High power and single frequency quantum cascade lasers for gas sensing

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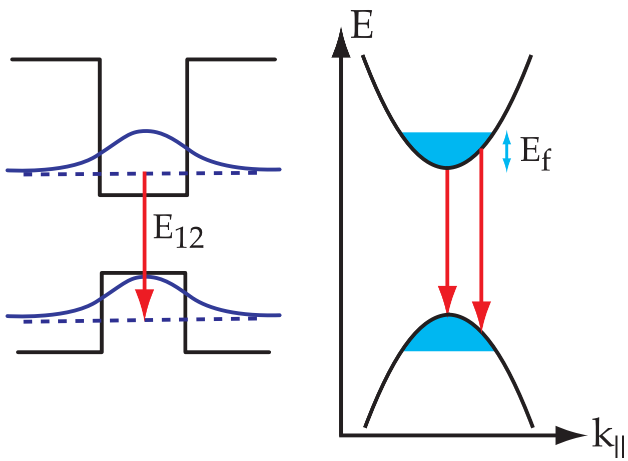
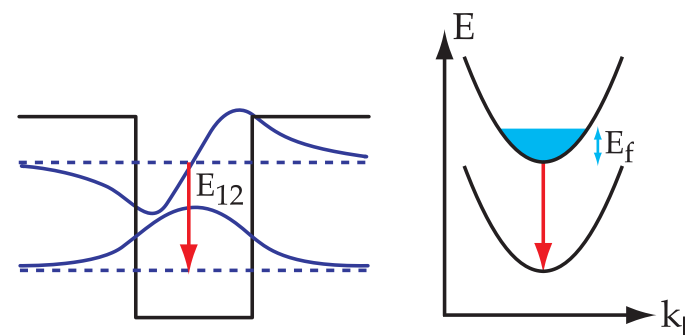
Outline

- Introduction
- Applications
- High power Fabry-Pérot devices
- High power pulsed DFB devices
- Cryogenic continuous-wave devices
- Reliability of the devices

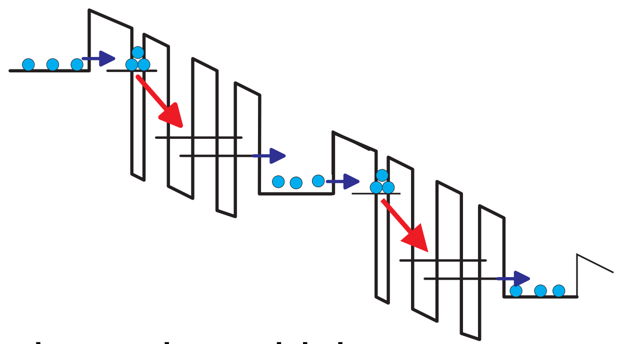
Interband vs intersubband



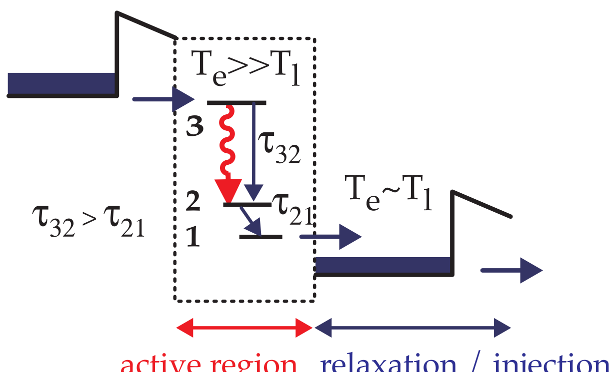


- **Interband transition**
  - bipolar
  - photon energy limited by bandgap E_g of material
  - Telecom, CD, DVD,…
- **Intersubband transition**
  - unipolar, narrow gain
  - photon energy depends on layer thickness and can be tailored

