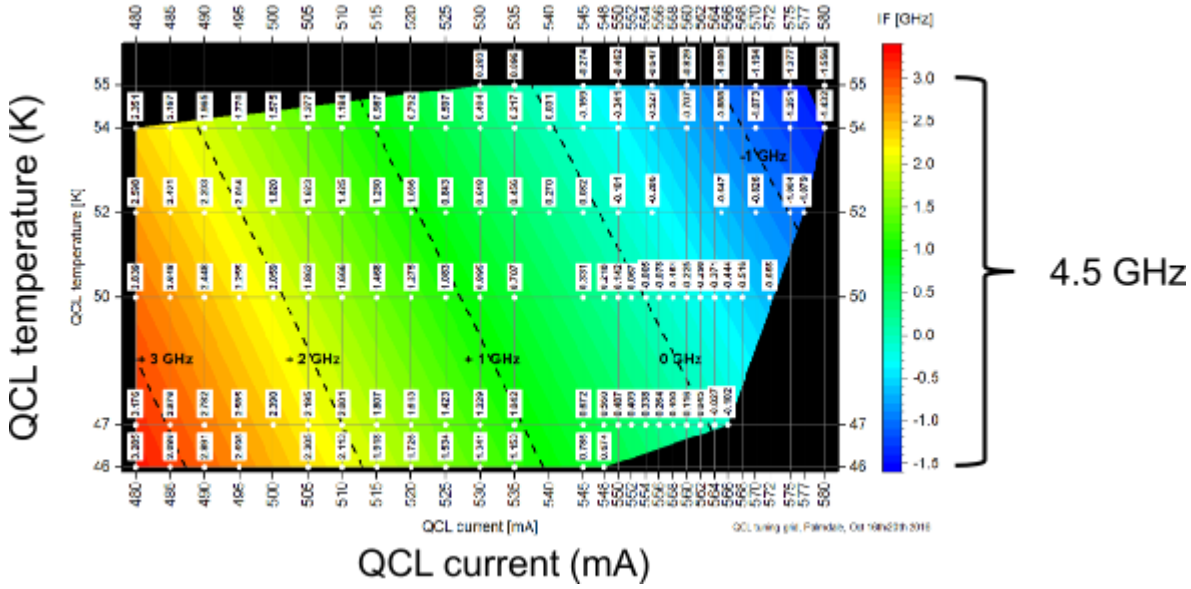
HIGH-POWER MICRO-OPTICAL BENCH TERAHERTZ QUANTUM-CASCADE LASER

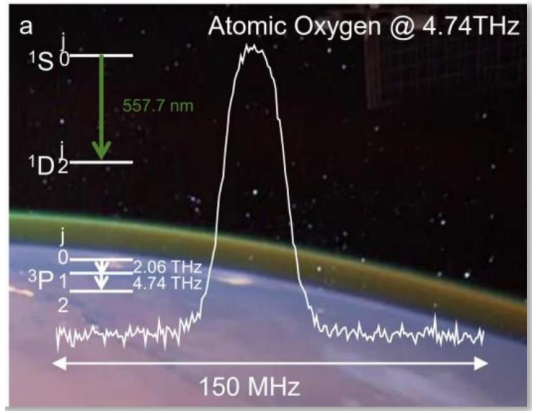
R. Voigt[1,2], M. Wienold[1], H.-W. Hübers[1,2], L. Schrottke[3], K. Biermann[3], X. Lü[3], V. Pistore[3], A. Sahm[4], K. Paschke[4]

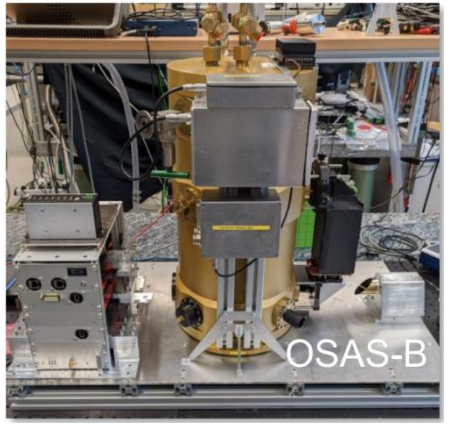
[1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany
[2] Humboldt-Universität zu Berlin, Department of Physics, Newtonstr. 15, 12489 Berlin, Germany
[3] Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e. V., Hausvogteiplatz 5–7, 10117 Berlin, Germany
[4] Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

THz absorption spectroscopy with QCLs

- Transmission measurements of molecular gases as function of current or temperature
- Spectral fingerprinting of molecular species
- Reference spectra for astronomy and atmospheric research
- Heterodyne spectroscopy used by SOFIA and OSAS-B investigate atomic oxygen at 4.7 THz







T. Hagelschuer, M.Wienold, et al., IEEE TST 9, 606 (2019)

Challenges of spectroscopy with QCLs

- Frequency and power instabilities due to optical feedback
- Frequency tunability by current and temperature limited to a few GHz
- Cryogenic operating temperatures for continuous wave operation in the mW range required

Micro-QCL Goals

- Beam shaping optics and an integrated optical isolator to reduce optical feedback
- Development of QCLs with operating temperatures higher than 80K
- Increasing the frequency range by integration of light-induced frequency tuning (LIFT)
- QCL chip with the most important optical components in a small micro optical assembly, not larger than a matchbox (50 x 35 x 15 mm^3)

Micro-QCL: Partners and tasks

HUB:

Performance parameters of micro-integrated THz QCLs

Doppler-free and broadband molecular spectroscopy

PDI:

QCL active medium and waveguide design

Fabrication of QCLs

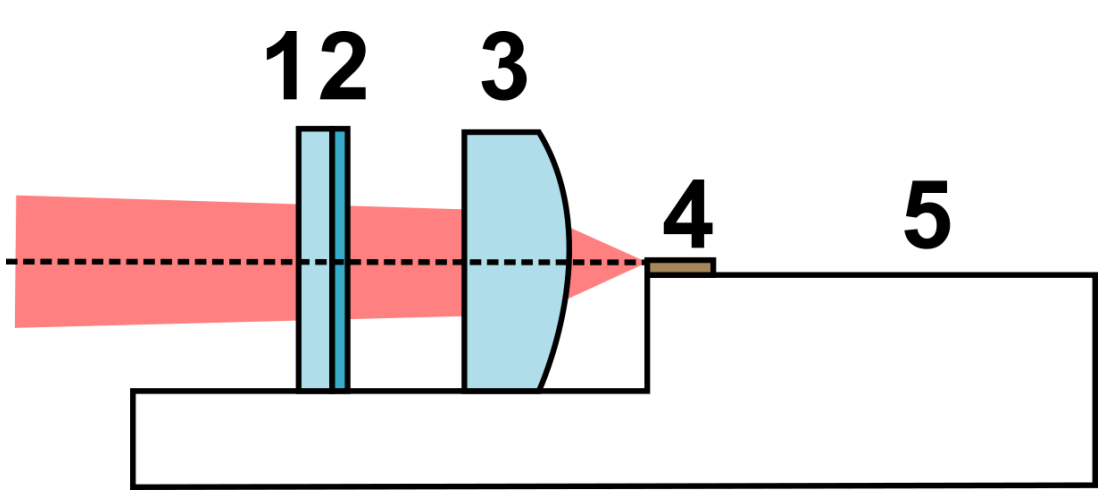
FBH:

