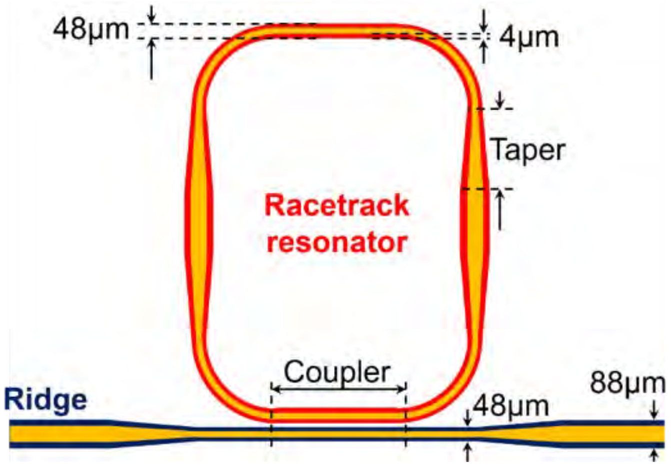
Racetrack resonator provides integrated power adjustment

Potentially very fast tuning (GHz?)

No external modulator needed!



Kundu et al., Opt. Express **28**, 4374 (2020)

Power control via RTR

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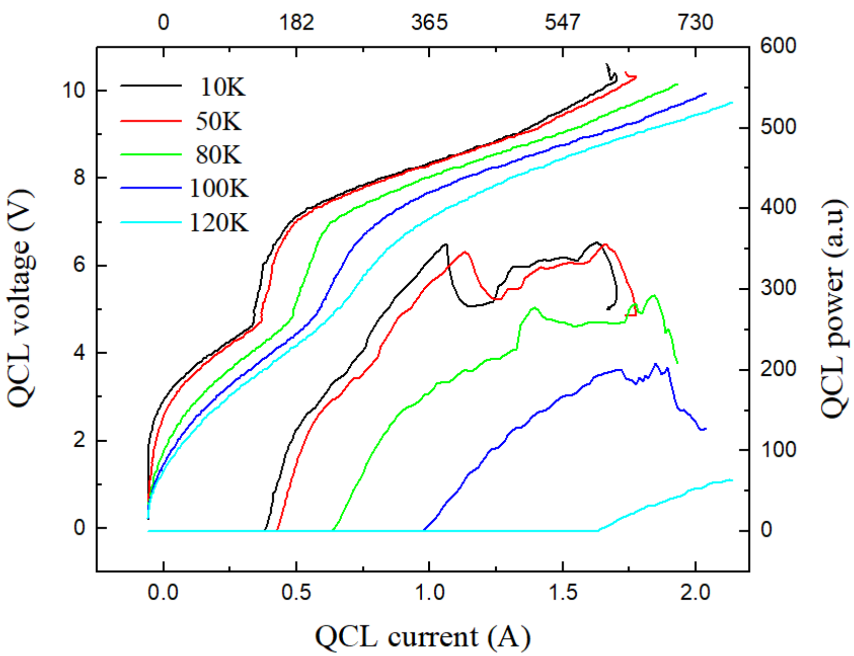