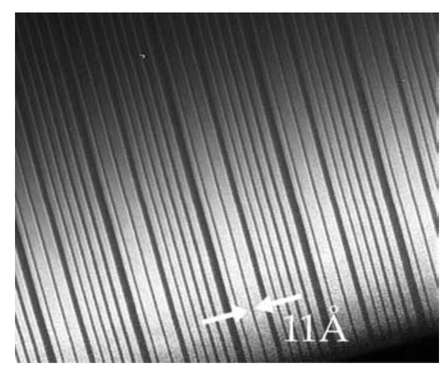
Quantum cascade lasers



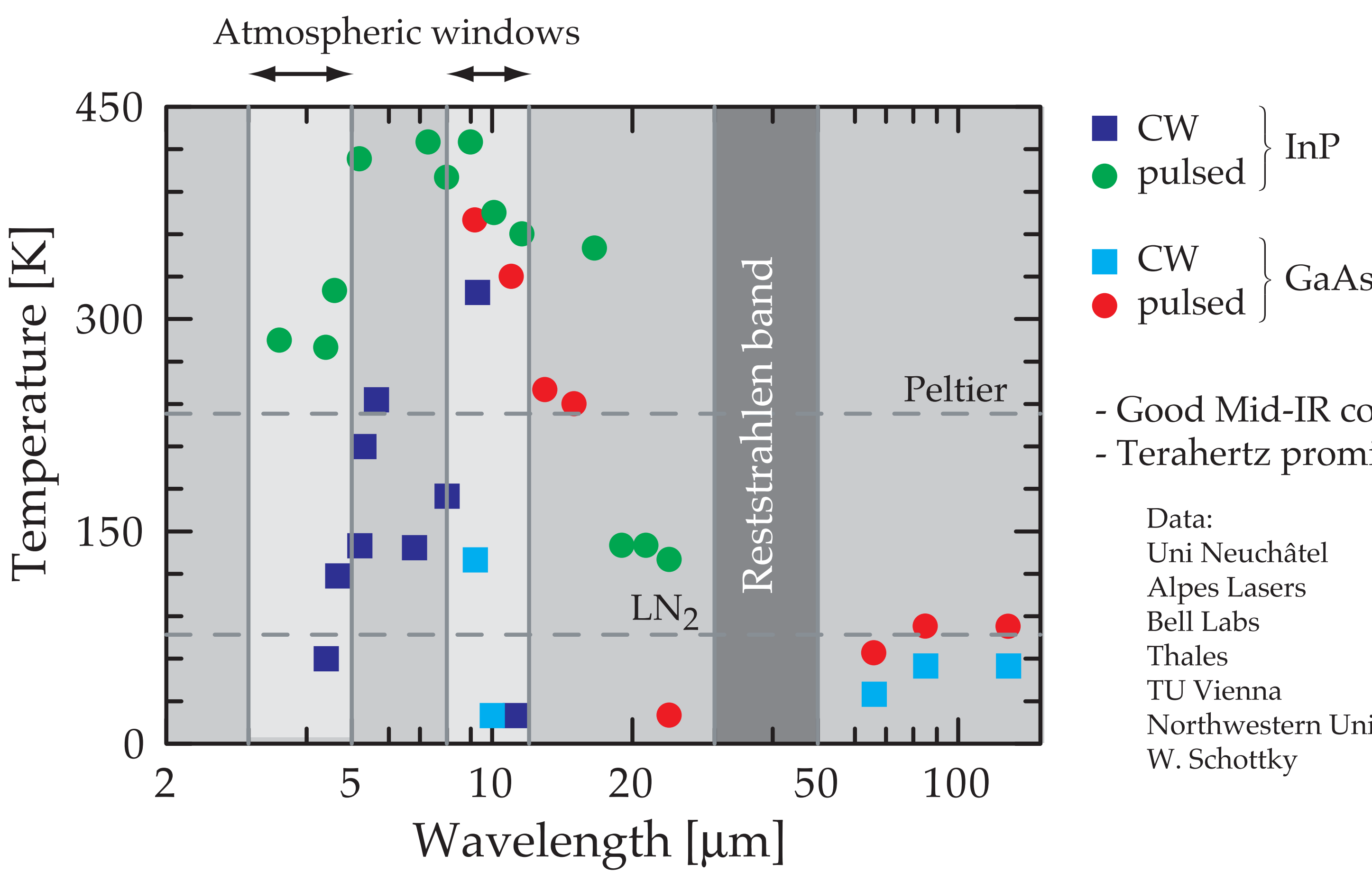
- **Cascade**
  - each e- emits N photons
- **Active region / injector**
  - active region ⮝ population inversion which must be engineered
  - injector ⮝ avoid fields domains and cools down the electrons