Construction and fabrication of micro-optical benches

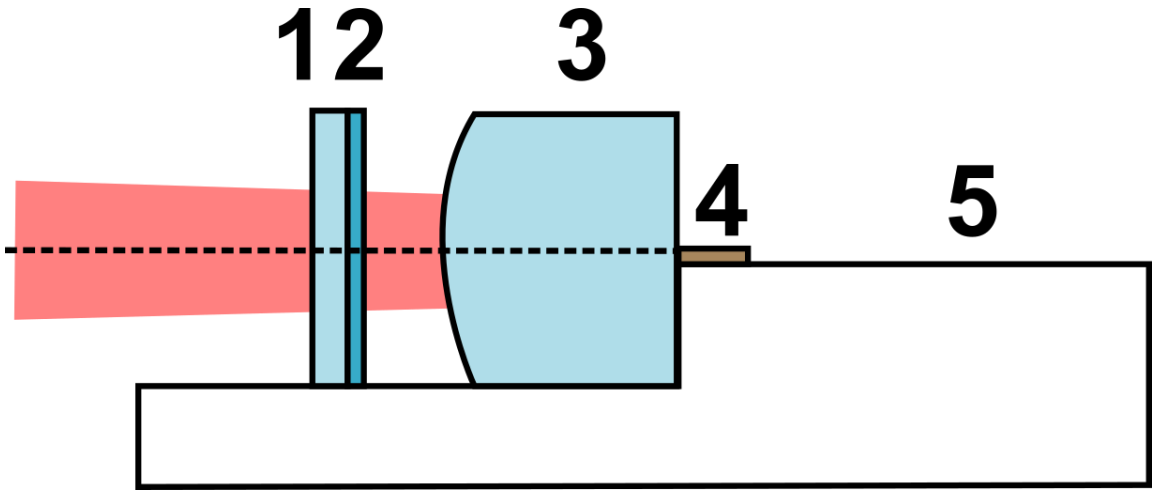
Micro-optical assembly

Micro-QCL Layout

Aspherical lens



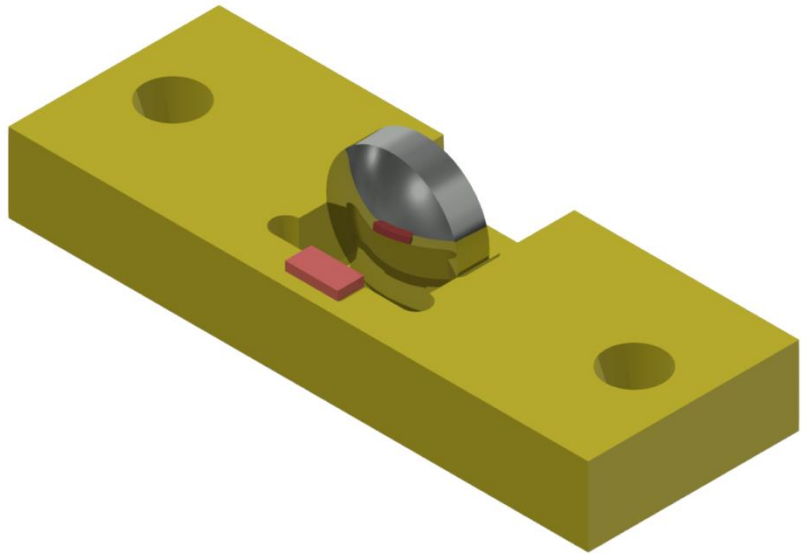
Immersion-like lens

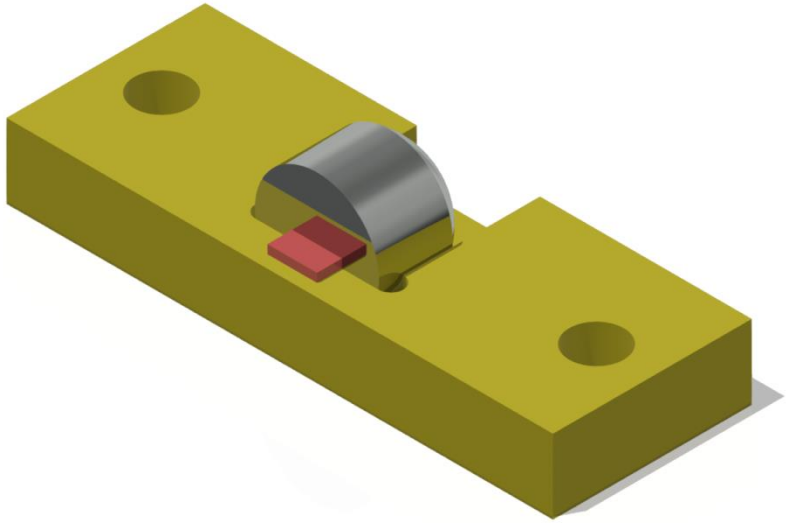


(1) λ/4 wave plate, (2) wire grid, (3) silicon lens, (4) laser chip on submount, (5) micro-optical carrier

Micro-QCL Layout

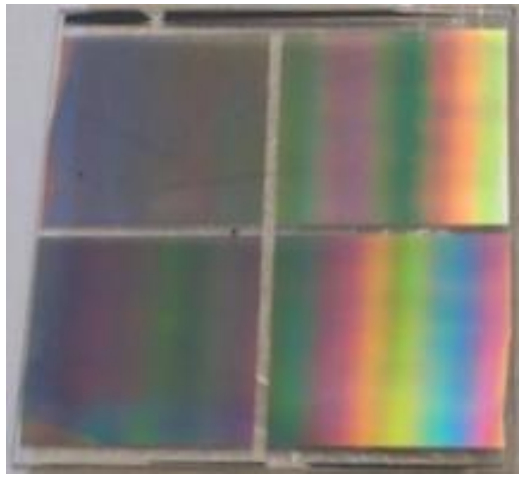
- Groove to ensure the correct height of the QCL relative to the lens
- Immersion lens in direct contact with laser facet – L1
- Aspherical lens in 1.26 mm distance from facet – L2