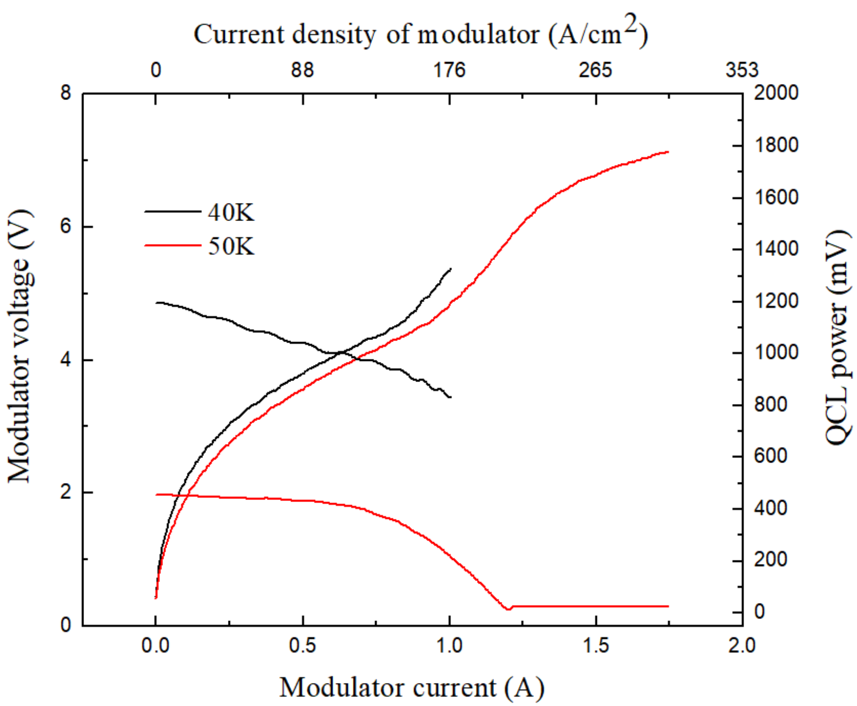

The QCL lases at **0.5 A threshold; peak emission at 1.30 A**

The output **power decreases** as RTR current increases

QCL Power locking

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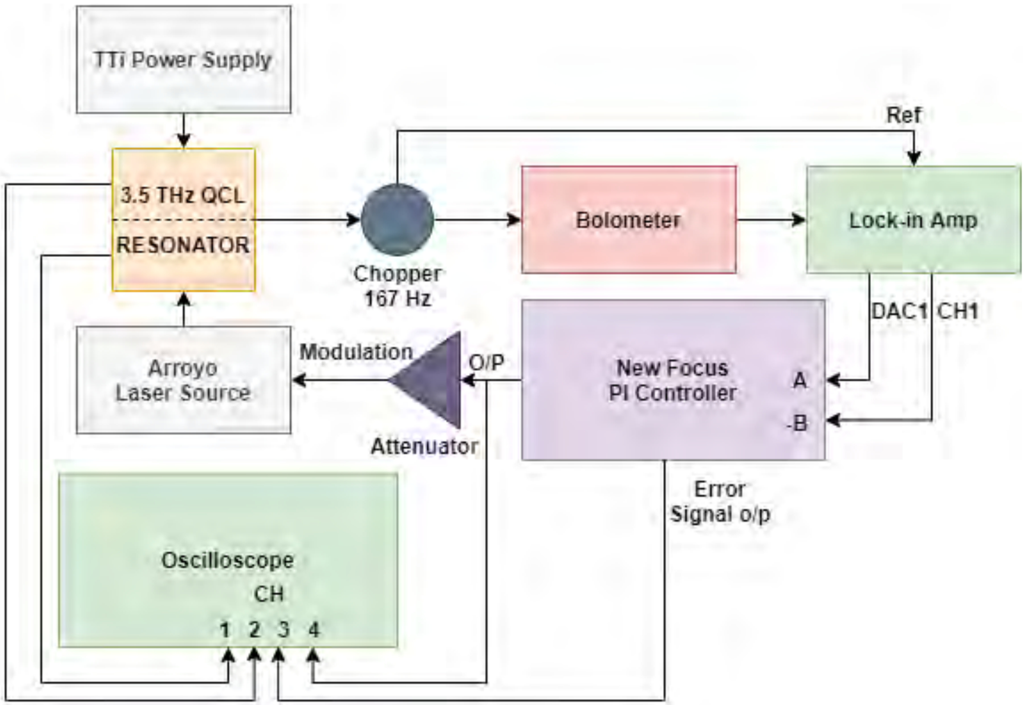