- **MBE**
  - growth of thin layers
  - sharp interfaces



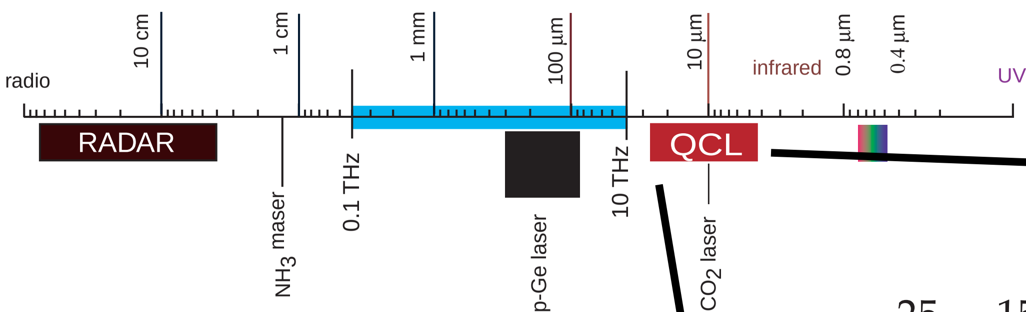
State of the art: QCL performances

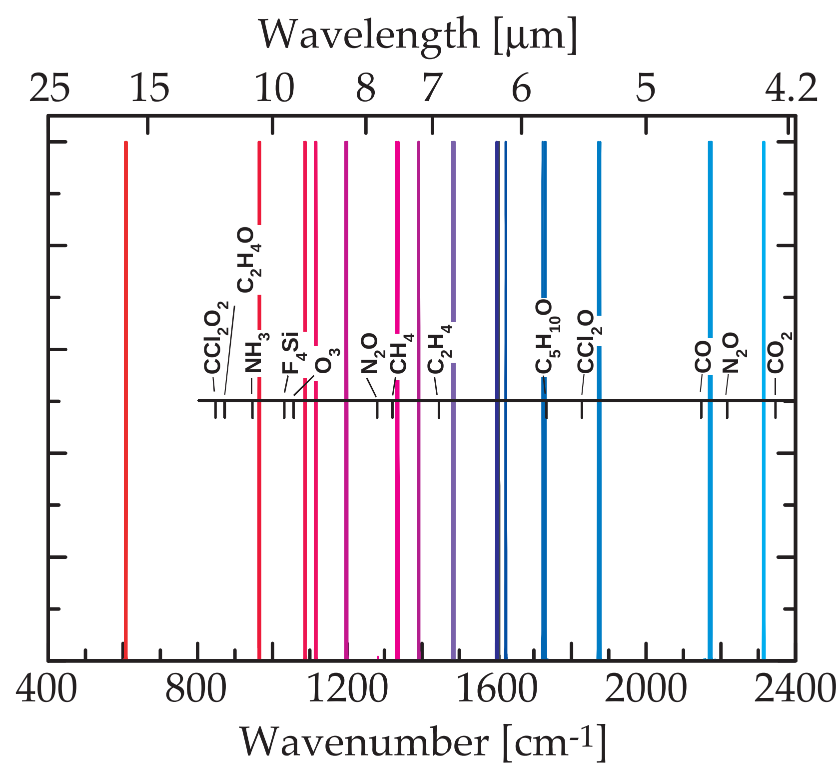


- Good Mid-IR coverage
- Terahertz promising

Data:
Uni Neuchâtel
Alpes Lasers
Bell Labs
Thales
TU Vienna
Northwestern Uni
W. Schottky

Spectrum covered by Alpes Lasers dfb QCLs





High power QC lasers using new designs:

- Bound-to-continuum (patent n° wo 02/019485A1)
- Two-phonon resonance (patent n° wo 02/23686A1)

Applications: chemical sensing by optical spectroscopy

- Vibrational mode of molecules in Mid-IR
- Detection techniques:
  - photo-acoustic
  - TILDAS
  - cavity ringdown
  - …
- Can be used for
  - trace gas analysis, process control
  - liquid detection spectroscopy

Needs:

high-power laser

narrow linewidth (single mode)

continuous-wave operation

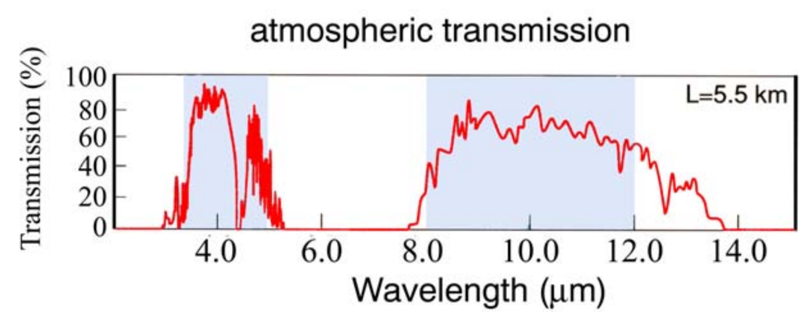
Talks in TDLS'03:
- Barry McManus: 'Trace Gas Instrumentation Using Pulsed Quantum Cascade Lasers'
- Mark Zahniser: 'Trace Gas Measurements Using Pulsed Quantum Cascade Lasers '
- Frank Tittel: 'Chemical Sensing with Quantum Cascade Lasers '

Applications: chemical sensing by optical spectroscopy

- Typical applications:
  - atmosphere diagnostics
  - pollution monitoring
  - non-invasive medical diagnostics
  - detection of biological contaminants, drugs or explosives
  - ammonia (NH_3) monitoring in process industry
  - CO, NO, SO_2, SO_3 (e.g. in combustion processes)
  - CH_4, HF, H_2S, in petro-chemical processing facilities (e.g. gas leak detector)
  - CO_2, O_3 for environment monitoring
  - Large organic hydrocarbon molecules like benzene

Other applications

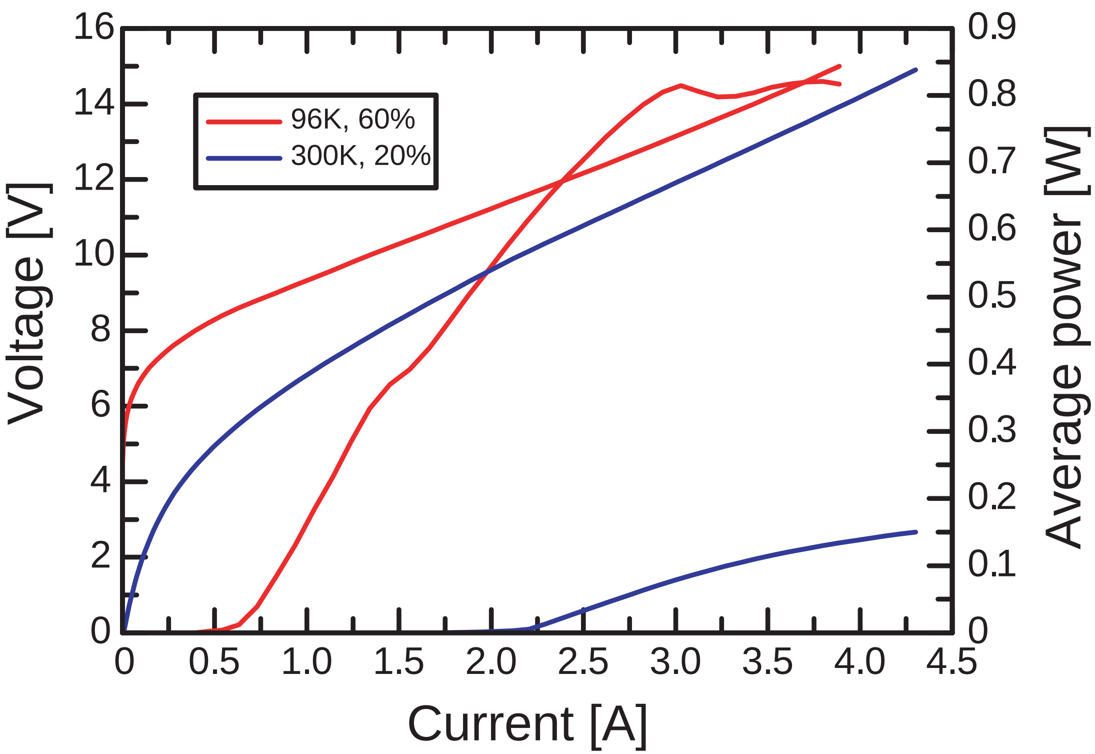
- Telecommunications
  - Free-space optical data transmission for the last mile (high speed with no need for licence and better operation in fog, compared to $\lambda = 1.55$ µm)