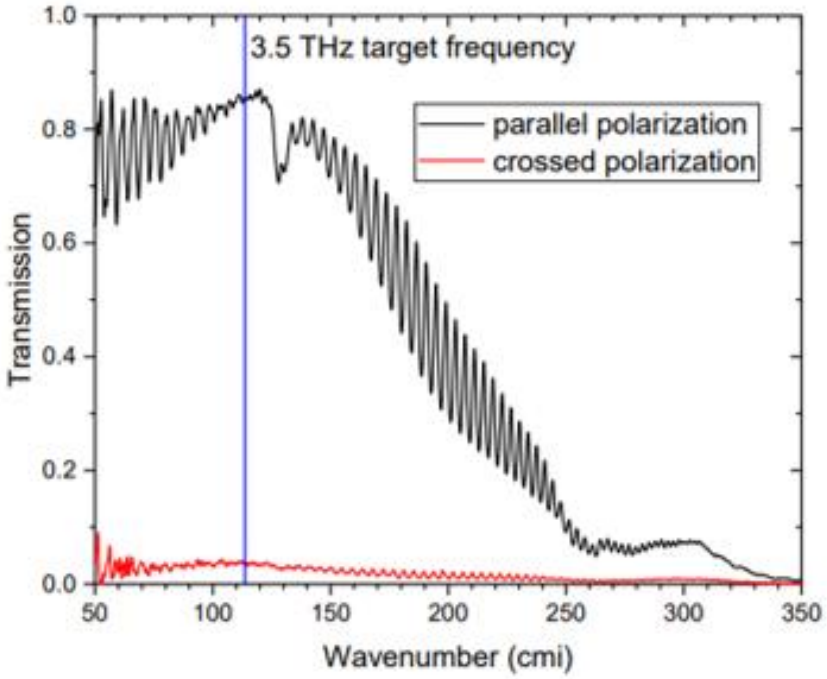




Micro-QCL Optical Isolation

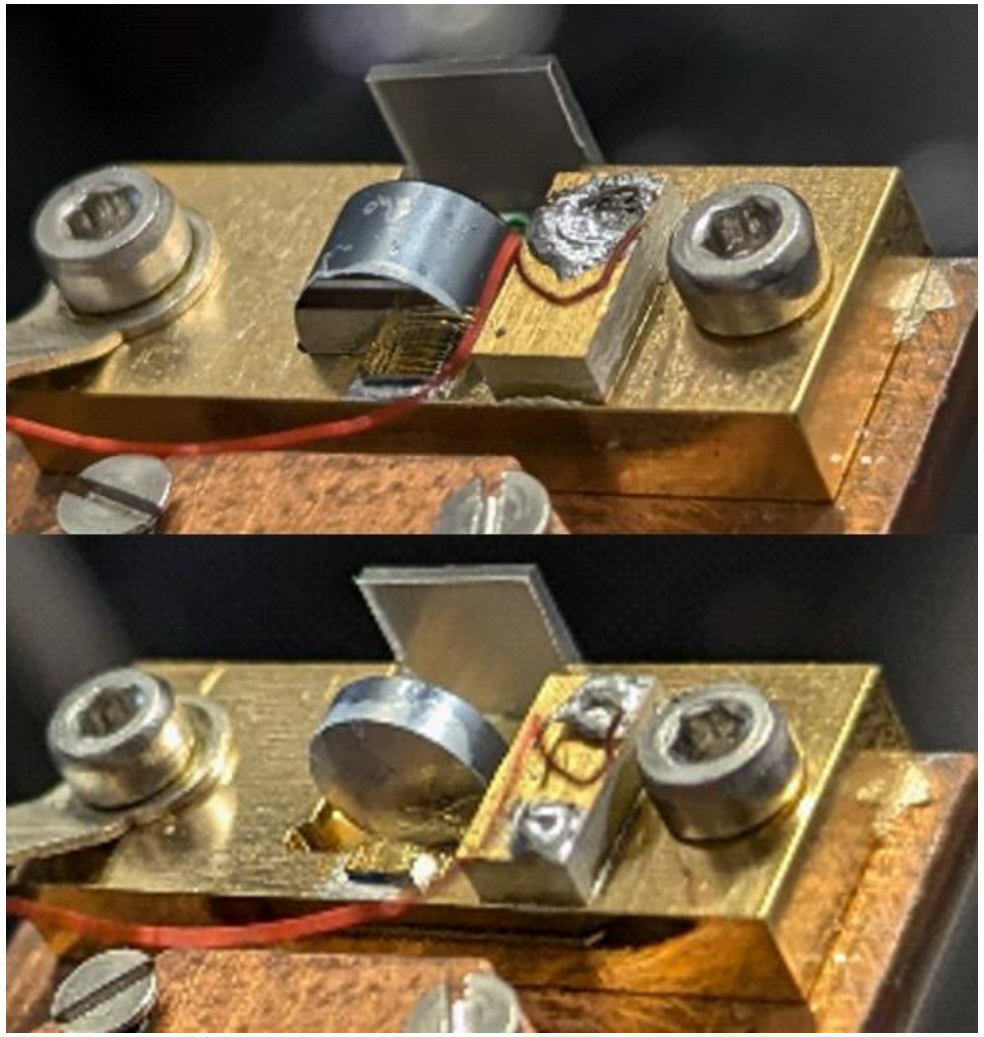
- Optical isolation achieved by wire grid and λ/4 wave plate
- Wire grid evaporated onto λ/4 wave plate
- 14.3 µm thick λ/4 anti-reflection coating