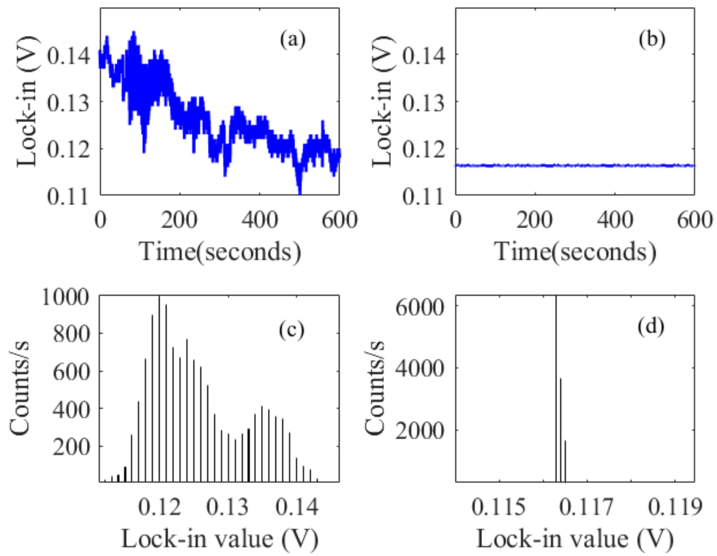

Set point at 0.116V with a **time constant** set of **50ms**. Proportional gain is set at **2**

The output was **power-locked** for **623 seconds** at 40K temperature

Waveguide Integrated QCL+ RTR

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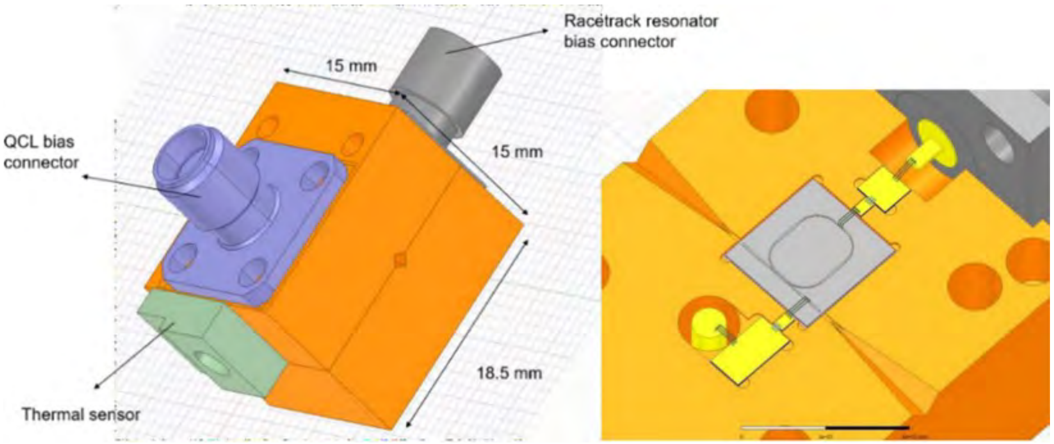