- Terahertz field
  - Astronomy
  - Medical imaging
  - Chemical detection
  - Telecommunications for local area network (LAN)

Talks yesterday:
- Ruedeger Koehler: ‘Terahertz Quantum Cascade Lasers’
- Daniel Hofstetter: ‘Latest Progress on Intersubband Devices: Lasers and Detectors from the Near- to the Far-Infrared’

High average power FP QCL: RT-HP-FP-150-X



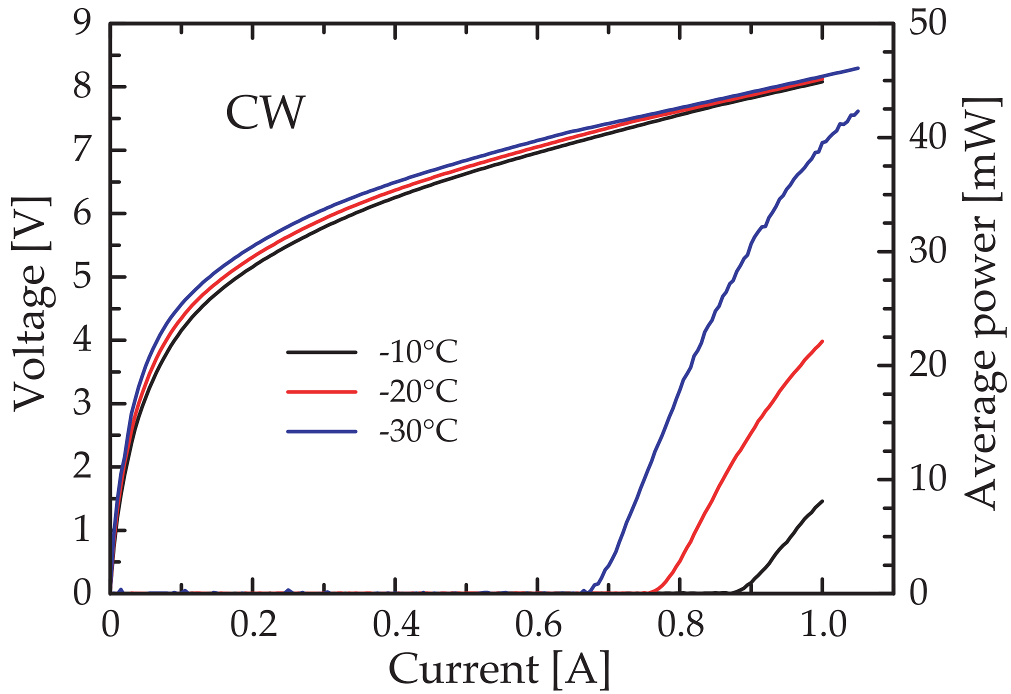
Characteristics

Back-facet coated
$\lambda = 7.9\ \mu m$

@300K: Average power:
P = 150 mW
threshold current density:
$j_{th} = 3.0\ kA/cm^2$

@96K : P = 0.82 W (60% dc)
$j_{th} = 0.75\ kA/cm^2$
P in CW: P = 300mW
($j_{th} = 0.78\ kA/cm^2$)

Continuous-wave FP QCL on Peltier



Characteristics

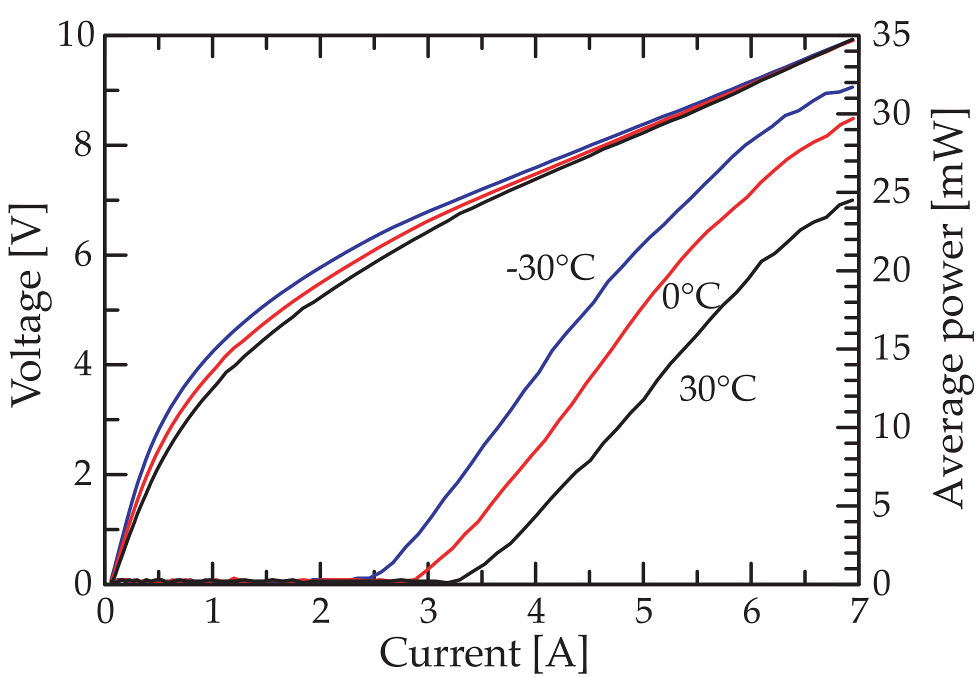
1.5 mm-long, 12 µm-wide laser
Buried-heterostructure
Back-facet coating
CW operation at $\lambda \approx 9.2$ µm on Peltier