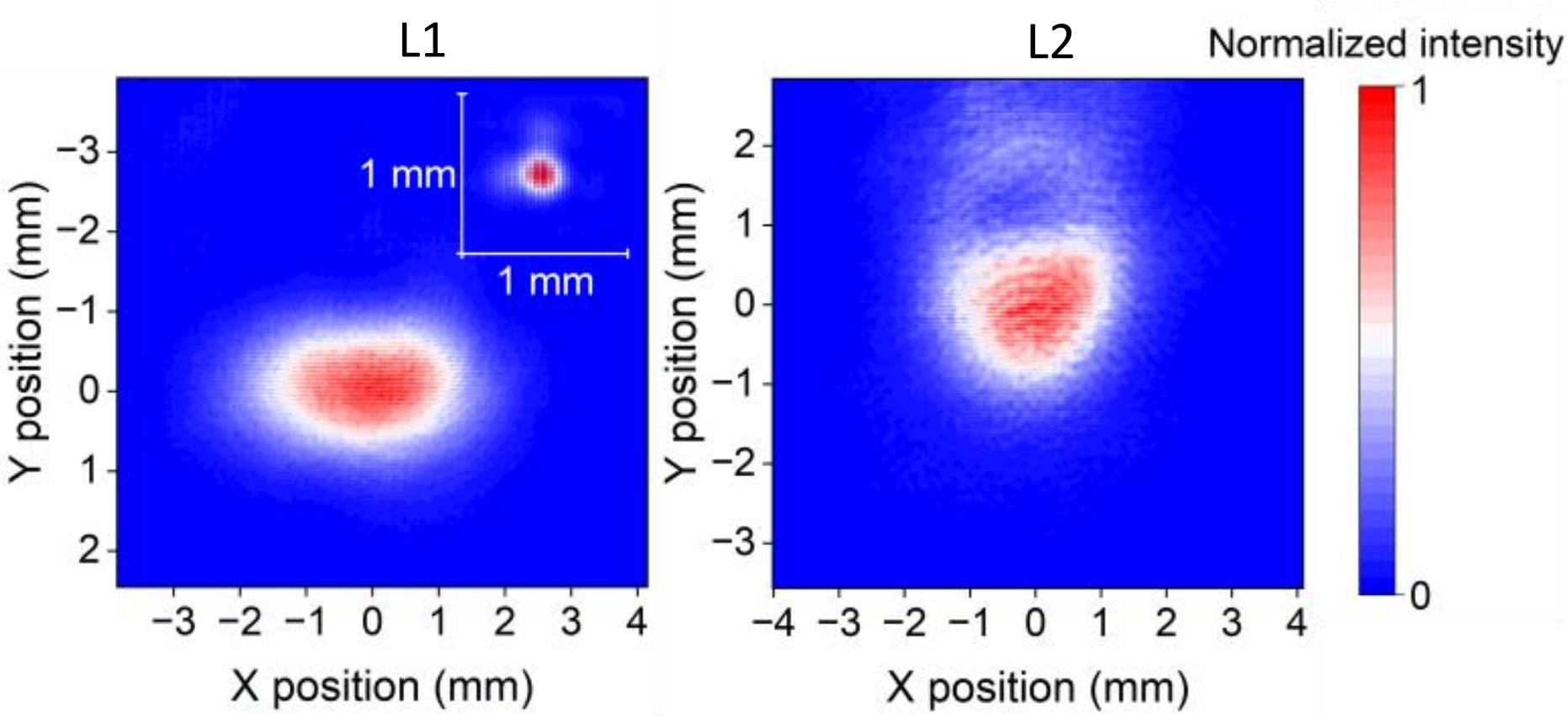


Micro-QCL QCLs

- 3.4-THz GaAs/AlAs based QCLs
- Fabry-Pérot cavity
- 0.12 x 0.871 mm² and
  0.12 x 0.965 mm² laser ridges
- 22 mm x 8 mm total submount



Beam Profiles



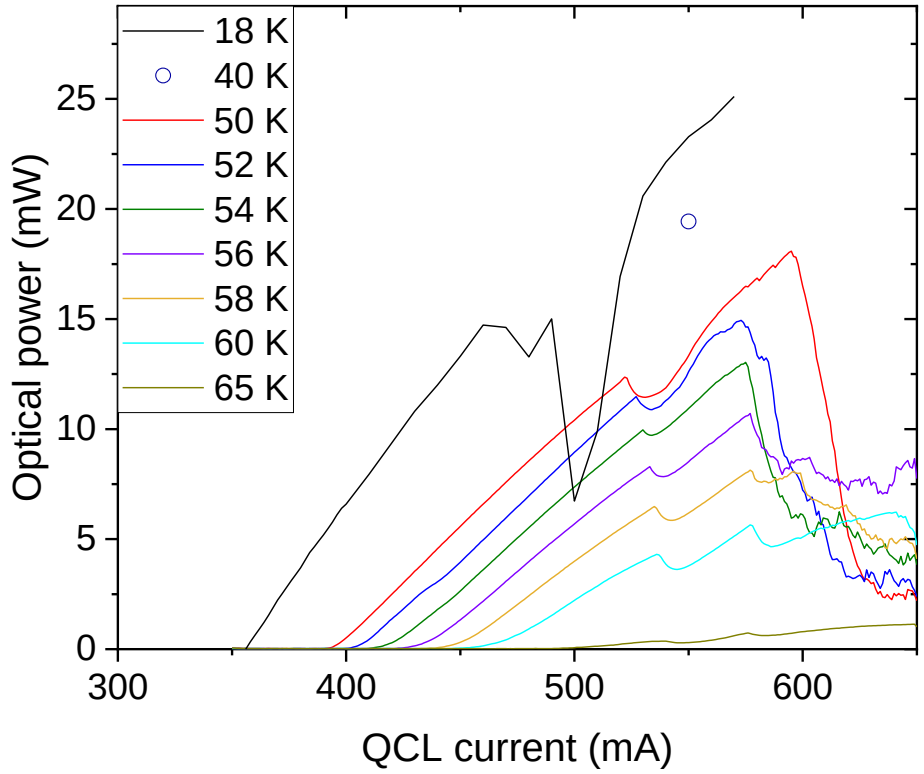
1.8 mm x 1.2 mm

2.2 mm x 1.7 mm

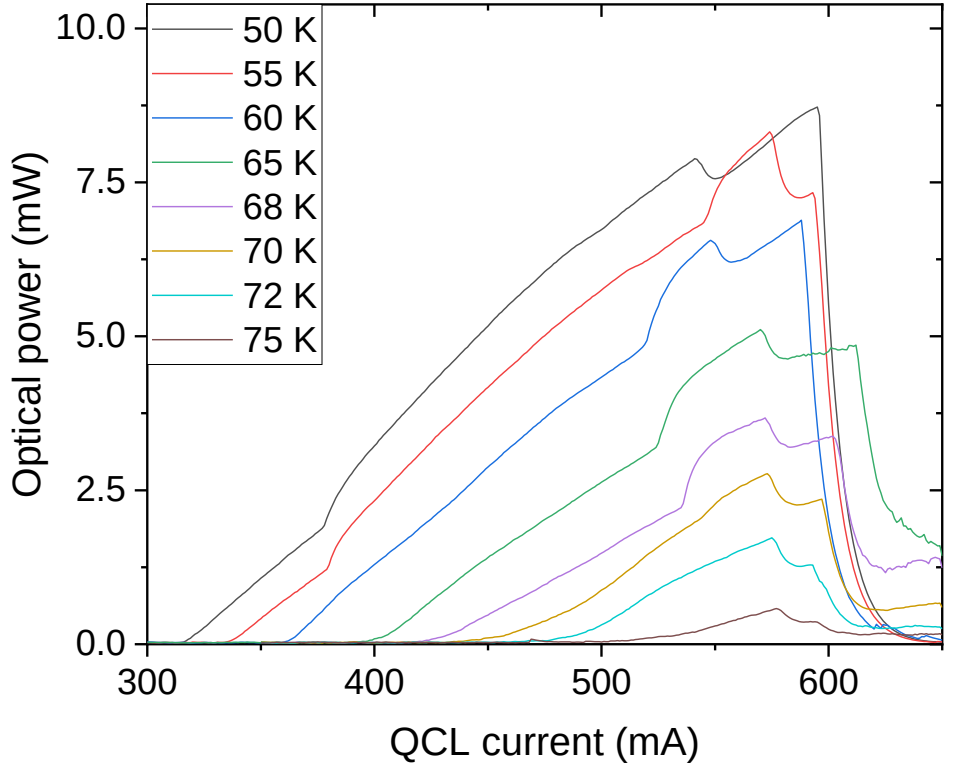
235 × 237 µm with additional f=38 mm lens