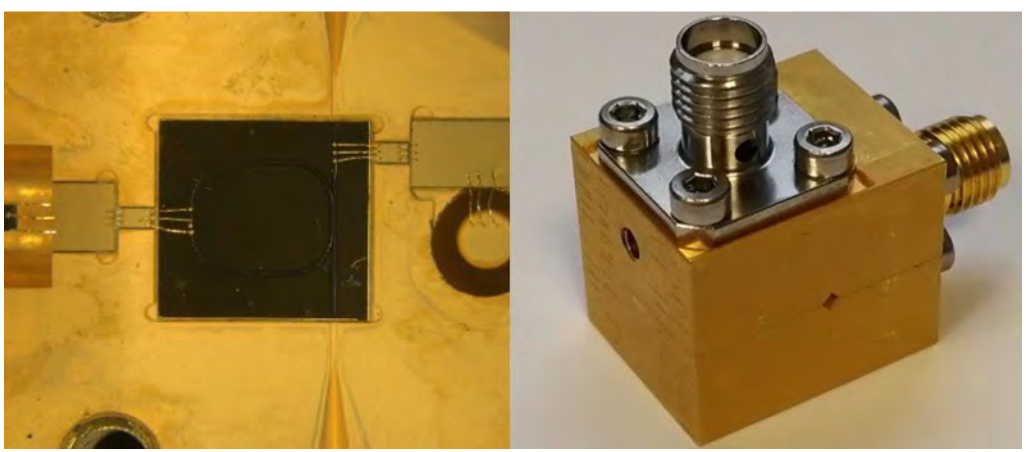

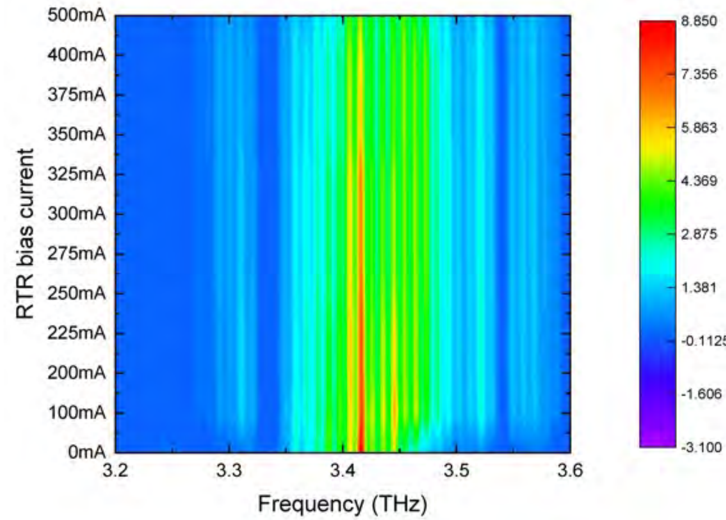

QCL bias 1200 mA (peak value)