@-30°C: Average power:
P = 42 mW
Threshold current density:
j_{th} = 3.8 kA/cm^2

- typically designed for Free Space Optics data transmission

High average power DFB QCL: RT-HP-DFB-20-X

Distributed feedback QC laser at 8.35µm with InP top cladding



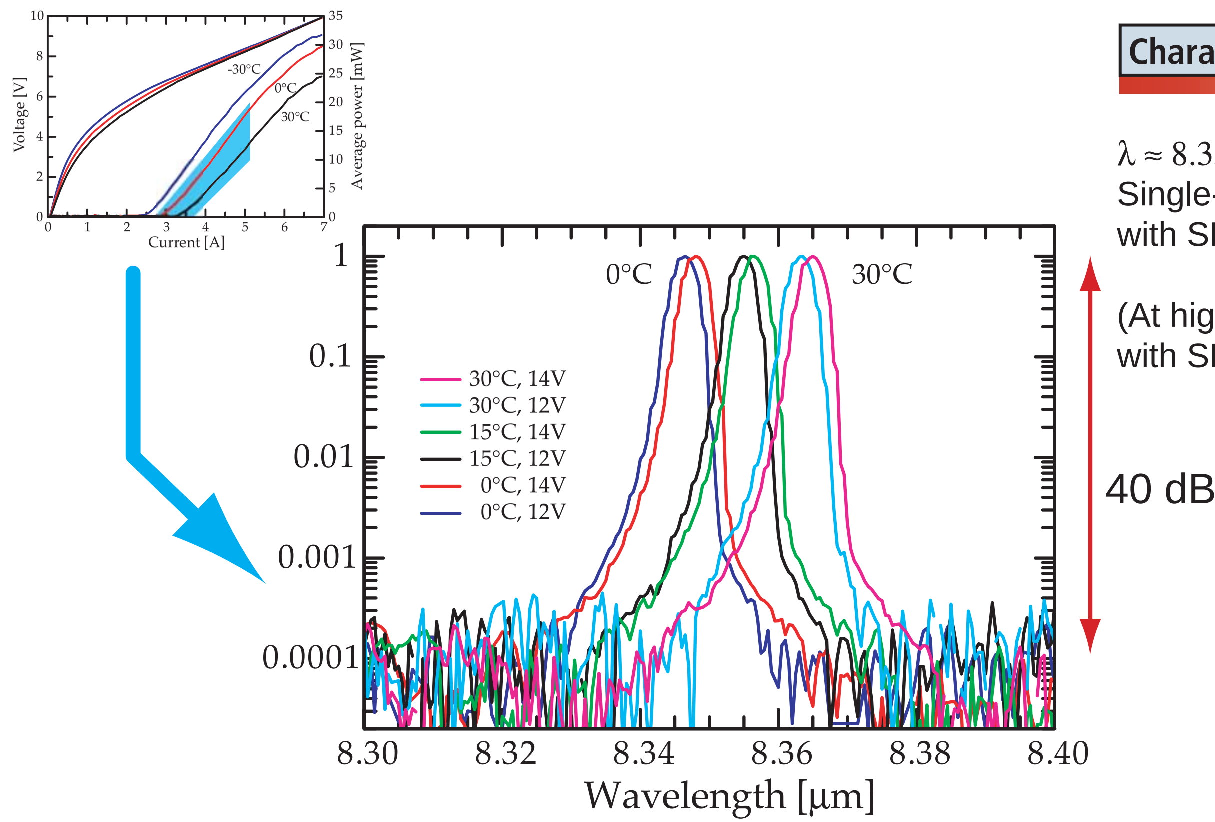
Characteristics

3mm-long, 28µm-wide laser
$\lambda \approx 8.35$ µm

@-30°C: Average power (2% dc):
P = 32 mW (1.6 W peak power)
threshold current density:
j_{th} = 2.9 kA/cm^2