Power

L1

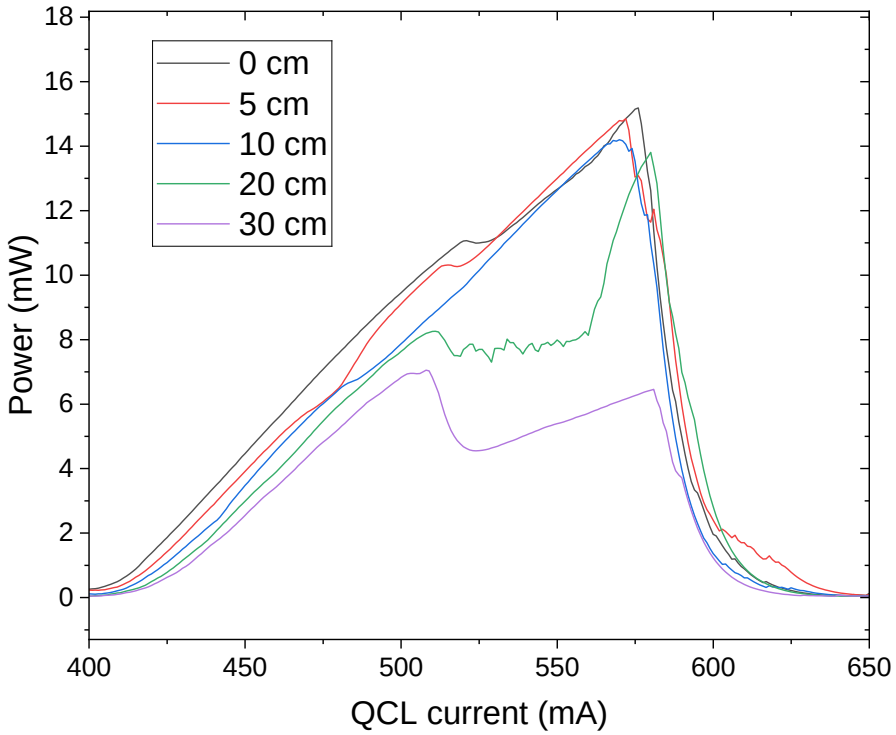

18 K
40 K
50 K
52 K
54 K
56 K
58 K
60 K
65 K
Optical power (mW)
QCL current (mA)
0
5
10
15
20
25
300
400
500
600

L2


50 K
55 K
60 K
65 K
68 K
70 K
72 K
75 K
Optical power (mW)
QCL current (mA)
0.0
2.5
5.0
7.5
10.0
300
400