RTR bias varies

Gas spectroscopy applications using THz QCLs and antenna-coupled FET detectors

Real-time spectroscopy

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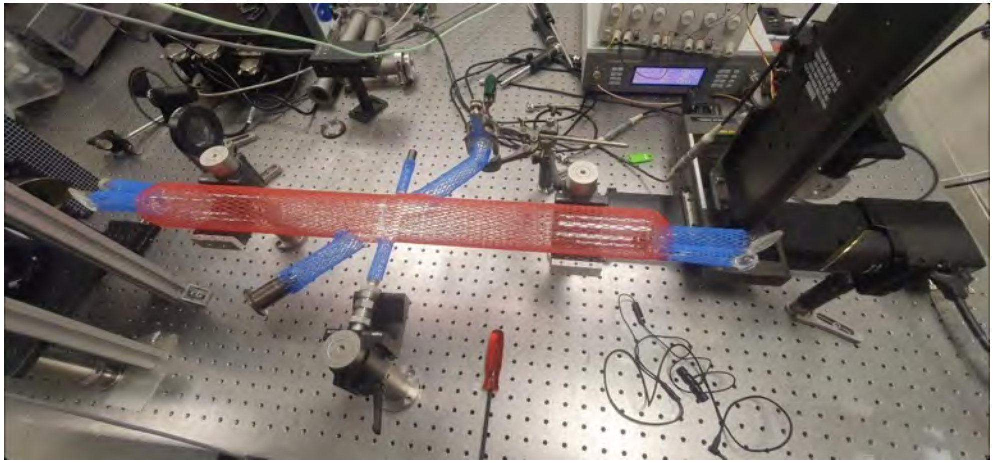
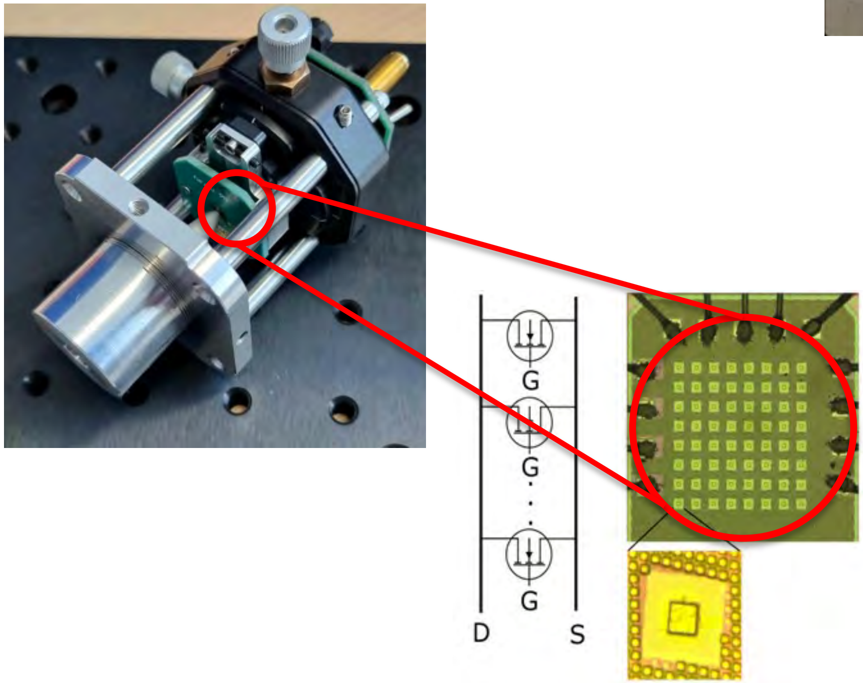
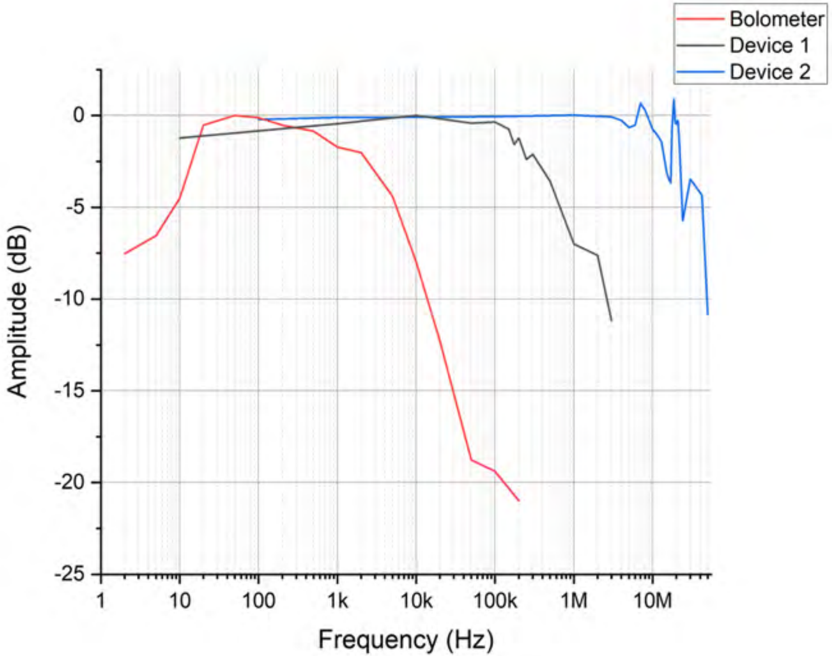
Antenna-coupled
FET detectors:
>10 MHz bandwidth