@30°C : P = 25 mW (1.25W peak power)
j_{th} = 3.8 kA/cm^2

High average power DFB QCL: RT-HP-DFB-20-X



Characteristics

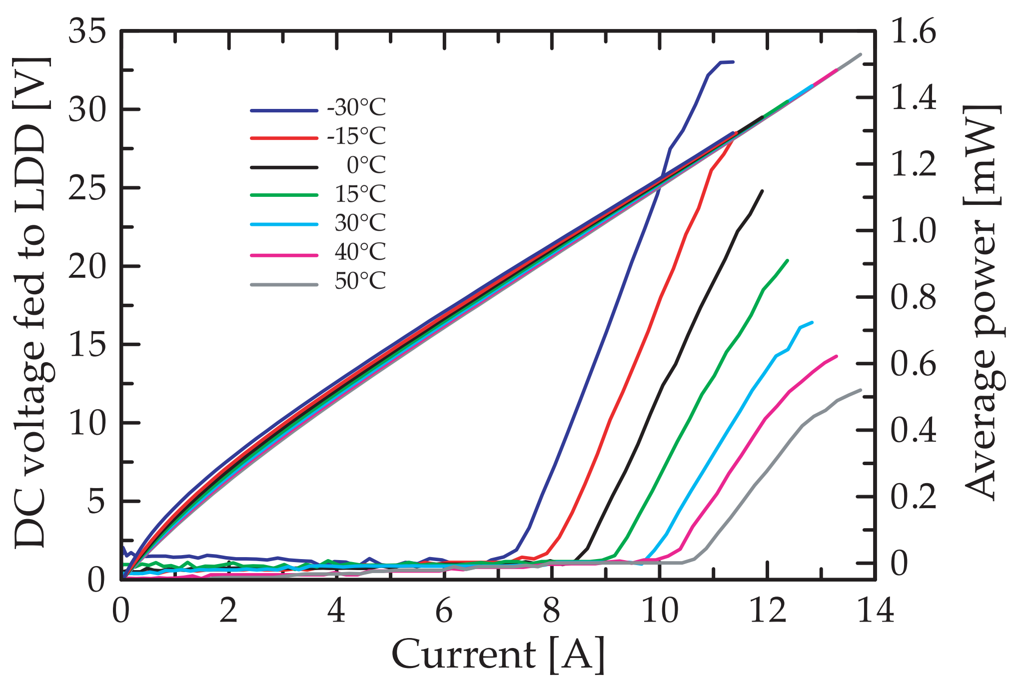
$\lambda \approx 8.35$ µm
Single-mode operation at $T \geq 0°C$ with SMSR $\geq$ 40 dB

(At high bias, single-mode operation with SMSR $\approx$ 20 dB)

Long-wavelength (λ≈16.4μm) B2C DFB QCL: RT-P-DFB-1-X

Laser based on a bound to continuum design, $\lambda \approx 16.4$ μm

Rochat et al., APL **79**, 4271 (2001).



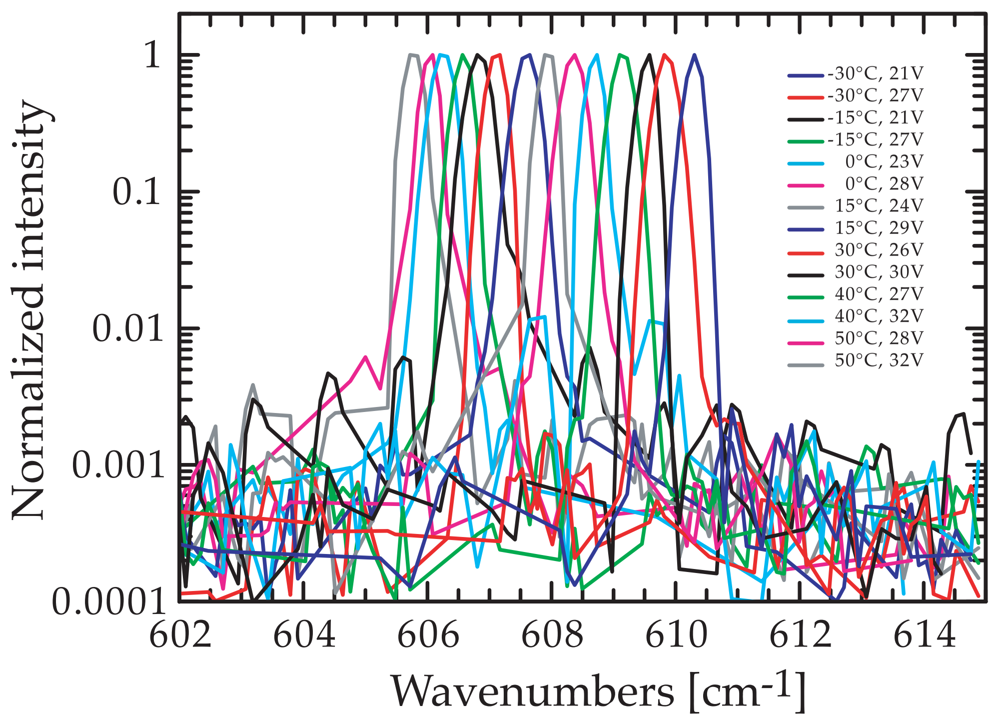
Characteristics

3 mm-long, 44μm-wide laser
$\lambda \approx 16.4$ μm

@-30°C: Average power (1.5% dc):
P = 1.5 mW (100 mW peak power)
Threshold current density:
j_{th} = 5.4 kA/cm^2