500
600

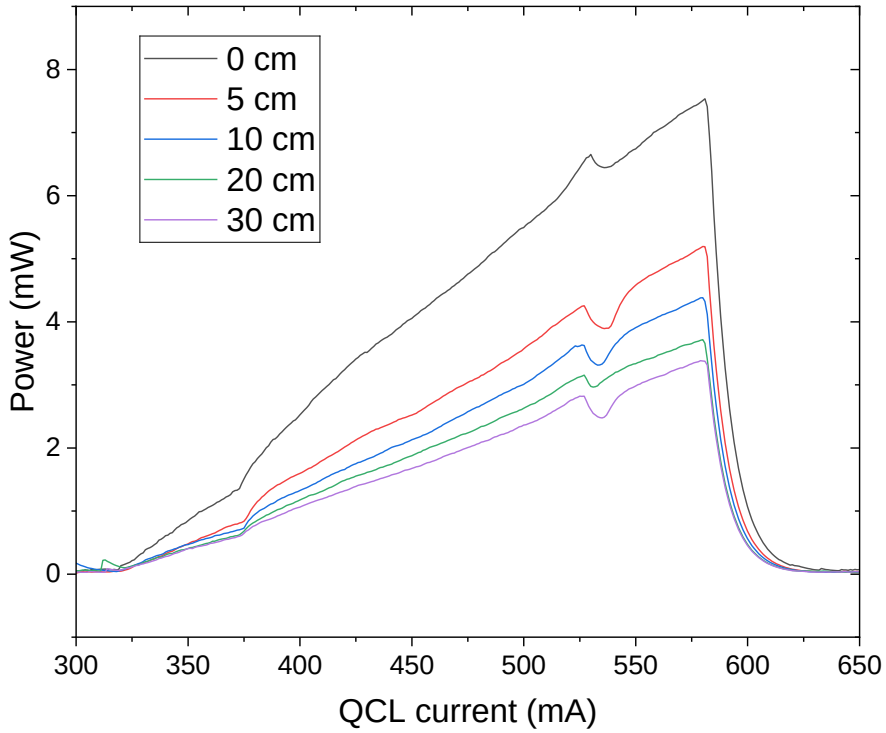
Power Loss

L1



0.8 % per cm

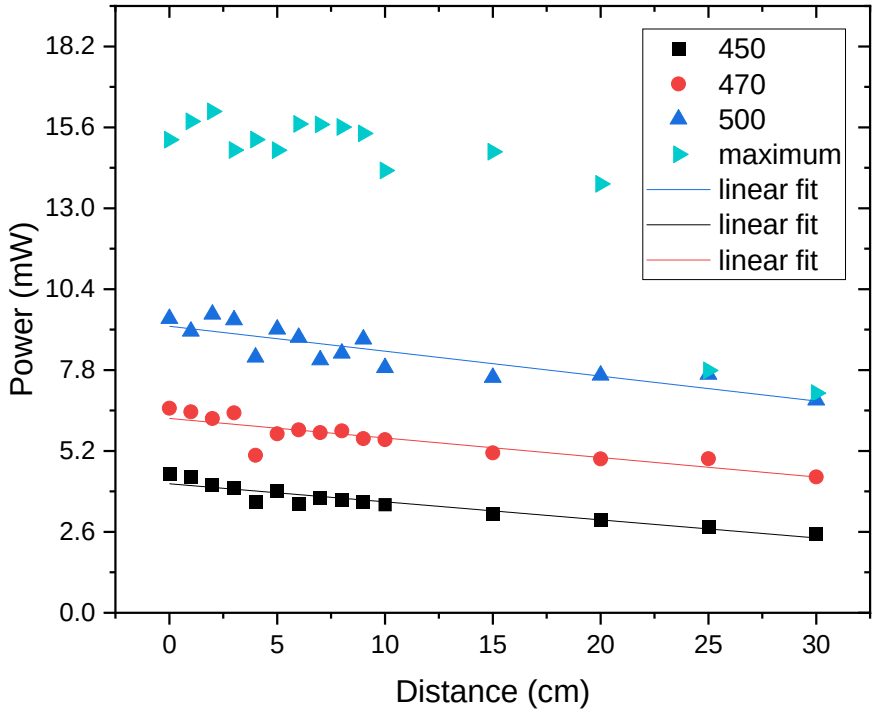
L2



0.6 % per cm

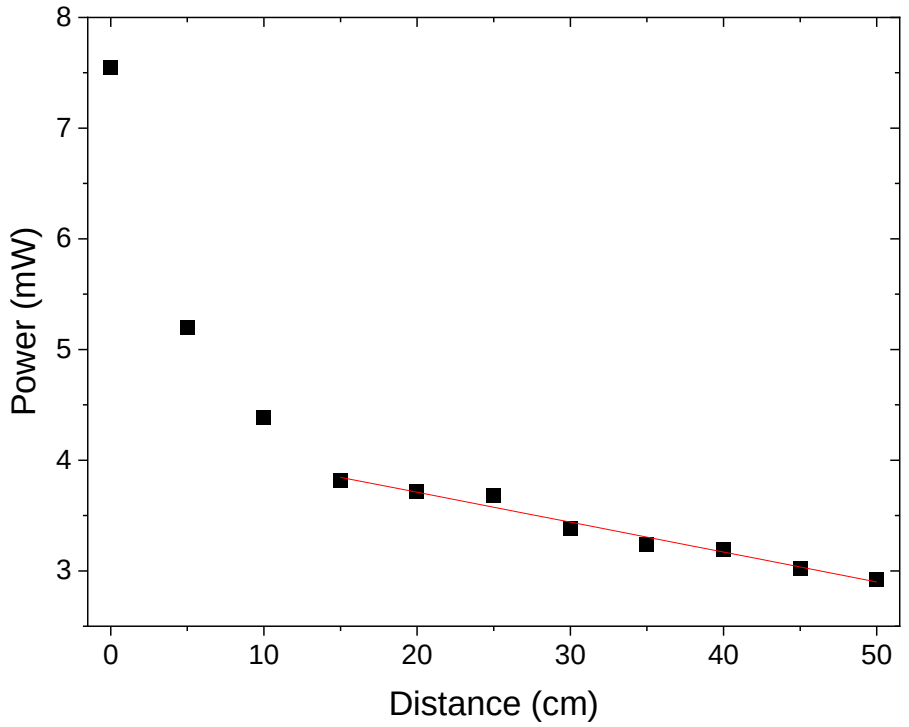
Power Loss

L1



0.8 % per cm

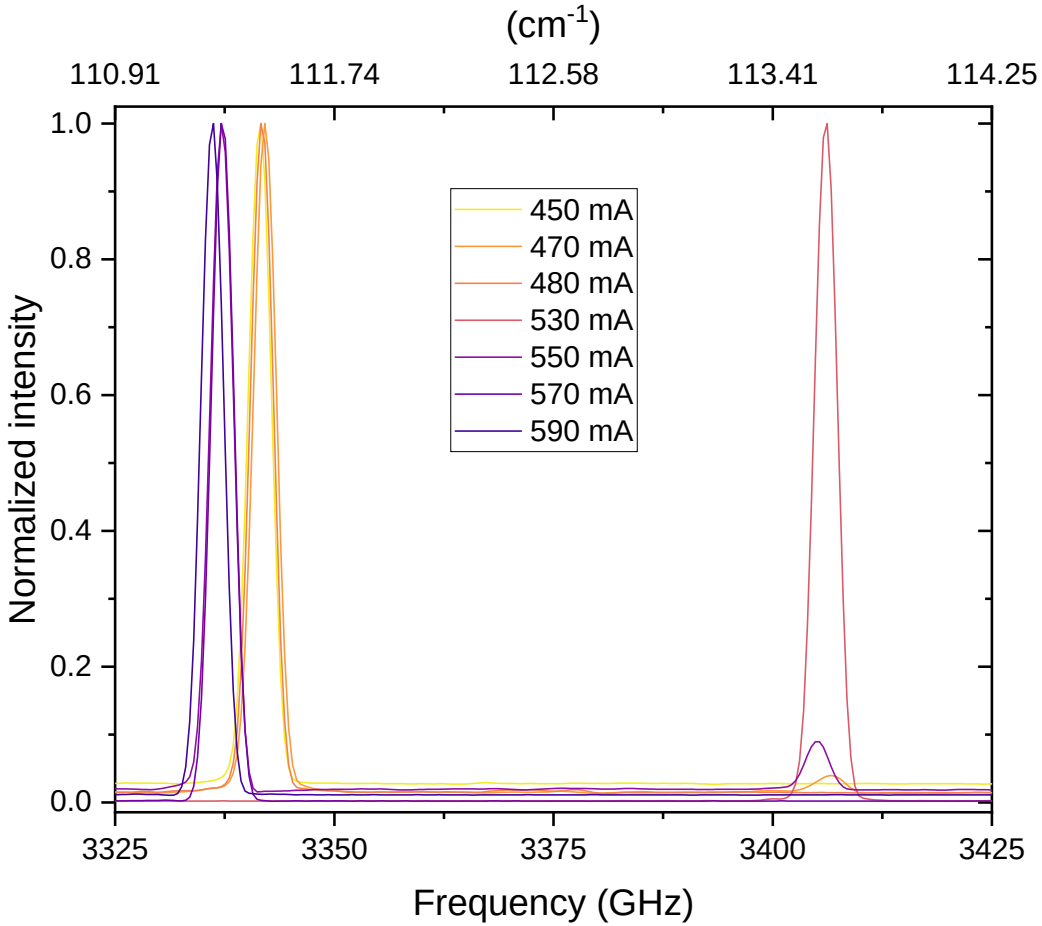
L2