Real-time spectroscopy

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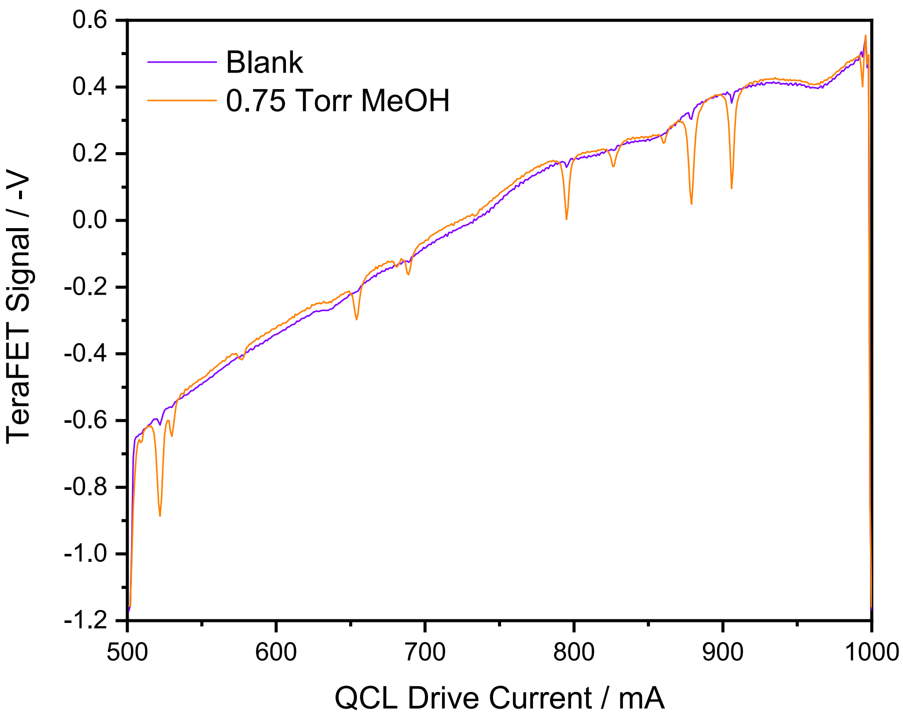
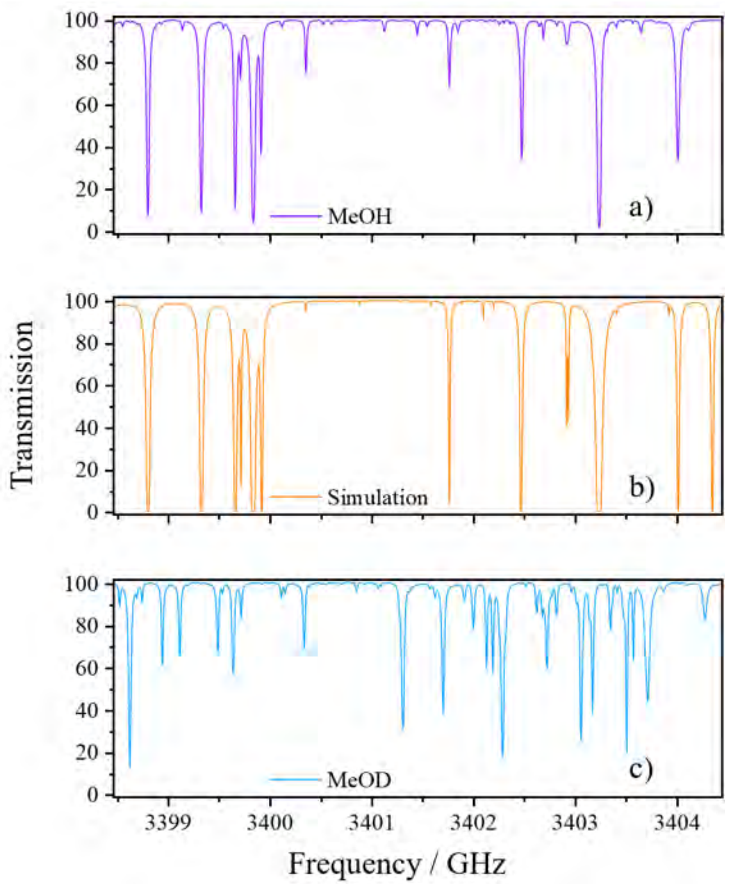
Real-time scanning across full QCL bandwidth