@50°C : P = 0.5 mW (33 mW peak power)
j_{th} = 7.9 kA/cm^2

Long-wavelength (λ≈16.4μm) B2C DFB QCL: RT-P-DFB-1-X



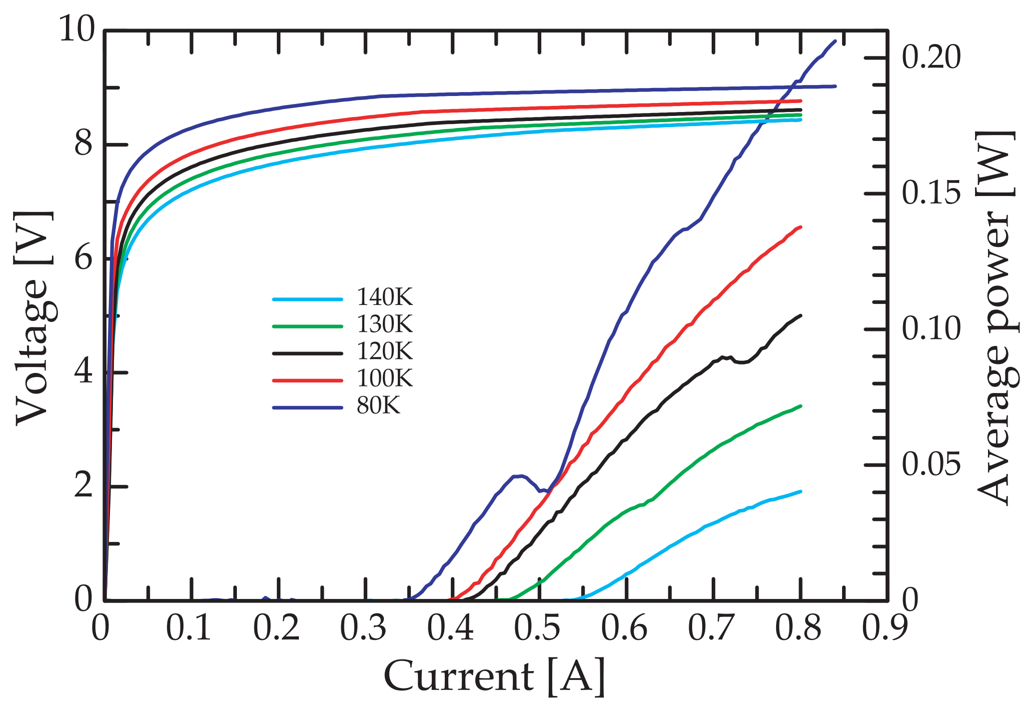
Characteristics

3mm-long, 44μm-wide laser
$\lambda \approx 16.4$ μm

single-mode emission:
Side Mode Suppression Ratio > 25 dB

tuning range:
605.76 cm^{-1} (16.51 μm) at 50°C to
610.30 cm^{-1} (16.38 μm) at -30°C