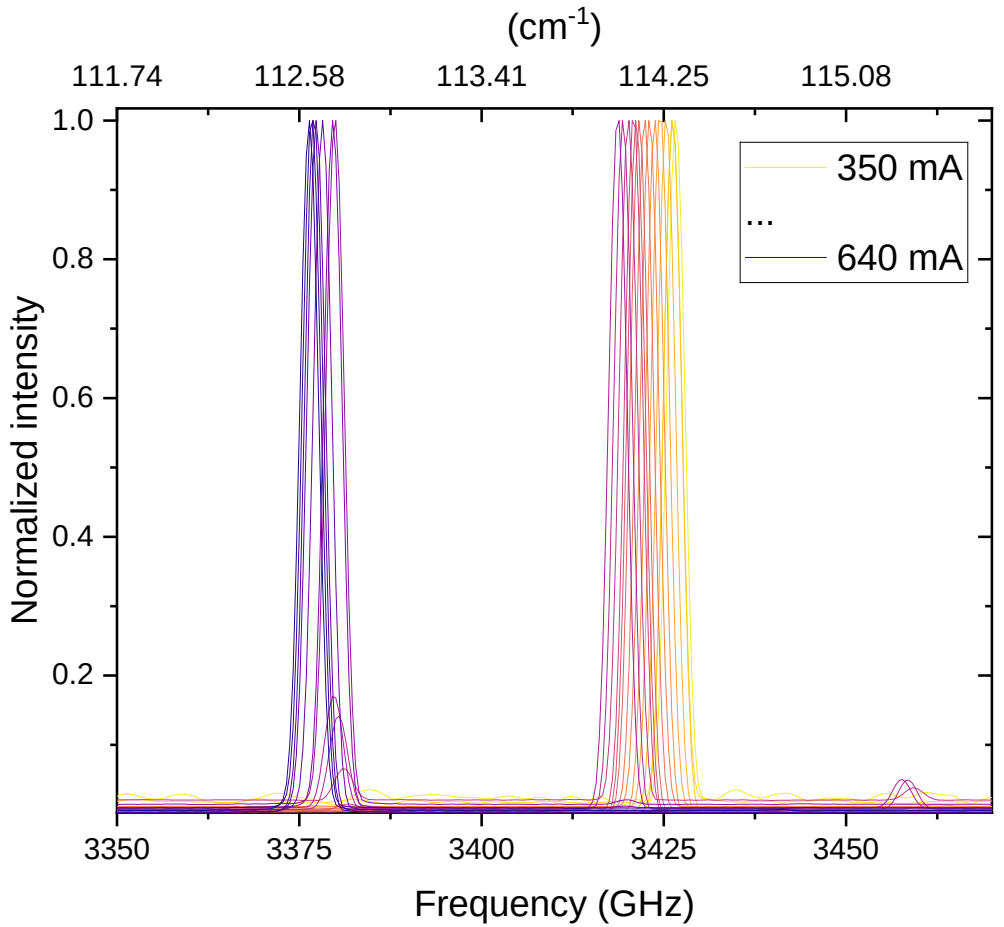
0.6 % per cm

Frequencies

L1

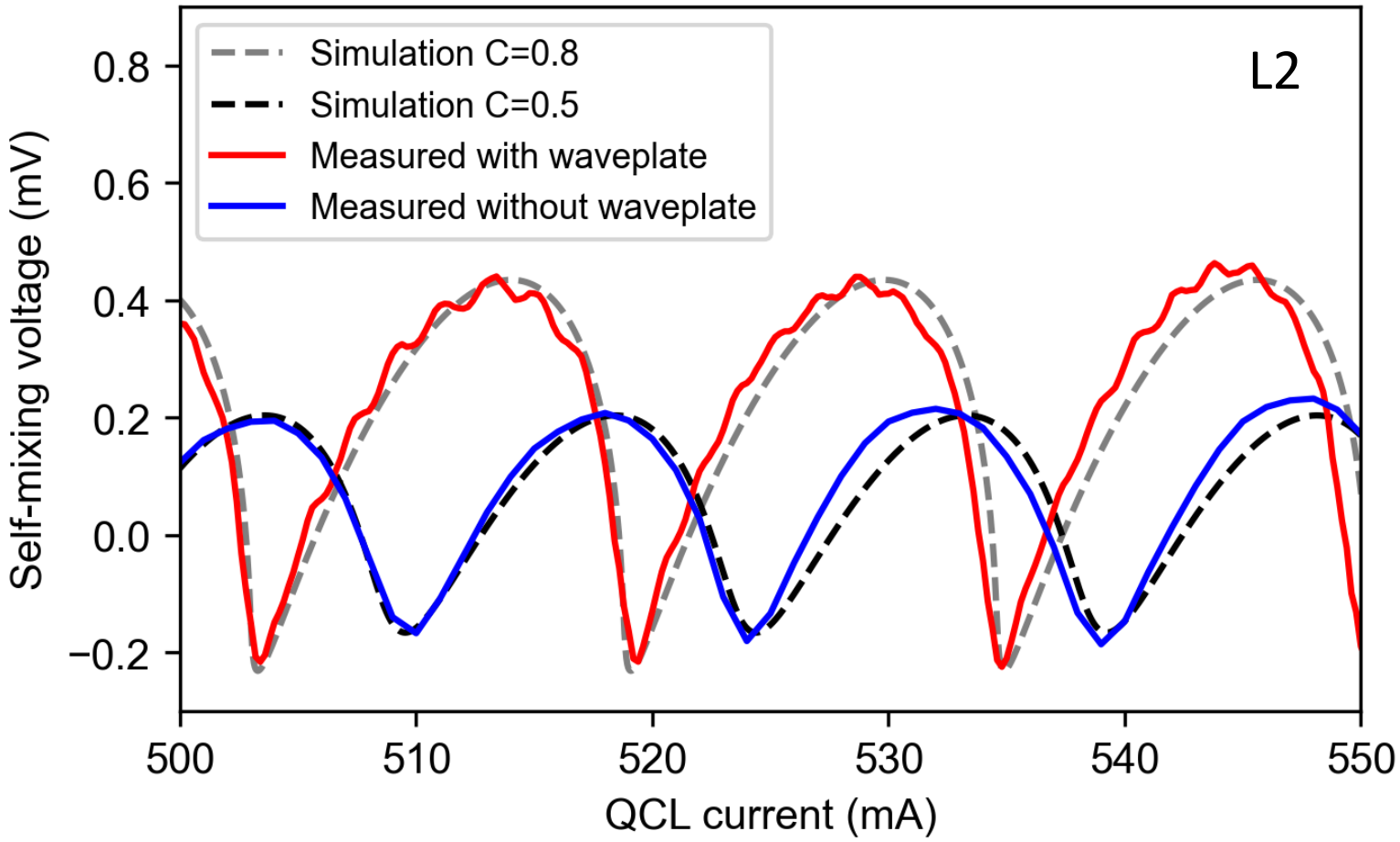


L2



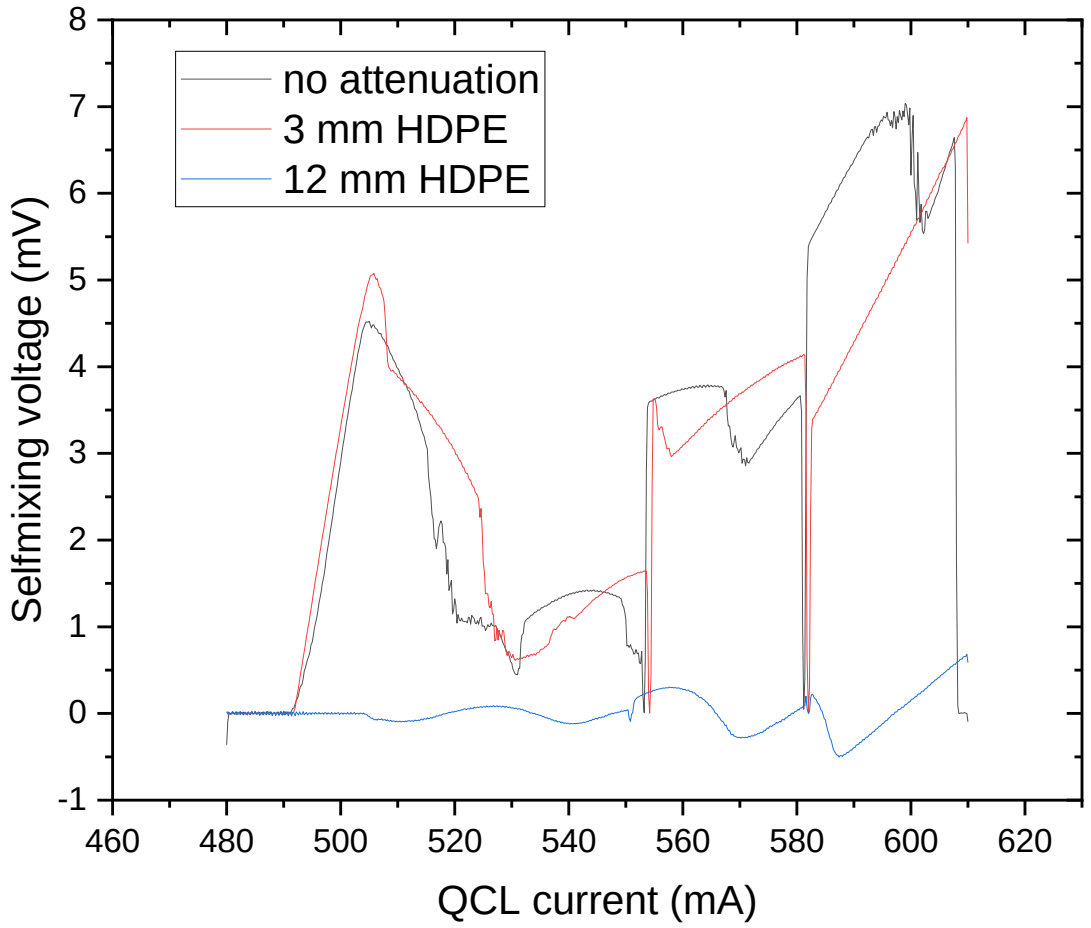
Optical Isolation

- Measurement of self-mixing voltage of L2
- Comparison with simulations indicate 70% reflected power reduction