Rapid-scan FTIR

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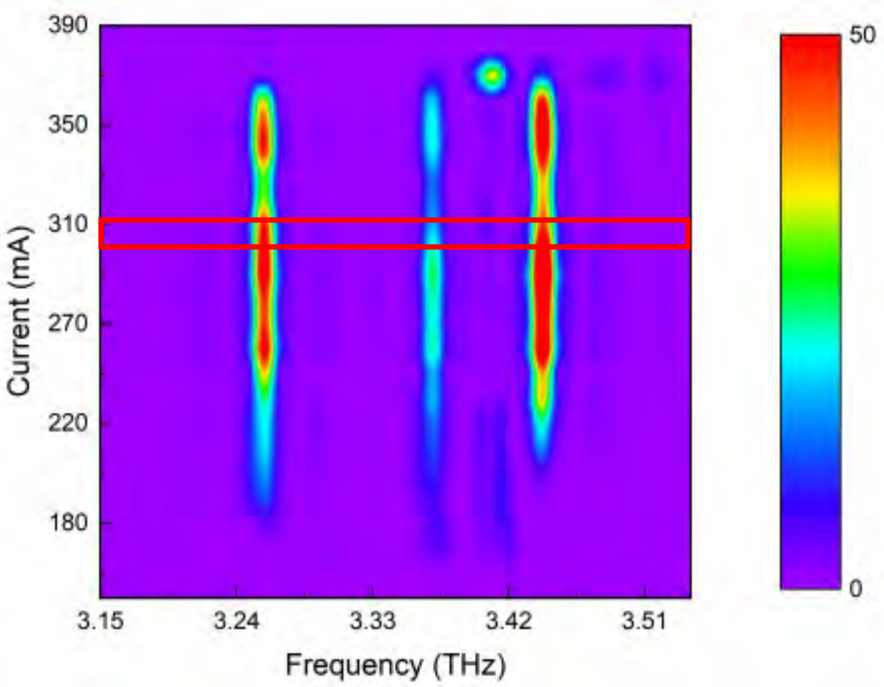
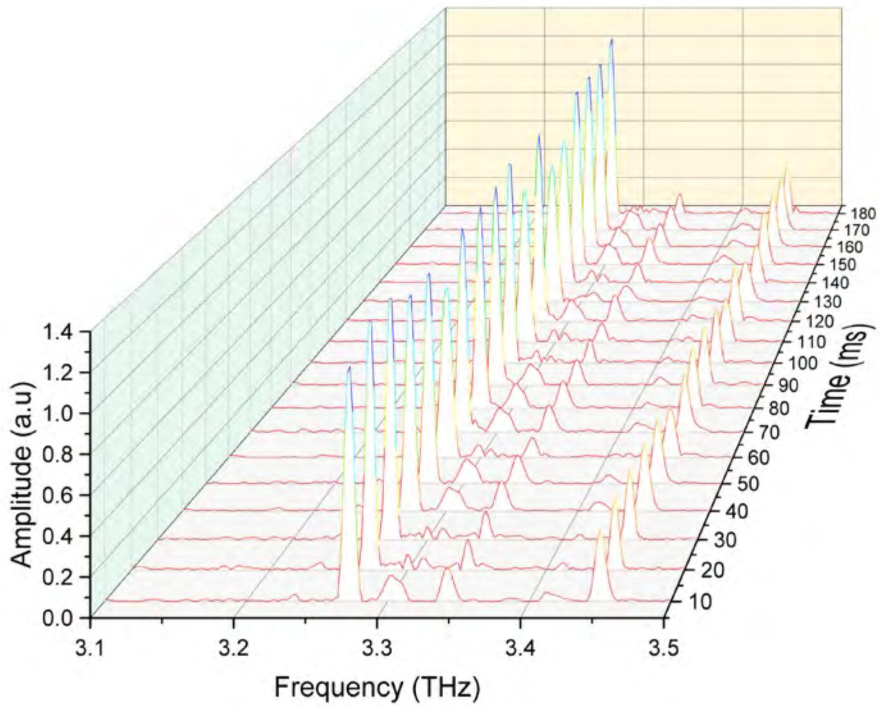
FTIR measurements at 10-ms resolution