CW operation at $\lambda \approx 6.73\mu m$: LN2-CW-DFB-100-X

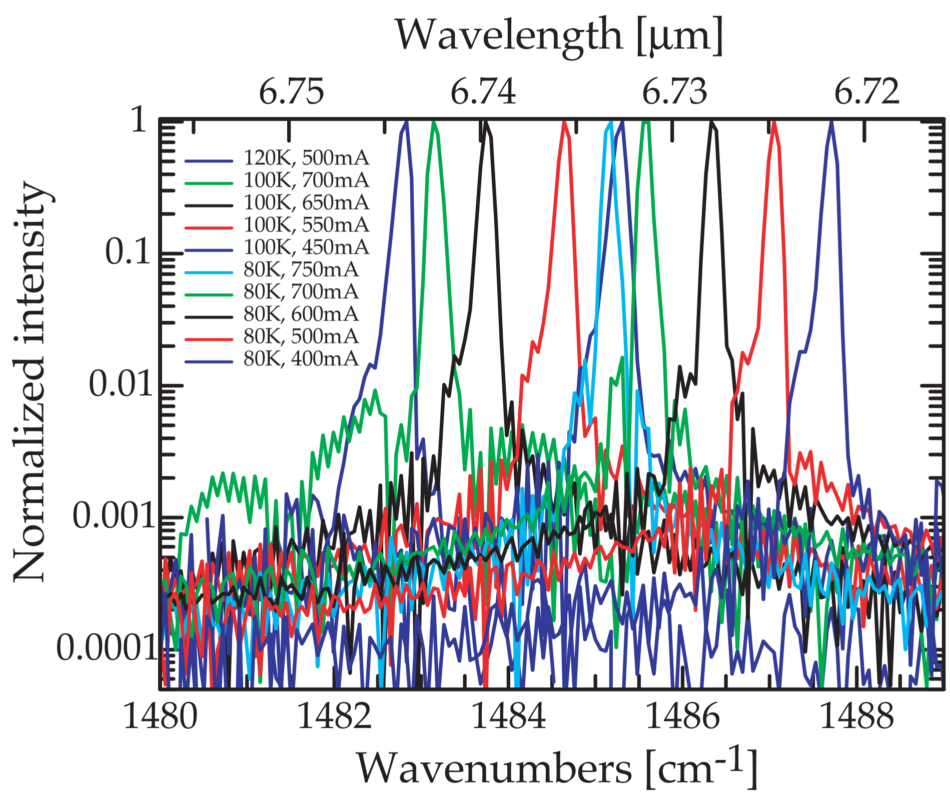


Characteristics

1.5 mm-long, 23 μm-wide laser
CW operation at $\lambda \approx 6.73$ μm

@80 K: Average power P = 0.2 W
Threshold current density:
j_{th} = 1.0 kA/cm^2

CW operation at λ ≈ 6.73µm: LN2-CW-DFB-100-X



Characteristics

1.5 mm-long, 23 µm-wide laser
CW operation at λ ≈ 6.73 µm

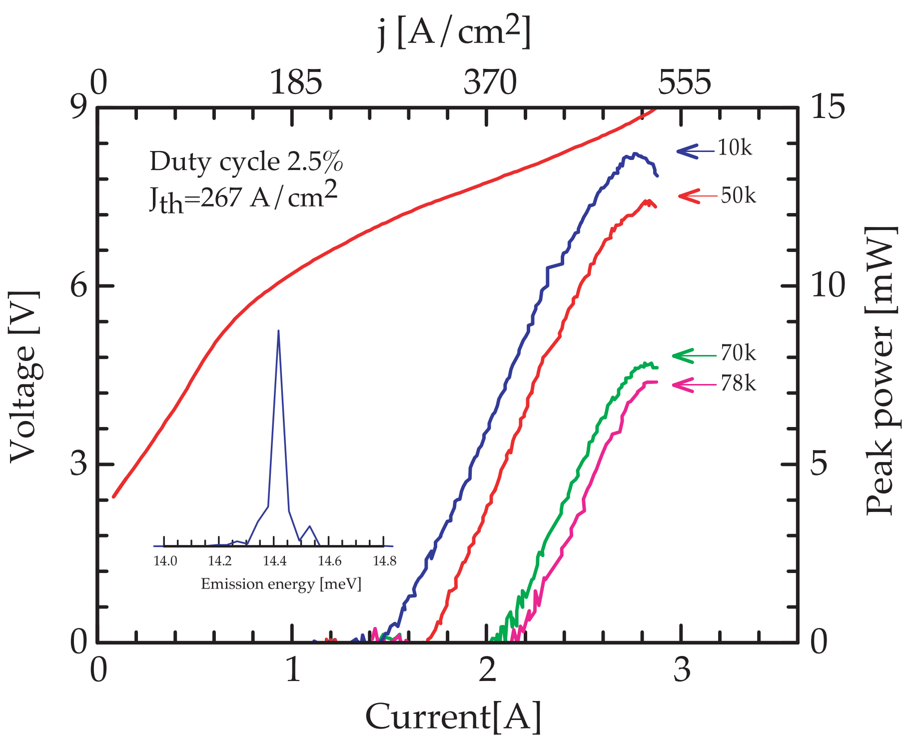
single-mode emission:
Side Mode Suppression Ratio > 30 dB

tuning range:
1482.8 cm^{-1} (6.744 µm) at 120K to
1487.7 cm^{-1} (6.722 µm) at 80K

Terahertz QC laser

THz QC laser based on a bound to continuum design, $\lambda \approx 87\ \mu m$

Structure grown at University of Neuchâtel (L. Ajili, G. Scalari, M. Beck and M. Giovannini)



Characteristics

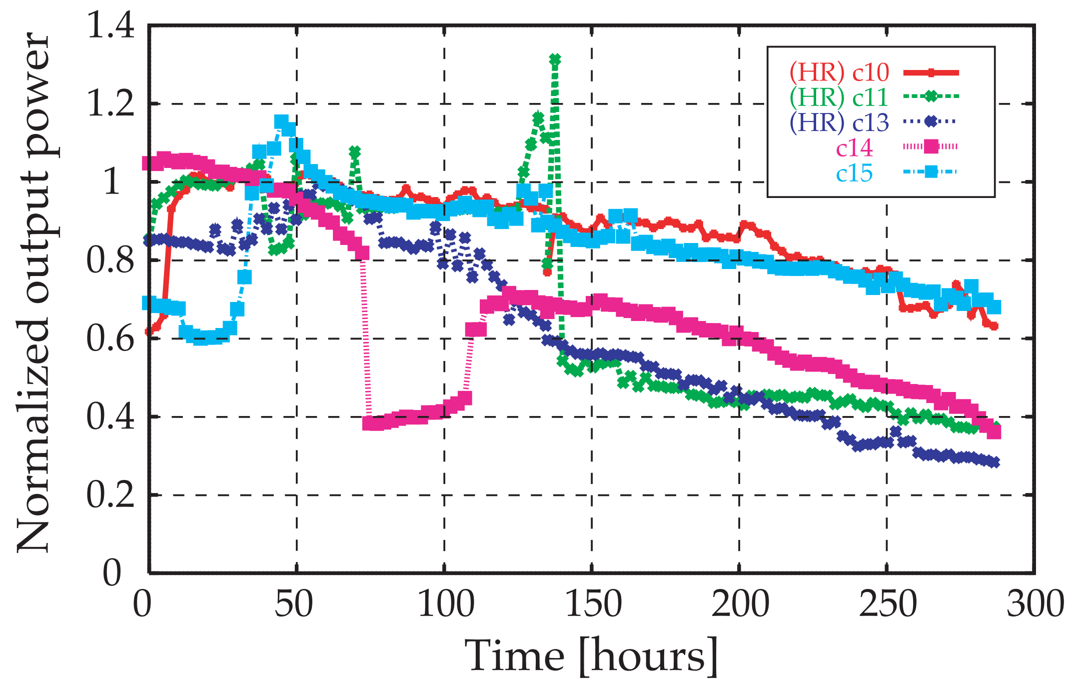
THz QC laser: $\lambda \approx 87\ \mu m$
2.7mm-long, 200µm-wide laser
back-facet coated

@10 K: Peak power (2.5% dc):
P = 14 mW
threshold current density:
j_{th} = 267 A/cm^2

pulsed operation up to 78K
CW operation up to 30 K

Reliability of the devices

Lifetime measurement (partly with HR coating)
ageing at 130°C and 2 % duty-cycle, monitor signal at 30°C



=> lifetime of the devices > 40 years

Advantages of QCLs

Type	Duty-cycle	Temperature	Temp. cycling	Power	Linewidth	Portable	Tuning
DFB	Pulsed (CW)	RT	√	30 mW (4mW)	< 330 MHz	√	0.4 %
	CW	LN2	√	5 mW @ 4.6 150 mW @6.7 40 mW @9.2	< 3.5 MHz		0.4 %
FP	Pulsed CW	RT	√	200 mW 20 mW	1 - 4 %	√	N/A
	Pulsed CW	LN2	√	0.8 W 200 mW	1 - 4 %		N/A