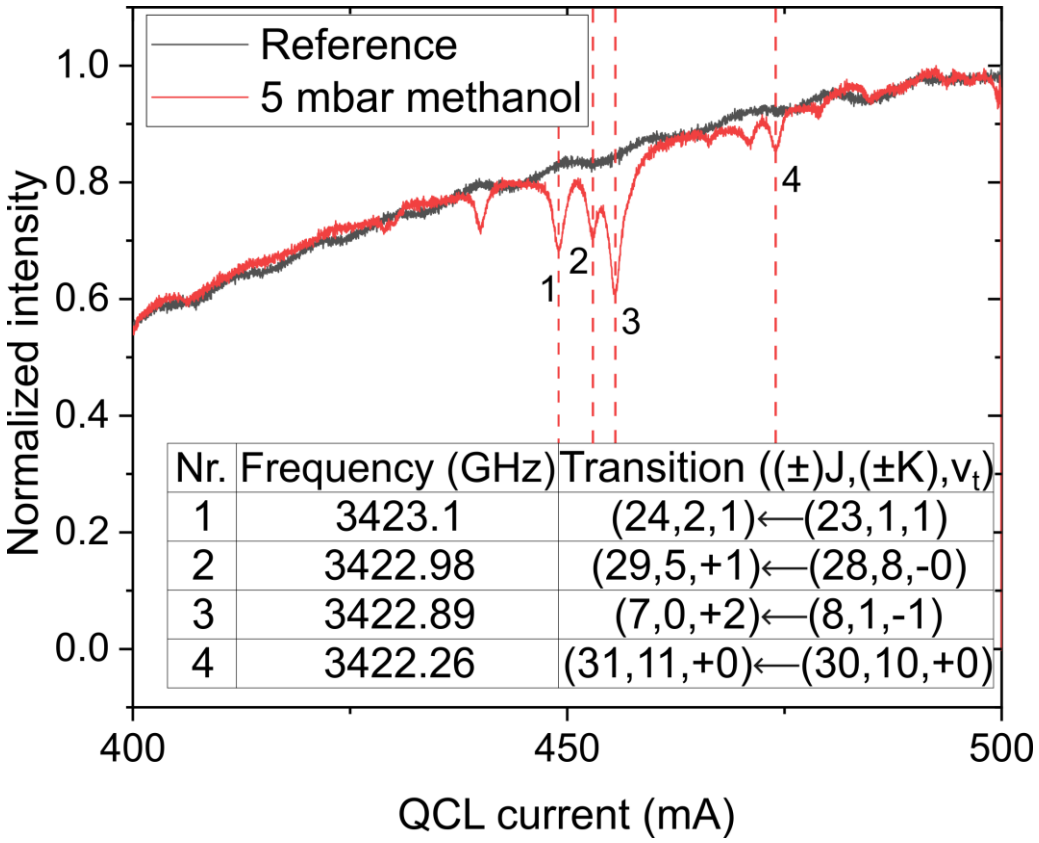


Optical Isolation

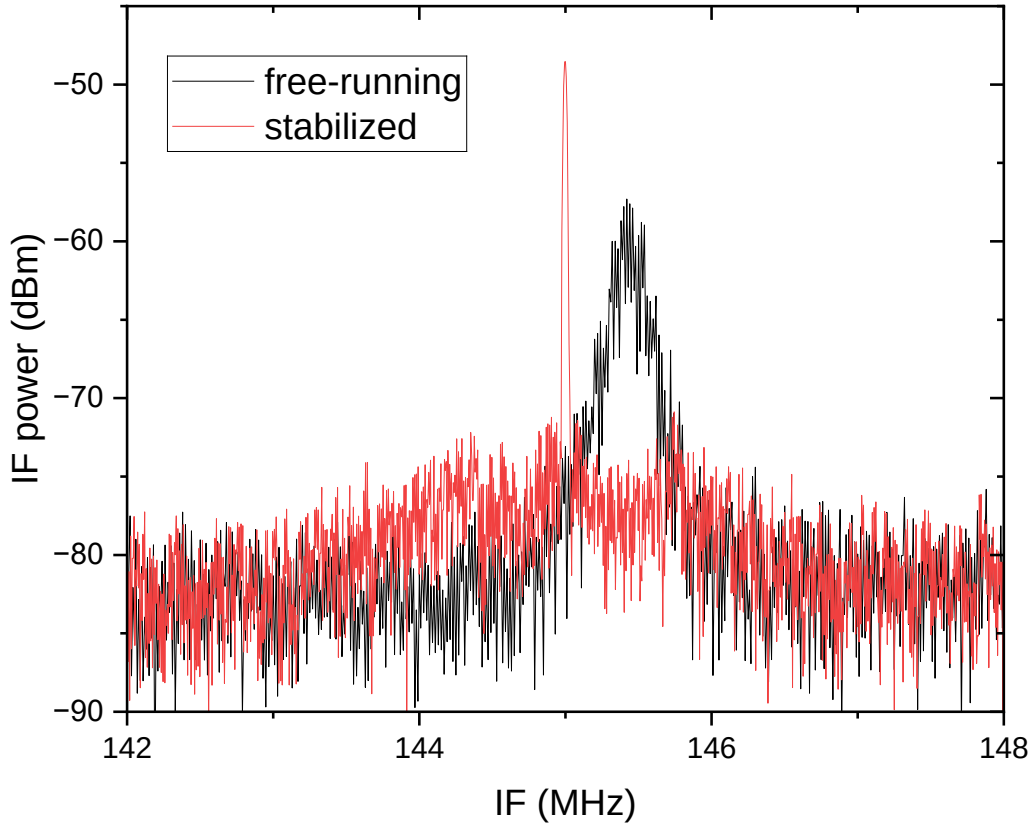
- Measurement of self-mixing voltage of L2
- Comparison with simulations indicate 70% reflected power reduction



Spectroscopy Application



Nr.	Frequency (GHz)	Transition ((±)J,(±K),v_t)
1	3423.1	(24,2,1)←(23,1,1)
2	3422.98	(29,5,+1)←(28,8,-0)
3	3422.89	(7,0,+2)←(8,1,-1)
4	3422.26	(31,11,+0)←(30,10,+0)



Summary

- Micro-QCL combine optical isolation and beamshaping directly on a small submount
- Using an immersion lens with AR coating significantly increases output coupling but also optical feedback effects
- Micro-QCL design should be adjusted for specific applications

Thank you for your attention!