Next steps…

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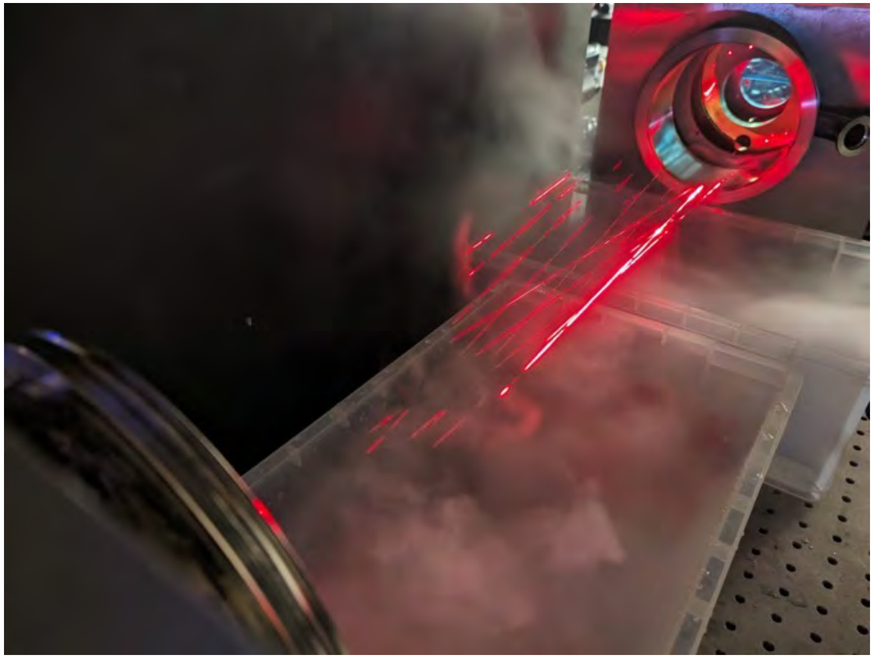
Herriot cell for multi-pass photochemistry



Summary

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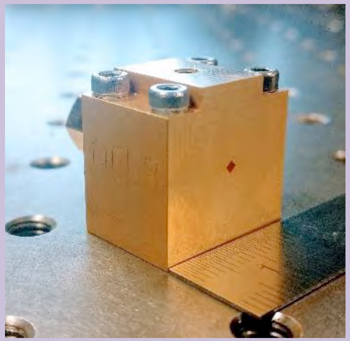
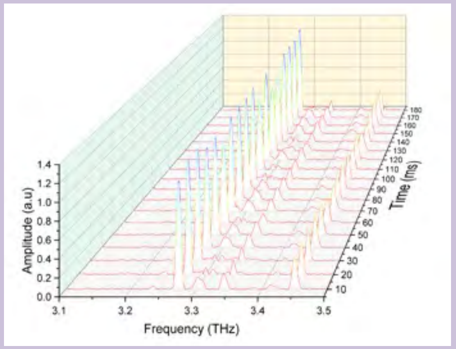
Integrated THz devices



Real-time gas sensing



Multi-pass capability (soon!)

Postgraduate study opportunities available!

PDRA positions coming soon…

Acknowledgments

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- Centre for Earth Observation Instrumentation & UKSA
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CEOI

UK SPACE AGENCY

DFG Deutsche Forschungsgemeinschaft

Colleagues and collaborators

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- Goethe University Frankfurt: J. Holstein, A. Krysl, F. Ludwig, A. Lisauskas, H. Roskos

RAL Space

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